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Standardization in the Classical *UBVRI* Photometric System

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Abstract. There occur projected against the celestial sphere a wide range of phenomena for which observers and experimenters need intensity and color information. A fundamental datum for celestial objects is their intensity measured along the electromagnetic spectrum. Through considered choices of filters, one may establish photometric systems which isolate portions of the spectrum, and such systems in turn may be used to define color indices. Therefore, there is a long-term need for accurate photometric standard stars, those with known intensities and color indices at a variety of wavelengths.

References to history will set the stage for introduction of the *UBVRI* photometric system. It provides a common thread with previous centuries of photometry, and can provide similar continuity to the future. Much of this contribution will be a discussion of a set of procedures which may be followed, and some of the pitfalls that may be encountered, in establishing a useful optical photometric system.

1. Introduction

Astronomical photometry provides one of the basic foundation stones in the arsenal of astronomical observational data which astronomers use to probe the workings of the Universe and its contents. Via astronomical photometry, one may divide up the electromagnetic spectrum into wavelength intervals, each of which may be used to determine an intensity centered at that wavelength. These intensities may be turned into magnitudes via a relation confirmed by Pogson in 1856: $m_1 - m_2 = 2.5 \log(I_2/I_1)$. The magnitude scale is set by the statement that a light flux ratio of 100 is equivalent to a difference of exactly five magnitudes in brightness. Magnitudes, defined at a given wavelength, further lead to a quantity called a color index, which is the difference between the magnitude of an object as measured at two different wavelengths. This chapter shall be confined to the optical portion of the electromagnetic spectrum.

First, a quick look back at optical photometry as it was practiced in the past. Weaver (1946 a–f) wrote an interesting history of astronomical photometry some sixty years ago in a series of papers in the journal *Popular Astronomy*, a journal no longer in existence. Since then, an exhaustive treatment of the history of photometry has been written by Hearnshaw (1996), a highly recommended treatise. Weaver divided the astronomical photometric history up to the mid-1940s into four time periods. To Weaver's four periods, then, one now would add a fifth, the era of CCDs as detectors. Hearnshaw covers photometric history from the visual efforts of the ancients through photomultipliers. His review stopped with the advent of charge-coupled devices (CCDs).

Period I began when humans initially began to watch the sky, and attempted to record the brightness of objects that they saw. The Greek astronomer Hipparchus divided the naked eye stars into six brightness classes. His catalogue of some 1,000 stars was ranked by "magnitudes" one through six, with magnitude one being the brightest, and magnitude six the faintest. For something like the next 2,000 years, each observational astronomer, using the eye as a detector, developed his own photometric system, essentially based on the sensitivity of his eye. Attempts were made to relate the observations of one individual to those eye-estimates of another. However, because no standard scale of brightness existed, systematic differences occurred between the results of different observers. The accuracies of the eye-estimates probably were of the order of 0.25 magnitude (see Weaver 1946a). The eye-estimates which appeared in Ptolemy's *Almagest* were perhaps the earliest catalogued and published photometric results. The largest, and most important catalogues which resulted from this era, though, were the great Durchmusterungen published in the mid- to late-1800s. These included the *Bonner Durchmusterung* (458,000 stars north of -2° declination), the *Südliche Durchmusterung* (133,000 stars between -2° and -23°), and the *Cordoba Durchmusterung* (580,000 stars between -22° and the south celestial pole). These catalogues contained something over one million stars.

Period II saw the introduction of mechanical instruments which could aid the human eye in measuring the brightness of celestial objects. Examples are the polarizing photometers and the meridian photometers. The big advance of the second period in astronomical photometry was the specification and practical establishment of a standard brightness scale. This followed the announcement by Fechner in 1859 of his relation which stated the connection between the "subjective experience of brightness and objective physical cause" (Weaver 1946a). The magnitude scale has been fixed, for more than one hundred years, now, via the definition $m_1 - m_2 = 2.5\log(I_2/I_1)$. The internal accuracies achieved by some of the observers of the second period with their mechanical photometers approached $0\overset{\mathrm{m}}{.}05$ (Weaver 1946a).

Period III of astronomical photometry began about 1839 when the photographic process was able to record the moon. By 1850, J. A. Whipple, under the direction of W. C. Bond at Harvard, was successful in recording stars via photography (Bond 1850). The technique already had achieved great success by the late 1800s. One can see evidence of this in the great photographic surveys of the sky which were undertaken by Pickering at Harvard and others in Europe and South Africa. In particular, Kapteyn and Gill produced the *Cape Photographic Durchmusterung* (Annals of the Royal Cape Observatory, Volumes 3–5) in the interval 1896–1900. And the fabulous *Harvard Photographic Plate Collection* was begun in that time frame.

Photographic photometry provided a great step forward in the accuracies with which one could measure the brightness of a celestial object. By the mid-twentieth century, better iris photometers permitted an improvement in the accuracies obtainable of stellar magnitudes by perhaps a factor of five. Descriptions of iris photometers may be found, for example, in Cuffey (1956) and in Weaver (1962). Cuffey taught his students, including this author, that he could "obtain with his iris photometer, for stellar images that were round, sharp, and well-exposed, a mean error of a photometer setting in the range 0.007 to 0.015 magnitude" (Weaver 1962). He further noted that in all instances, the plate error, which arose from the characteristics of the photographic process, was much larger than the measuring error, and that one could expect that the mean error of a single measurement of a star image would lie in the range of $0\overset{m}{.}03$ to $0\overset{m}{.}04$. The best photographic photometry probably achieved an external accuracy of something like $0\overset{m}{.}02$. Since the emulsions were of varied characteristics, standardization problems were severe.

Period IV of astronomical photometry as described by Weaver essentially began with Stebbins' work (Stebbins & Brown 1907) with a selenium cell in 1907. Schulz (1913), working with J. Kunz at the University of Illinois, published the first stellar measurements made with a photoelectric cell. Stebbins and others continued the slow improvement of the devices. The technique received a great boost in 1932 when Whitford (1932) perfected an amplifier which could be applied to a photoelectric photometer. Whitford (1962) describes much of the early work in his chapter in the *Handbuch der Astrophysik*. Whitford's (1986) reminiscences in *Annual Reviews* also are of interest. A thorough review may be found in Hearnshaw (1996), Chapter 5.

Photoelectric photometry got another boost at the end of World War II with the availability of the RCA 1P21 photomultiplier. Kron (1946) discussed the characteristics of the 1P21 which showed it to be 10 to 25 times more sensitive than any device previously used for photometry in the blue portion of the optical spectrum. Olin Eggen was one of the early exploiters of this technology (e.g., Eggen 1955).

The last part of the photoelectric photometry era saw the introduction and exploitation of the RCA 31034A photomultiplier (now called the C31034A by the current manufacturer, Burle Industries). This photomultiplier has good response from 3000 to 8500Å. Its use was pioneered in South Africa by A. W. J. Cousins, in Australia by M. S. Bessell, and in Chile by J. A. Graham.

The past twenty plus years have seen the invention and application of charge-coupled devices to astronomical photometry, opening still greater vistas for very faint observational studies. Following Weaver's lead, we might call this Period V.

It is useful to note that up to the time of the appearance of CCDs, there always was a common thread through history, tying together the different photometric systems. The chronological thread up to the late twentieth century, was the human eye, the photovisual magnitude via photography, the V magnitude in the UBV photometric system, the y magnitude in Strömgren *uvby* four-color system, the V in the Geneva system, the V in the Walraven system, and the V in the Vilnius system (Drilling & Landolt 1999, Table 15.5). Chief among these, and other, photometric systems, the UBV photometric system has played the central role now for over half a century.

We observational astronomers should take every opportunity to continually make the case that small and medium-size telescopes have, and continue, to play a strong role in astronomical photometry, and in the process of providing high quality standard photometric systems for use by the greater astronomical community. The situation has been described in *The Future of Small Telescopes in the New Millennium*, edited by Oswalt (2003).

2. Photometric Systems of the Mid-20th Century

Following the debut of photoelectric photometry, several important photometric systems based on photomultipliers as detectors were developed during the middle of the 20th century. These systems include the original UBV system (Johnson & Morgan 1953; Johnson & Harris 1954; Johnson 1963; Morgan 1988); the $UBVRI$ system[1], the Strömgren *uvby* system invented by B. Strömgren (1963, 1966) with most of the defining work at the telescope done by D. L. Crawford, J. Barnes, and C. L. Perry, the DDO system of van den Bergh and McClure (McClure & van den Bergh, 1968; McClure 1976), the Geneva system by various Swiss astronomers described in Golay (1974), the Washington system (Canterna 1976, Harris & Canterna 1979) and now Geisler (1984, 1990) and Geisler, Claria, & Minniti (1991) and the Vilnius system of Straizys (1977, 1992). One can refer to the volume *Problems of Calibration of Multicolor Photometric Systems*, edited by Philip (1979) for additional information. There is no time to discuss the different systems here, each of which has its own uses. Photometric systems developed within the last decade or two will be discussed elsewhere in this workshop.

Although this chapter is not the place, two of these photometric systems deserve special mention and a complete description elsewhere. In particular, see a beautiful set of articles in *Orion* on applications of the Geneva system by Cramer (2004a, b, 2005a–e). The Vilnius system developed by Straizys (1963, 1964, 1965) and colleagues (1963, 1972) has a complete description in Straizys (1992, updated in 1995 printing). A compilation of results obtained with the system was published by Straizys and Kazlauskas (1993); an update is being prepared (Straizys 2006).

Of chronological interest was the joining of the Vilnius and Geneva photometric systems into an entity called the VilGen photometric system (Straizys & Hauck 1982; North, Hauck, & Straizys 1982). Although the potential of the VilGen system was not realized, that attempt to join existing medium-band photometric systems into an even better photometric system lead to later discussions between V. Straizys, D. Crawford and A. G. D. Philip (Straizys 2006). The result was the invention of the StromVil photometric system (Straizys, Crawford & Philip 1996) which has been considered as the photometric system to be used with the GAIA project.

A reason for taking a few paragraphs to describe other photometric systems in a chapter on $UBVRI$ photometry is because historically at times the $UBVRI$ system was more of a "discovery" system. Interesting objects would be identified, and then some of the more specialized photometric systems would be used in more detailed investigations. And the medium-band photometric systems, such as the Strömgren, Geneva, Vilnius and StromVil systems offer better photometric spectral resolution and accuracy. It now is recognized, though, that equally accurate results can be obtained with a broad-band system like the $UBVRI$ photometric system (Bessell 1993).

Readers should be aware of important general literature references to photometric systems, including Golay (1974) and Straizys (1977, 1992), as well as

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[1] Two versions, one Harold Johnson's (Johnson, Mitchell, Iriarte & Wisniewski 1966; Moffett & Barnes 1979a, b) and the other Kron's (Kron, White, & Gascoigne 1953) and Cousins' (1976).

pertinent chapters in volumes edited by Butler & Elliot (1993), Elliot & Butler (1993), and Kilkenny, Lastovica, & Menzies (1993).

3. The *UBV* Photometric System

Studies of the history of photometry, such as those written by Weaver (1946a–f) and Hearnshaw (1996), remind us that during most of history, the human eye was the detector of record. The peak sensitivity of the human eye falls approximately at 5500Å, the central wavelength of visible light. There was a reason, then, that early photographic photometry, through use of a yellow filter placed in front of the emulsion, was made to match the eye's peak sensitivity at 5500Å. The photographic emulsions as initially manufactured naturally were sensitive to shorter wavelengths, leading to the invention of the color index $m_{pg} - m_{pv}$ [see Charlier (1889) and Scheiner (1890) via Hearnshaw (1996), p. 144]. For some years, the definitive photometric standard system was the International System of magnitudes and colors as defined by the stars of the North Polar Sequence (NPS). The NPS, as a standardization sequence, had problems, among which were: 1) the sequence was too far north for many observers; 2) the m_{pg} magnitude was not defined well enough to permit accurate transformations, and 3) there were too few stars in the sequence to ensure accurate transformations. The m_{pv} magnitude did provide the direct link between older visual magnitudes and the modern V magnitude.

This author believes it important to recognize the importance of the ties to photometric data acquired over the centuries and that astronomers have tabulated, since the old photometric systems are bound together via the human eye and a filter defining a visual, V, magnitude. He posits the importance of all future photometric systems also containing a magnitude as close as possible to the Johnson V magnitude, thereby continuing on into the future the all important ability to better tie together the different major photometric systems.

Even though it has been stated (Morgan 1988) that the UBV photometric system was invented by W. W. Morgan, conversations with colleagues of the period indicate a collaboration between Morgan and Johnson, each individual possessing complementary talents (also see Hearnshaw 1996, page 423). Morgan was the spectroscopist, and Johnson the instrumentalist and photometrist. Johnson (1955) laid out the reasons for moving to a new photometric system. Quoting and paraphrasing him, he commented that a

> "*fundamental photometric system must include magnitudes and color indices for both reddened and unreddened stars from all parts of the Hertzsprung-Russell diagram. Johnson further stated that a new photometric system should be consistent with previous photometric systems.*"

A series of papers (recounted in Hearnshaw 1996, chapter 9.3) lead to the implementation of the UBV photometric system as described by Johnson & Morgan (1953). The dam broke, so to speak, with that paper, and a virtual flood of papers followed in the literature which reported the photometry of star clusters, intrinsic and variable stars, luminosity functions, galactic structure, etc. Now one could obtain more accurate color magnitude diagrams, could determine better photometric parallaxes, could more finely determine light curves which would lead to more precise physical characteristics of binary star components, and progress to a deeper understanding of the internal structure of intrinsically variable stars.

The set of stars which defined the *UBV* photometric system as originally published by Johnson & Morgan had on the order of three measures per star. The 94 *UBV* photometric standard stars in Johnson's *Basic Astronomical Data* paper (Johnson 1963), which earlier appeared in Johnson & Harris (1954), averaged more than 7 measures each. The ten primary standards given in a separate table therein were observed many more times, of course. The magnitudes and color indices for those stars define the *UBV* photometric system. Over the years, the recovered average mean error of a single observation of these standard stars seemed to run in the range of $0\overset{\text{m}}{.}015$ to $0\overset{\text{m}}{.}018$ for this author. Hence, he has taken these numbers to be an indication of the external accuracy that one could expect when using the *Basic Astronomical Data* (Johnson 1963) stars as standard stars.

Among the many recent examples in the literature of the uses of photometry are those in the volumes *The MK Process*, edited by R. F. Garrison (1983) and *The MK Process at 50 Years*, edited by Corbally, Gray, & Garrison (1994). These volumes honored W. W. Morgan's and P. C. Keenan's work in spectroscopy. One also can see the importance of accuracy in the volume *Calibration of Stellar Ages*, edited by A. G. D. Philip (1988). In Elizabeth Green's paper therein (Green 1988), one can learn of the difficulties of calibrating and/or correlating temperatures, gravities, and metallicities of celestial objects. One soon enters the realm where a few hundredths of a magnitude makes a significant difference. The same level of difficulty exists in the search for color gradients in galaxies.

The author's thesis, published in 1964 (Landolt 1964a, b), was a photographic study of two open clusters, calibrated with photoelectric sequences. The photoelectric calibrating sequences for the open cluster M 25 had been obtained by giants of observational photometry of the times (Sandage 1960, Johnson 1960, Irwin 1960, Wampler et al. 1961). Those sequences, inter-comparable via sequence stars identifiable by star charts, observed by the best observers of the time, had different zero points and color equations when inter-compared. How to choose which sequence should be used as the basic one? The work by Wampler et al. was chosen as the basic sequence, with which the other three sequences were compared, since the Wampler et al. sequence stars also had spectral types newly determined for them (by Kraft). The same situation had existed for the original Johnson & Morgan (1953) standard stars; Morgan had determined spectral types for all the stars for which Johnson had measured *UBV* magnitudes and color indices. Hence there was a tighter fit, a better cohesion, a more perfect interplay, a better physical understanding of the interrelationship between the photometry and the spectroscopy. Unfortunately, in the modern era, we know nothing of the spectral characteristics of the stars in the photometric sequences. It also is impossible at this point in history to inter-compare different observers' photometric results star by star, in part because the number of stars measured in a star cluster, for example, is so large, but also since individual stellar identifications in too many instances are not published.

The photoelectric photometric investigations discussed to this point have been done with single-channel photoelectric photometers. As an aside, one can point out that higher accuracies can be achieved if one uses, for example, a two-star photometer. Such an instrument was designed by R. E. Nather at the University of Texas. Its usefulness has been exploited by Nather & Warner (1971) and Grauer & Bond (1981), as well as various Texas astronomers. The fact that it is a two-star instrument means that two stellar objects may be monitored simultaneously. The photometer output is a ratio of the brightness of the two stars at a given wavelength. The fact that the output is a ratio means that the behavior of the sky conditions is much less important. Hence, one can work under less than ideal sky conditions. The accuracies that they achieved depended on the brightness of the star relative to the sky, of course. For stars very bright relative to the sky, the data were good to $0\overset{m}{.}003$, or so. Grauer et al. (1987), for instance, were able to set amplitude limits of a few millimagnitudes in a search for pulsating stars. Those numbers, though, refer to the internal accuracy. At today's point in time, the two-star photometer has been replaced by the CCD whereby many stars can be inter-compared at high precision.

4. The *UBVRI* Photometric System

The *UBV* photometric system was expanded to two additional spectral regions, *R* (7000Å) and *I* (9000Å), under the guidance of Harold Johnson (Johnson, Mitchell, Iriarte, & Wisniewski 1966, and references therein). The effective wavelengths of these *RI* filters had full width at half maximum of 2200 and 2400 Å, respectively. Fainter standards for the Johnson *RI* were published by Moffett & Barnes (1979a, 1979b) and by Kunkel & Rydgren (1979). Johnson et al. found it necessary, at that point in history, to use two different photomultipliers to acquire *UBV* and *VRI* data.

Once the Cousins-defined *RI* colors (effective wavelengths of 6400 and 7900 Å, respectively, with halfwidths of 1750 and 1400Å) were used to produce extensive standard stars (Cousins, as summarized by Menzies, Banfield & Laing 1980, Graham 1982, Landolt 1983, 1992a, Menzies et al. 1989), the Johnson *RI* version declined in use, in part due to the lack of standard stars, but most important, probably, due to the longer effective wavelengths and much larger full width at half maximum of the filter passbands. Those characteristics made the Johnson defined *RI* filters more subject to negative effects due to the varying transmission behavior of the earth's atmosphere at those longer wavelengths.

Actually, the first paper in the current context in which there were magnitudes called *R* and *I* was in Kron & Smith (1951). The effective wavelengths of their *RI* filters were 6800 and 8250Å with full width at half maximum of 1850 and 1480Å, respectively, the latter numbers measured by the author very approximately from Kron & Smith (1951, Fig. 2). Kron, White & Gascoigne (1953) established *RI* standard stars during observing sessions in Australia. Eggen (1975) added stars to the list of standards. The shorter wavelength *R* and *I* had the advantage of being somewhat more free of water vapor bands in the earth's atmospheric spectrum, and the narrower full width at half maximum gave better spectral resolution.

The Kron *RI* photometric system was modified and extended by Cousins (1976), whose work is the precursor to the *UBVRI* photometric system of today. Other relevant early papers include Cousins (1978, 1980) and Bessell (1976, 1979). In his papers, Bessell definitively showed the usefulness of the GaAs photocathode, comparing results from it with other photometric systems then in use. He also discussed filter combinations which would be optimum for use with the RCA 31034A photomultiplier.

Transmission curves for the *UBVRI* filter set used at CTIO are shown in Landolt (1992a; Figs 46–50). The corresponding numerical data for those transmission curves appear in that paper in Tables 6–10. Other examples for transmission curves appear in Bessell (1976) and Graham (1982). The transmission of these filters at full width at half maximum, varies between 700 and 1750Å. So with filters such as these, one is looking at a broad portion of the spectrum with relatively low resolution. The recipes for the broad-band *UBVRI* filter systems in use at Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO) are shown in Table 1. The KPNO filter recipes were put together by Bessell (1979) and those at CTIO were fine-tuned for the CTIO equipment by John Graham (1982).

Table 1. *UBVRI* broad-band filters.

CTIO		*UBVRI* Filter Set #3
V		2 mm GG 495 + 2 mm BG 18
B		2 mm GG 385 + 2 mm BG 18 + 2 mm BG 12
U		Corning 9863 + solid $CuSO_4$ crystal
R		2 mm KG 3 + 2 mm OG 570
I		3 mm RG 715 + 1 mm RG 780
KPNO	Filter Number	*UBVRI* Filter Set "J"
V	1112	2 mm GG 495 + 1 mm BG 18
B	1111	2 mm GG 385 + 1 mm BG 18 + 1 mm BG 12
U	kp 1248j	1 mm UG 2 + $CuSO_4$
R	1113	2 mm KG 3 + 2 mm OG 570
I	1114	3 mm RGN 9

A problem which afflicts almost all photometric systems is that they lack sufficient standard stars, and particularly faint standard stars. A remedy requires considerable allotments of observing time over an extended time interval at a telescope large enough to gather sufficient photons. Considerable time allotments are needed so that a sufficiently large number of measures of each star can be obtained to help beat down the errors. An extended time frame is necessary to help weed out objects variable in intensity and or color index. And a sufficiently-sized telescope is needed to make optimum the time needed to acquire the data. Then the task requires persistence. There can be surprises: both the ZZ Ceti variables (Landolt 1968) and the variability of the helium stars (Landolt 1973b, 1974, 1975), now called hydrogen-deficient stars, were discovered as an offshoot of standard star work. Such discoveries in great part are what make long-term standard-star projects such as this fun.

Remember that historically little has been known about most stars once one observes fainter than 12th or 13th magnitude. Therefore, the candidate stars to be made into photometric standards were searched out in several ways. One early

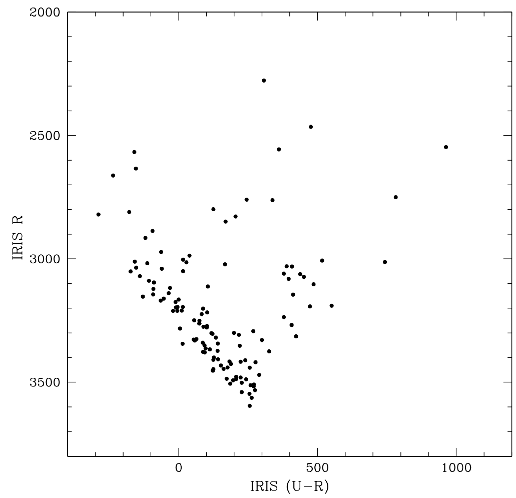

Figure 1. A plot of raw iris diaphragm R filter numbers versus the difference of raw U filter numbers minus raw R filter numbers.

effort by this author to identify candidate standard stars involved a photographic process. Photographic plates were obtained at the Yale 1.0-m telescope at CTIO of the *Kapteyn Selected Areas* through an appropriate combination of emulsion types and $UBVR$ filters. Those plates then were iris-photometered, and plots were made of iris diaphragm "magnitude readings" versus iris diaphragm "color index readings". An example of such a plot is given in Fig. 1. The goal was to identify stars of extreme red and blue colors in this manner, those stars then becoming candidates to be made into standard stars. The technique turned out to be a painfully slow time-consuming process which in the end identified very few potential candidates. There never seems to be enough sufficiently red or blue stars around when one undertakes the transformation process. Sad to say, after much effort, this photographic exercise at the Yale telescope only showed that most of the stars in the sky are of intermediate color, which a sane person ought to know. Hence, it was necessary to turn to the literature and search through surveys for stars of extreme color in an approximate 10° wide band around the celestial equator.

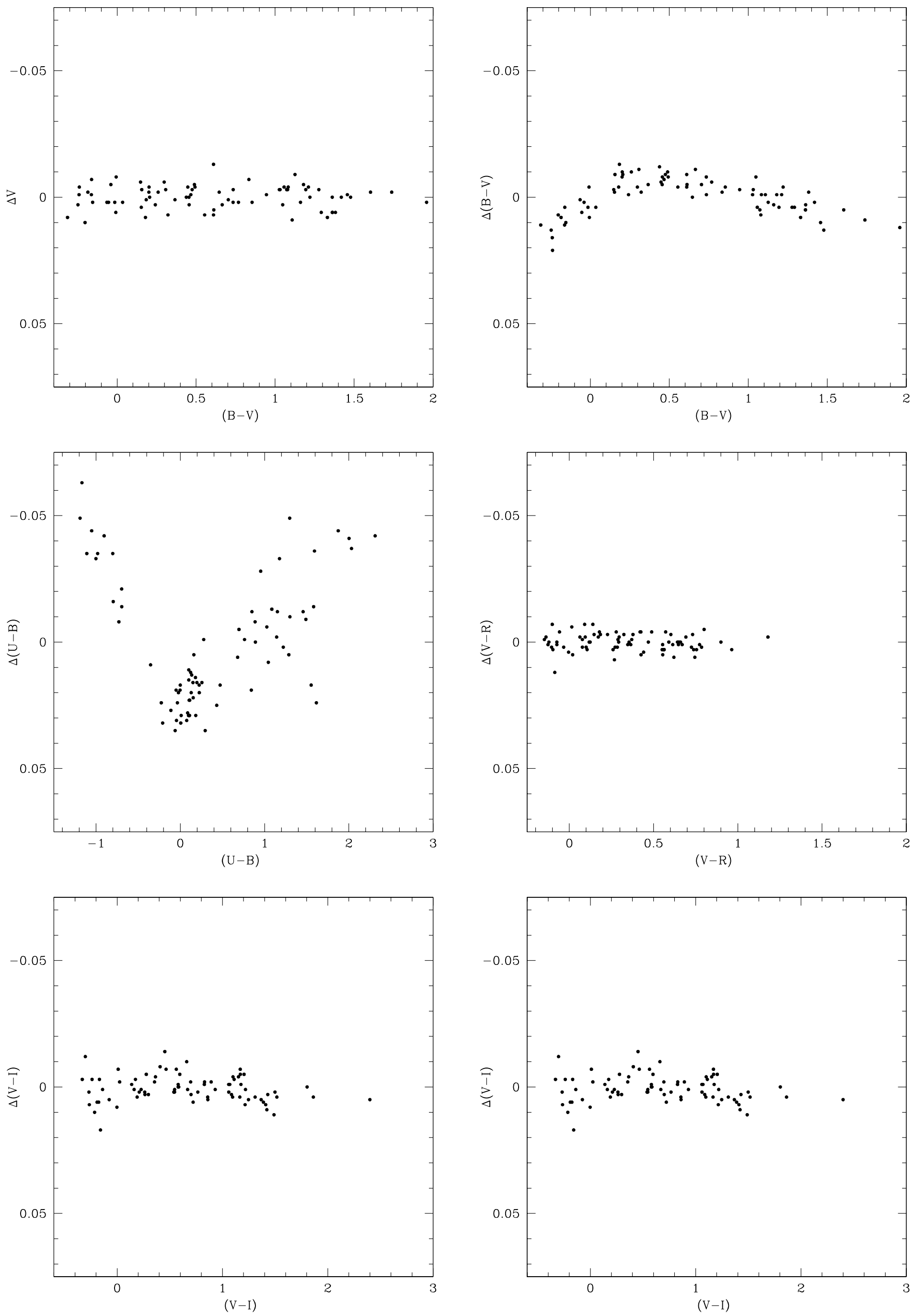

Figure 2. A comparison of the magnitudes and color indices obtained with the Hamamatsu R948-02 photomultiplier as a function of the transformed RCA 31034A data.

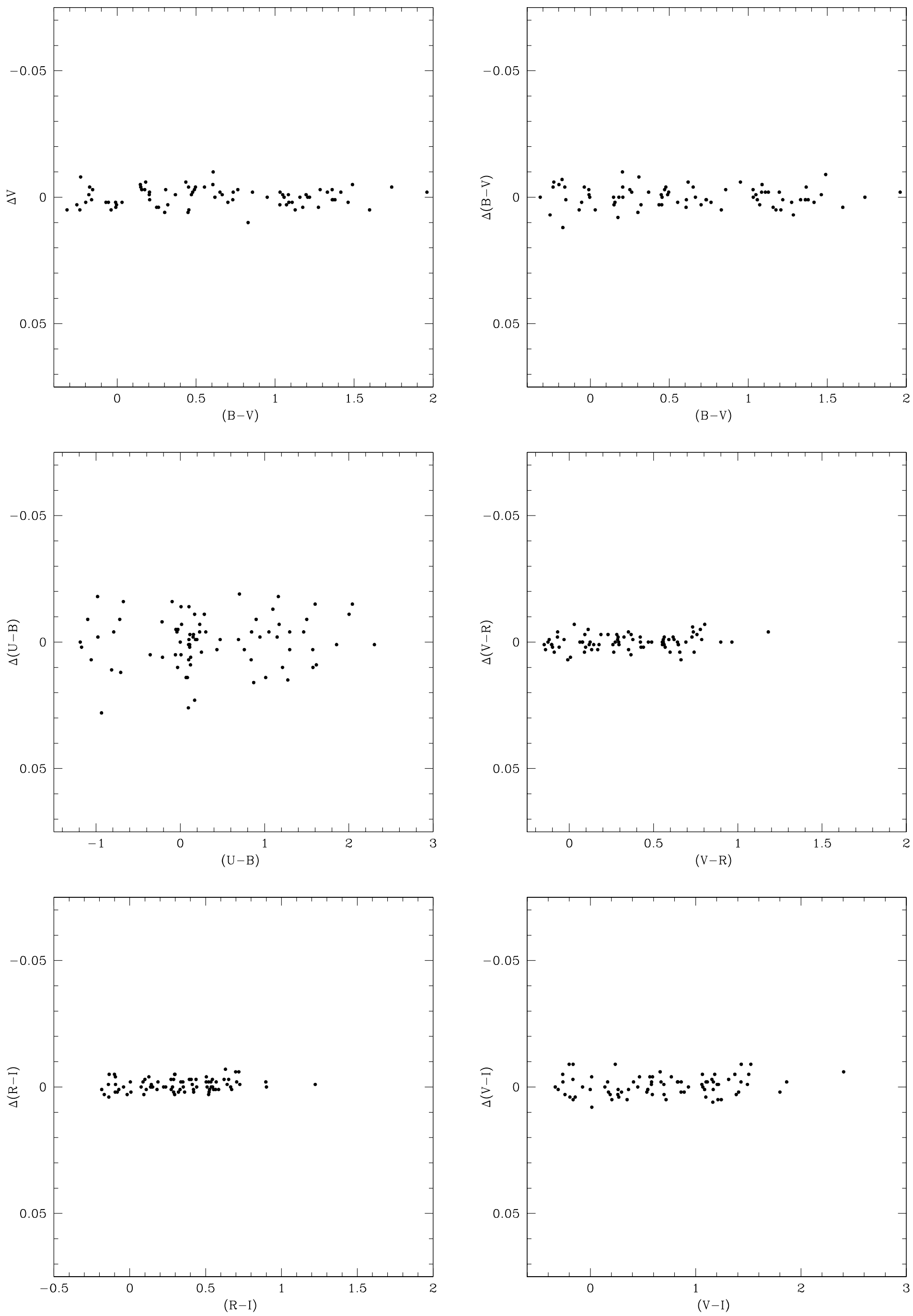

Figure 3. A comparison of the magnitudes and color indices for the 81 standard star subset after all non-linearity and transformation relations had been applied, as a function of Landolt's (1983) equatorial standard star data.

The most useful surveys in the literature were those of Feige (1958, 1959), Giclas et al. (in various Lowell Observatory Bulletins beginning with Volume 4), the *Palomar Green* (PG) survey (Green, Schmidt, & Liebert 1986), and Rubin, Westpfahl, & Tuve (1974). Other candidate stars were suggested by colleagues. Potential sequences of an areal extent to fit onto CCD chips were chosen in an effort to minimize the time it takes an observer to obtain either or both extinction and transformation object measurements.

If one sets about doing standard-star work, it is extremely important that as few as possible changes occur between observing sessions. That means that one should use the same photometer (detector), same filter set, same telescope (optics), and same mountaintop (elevation) throughout the project. It also is most important to cool to a standard stable temperature; for photoelectric work cool to dry-ice temperatures, −78.5 degrees C).[2] Use of a thermoelectric cooler, for instance, means that the photomultiplier will be cooled to different temperatures as the Earth's seasons progress. The result is that the operating temperature of the photomultiplier also will change with the seasons. If one does not follow the above precepts, differences will be present in the photometric data sets. Usually these differences show up as color-terms in comparison relations.

Figure 2, taken from Landolt (1992a), shows the consequences of changing photomultipliers. A RCA 31034 that had been used at CTIO for many years, ceased operation. A switch was made to a Hamamatsu R943-02 photomultiplier. Figures 2 and 3 compare magnitudes and color indices of the standard stars (Landolt 1983) observed in preparation for the Landolt (1992a, b) papers, as obtained with the Hamamatsu photomultiplier, with the data obtained for the same stars via the RCA 31034A, while operable, and which had been transformed to the photometric system defined by Landolt (1983). The figures illustrate that differences in magnitudes and color indices as obtained by two different brands of photomultiplier did exist. Parenthetically, one can show that differences in magnitudes and color indices obtained by the same brand of photomultiplier also are to be expected.

Linear regression relations which enabled the Hamamatsu-based data to be transformed onto the RCA 31034A based data (Landolt 1992a) are given below. The fact that these relations worked is illustrated in Fig. 3.

A rather standard (consistent) observing procedure has been followed over the years, and is described, for example, in Landolt (1992a). Data for a given star were obtained in a series of measures $VBURI$ $IRUBV$ star plus sky, followed by $VBURI$ sky measures. A diaphragm size near $14''$ was used as sufficiently large to handle most astronomical seeing situations. At the same time, that diaphragm size is sufficiently small to allow one to observe most field stars without worry of intrusion of light from nearby stars. Suffice it to say here that 15 to 25 standard stars were observed every night. Furthermore, extinction coefficients were determined each night. Both steps are necessary in the quest for accuracy. Something like 25% of each night's observing goes to "overhead", that is, to the acquisition of data to determine extinction and transformation coefficients.

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[2]Johnson (1962), and better, Bessell (1979), Appendix I.

$$
\begin{aligned}
V_{\rm sys} &= +0.00058 - 0.00073(B-V)_{\rm sys} + V_{\rm ham} \\
&\ \pm 0.00088 \pm 0.00104 \\
(B-V)_{\rm sys} &= -0.00030 + 1.05966(B-V)_{\rm ham} \qquad (B-V) \le +0.1, \\
&\ \pm 0.00231 \pm 0.01375 \\
(B-V)_{\rm sys} &= +0.00940 + 0.99453(B-V)_{\rm ham} \qquad +0.1 < (B-V) < +0.8, \\
&\ \pm 0.00182 \pm 0.00381 \\
(B-V)_{\rm sys} &= +0.01466 + 0.98623(B-V)_{\rm ham} \qquad (B-V) > +0.8, \\
&\ \pm 0.00448 \pm 0.00338 \\
(U-B)_{\rm sys} &= -0.03857 + 0.92527(U-B)_{\rm ham} \qquad (U-B) < -0.2, \\
&\ \pm 0.00621 \pm 0.00716 \\
(U-B)_{\rm sys} &= -0.02406 + 1.02597(U-B)_{\rm ham} \qquad (U-B) > -0.2, \\
&\ \pm 0.00292 \pm 0.00300 \\
(V-R)_{\rm sys} &= +0.00083 + 0.99771(V-R)_{\rm ham} \\
&\ \pm 0.00059 \pm 0.00126 \\
(R-I)_{\rm sys} &= -0.00151 + 0.99558(R-I)_{\rm ham} \qquad (R-I) < +0.2, \\
&\ \pm 0.00124 \pm 0.00972 \\
(R-I)_{\rm sys} &= +0.00220 + 0.99643(R-I)_{\rm ham} \qquad +0.2 < (R-I) < +0.7, \\
&\ \pm 0.00271 \pm 0.00573 \\
(R-I)_{\rm sys} &= -0.00667 + 1.00101(R-I)_{\rm ham} \qquad (R-I) > +0.7, \\
&\ \pm 0.01063 \pm 0.01215 \\
(V-I)_{\rm sys} &= -0.00055 + 1.00096(V-I)_{\rm ham} \qquad (V-I) < +0.4, \\
&\ \pm 0.00125 \pm 0.00520 \\
(V-I)_{\rm sys} &= +0.00783 + 0.99109(V-I)_{\rm ham} \qquad +0.4 < (V-I) < +1.2, \\
&\ \pm 0.00404 \pm 0.00509 \\
(V-I)_{\rm sys} &= -0.00111 + 0.99789(V-I)_{\rm ham} \qquad (V-I) > +1.2, \\
&\ \pm 0.00512 \pm 0.00338
\end{aligned}
$$

Extinction relations for the V magnitude, for example, take the form:

$$v = v' - Q_y X, \tag{1}$$

where v is the instrumental magnitude outside the earth's atmosphere corrected for extinction, v' is the instrumental magnitude uncorrected for extinction, Q_y is the extinction coefficient, and X is the air mass. The air mass is a function of the latitude of the observatory (telescope), and of the declination and hour angle of the star. A similar relation for the $(B-V)$ color index, for example is:

$$C_y = C'_y - k_1 X - k_2 C_y X, \tag{2}$$

where C_y is the $(B-V)$ instrumental color index outside the earth's atmosphere corrected for extinction, C'_y is the observed instrumental color index uncorrected for extinction, k_1 is the primary extinction coefficient, and k_2 is the secondary extinction coefficient. The primary and secondary extinction coefficients, respectively, for the other color indices are: k_3 and k_4 for $(U-B)$; k_5 and k_6 for $(V-R)$; k_7 and k_8 for $(R-I)$; and k_9 and k_{10} for $(V-I)$.

Primary extinction coefficients are calculated and applied to each night's data. Secondary extinction coefficients are calculated for each night's data, too. However, experience has shown that more consistent results are obtained when the average of the secondary extinction coefficients determined for each night of a run are applied to each individual night's data.

Table 2 shows night by night extinction data from KPNO during 1994 and part of 1995. Table 3 illustrates night by night extinction data for CTIO from 1999 into 2001. Table 4 summarizes the $UBVRI$ extinction characteristics at CTIO in the thirteen year interval 1977–1990. Finally, Table 5 compares average long-term extinction coefficients at KPNO and CTIO over the years. The secondary extinction coefficients, k_6, k_8, and k_{10}, have been set to 0.0 in Table 5. As indicated in Table 4, their range in values effectively is zero. Calculated values, as small as they are, are used in practice. The past fifteen or so years' extinction data have not been included in Table 5, so it is not known whether the one time close extinction similarity of the KPNO and CTIO sites still exists. The extinction coefficients in these Tables indicate the behavior of night-to-night extinction during a given observing run. Note that there can be large changes from night to night. To achieve the best photometric results, one *must* determine extinction every night.

If extinction changes from night to night, then there must be similar changes occurring throughout a night when one is observing. More recognition of this fact has been indicated in the literature and at conferences in recent years. The author has addressed this problem over the past few decades by applying small corrections to the magnitude and color indices for each program star as a function of time. The author begins a night by observing a set of five or six standard stars with as broad a range in color as possible, and then every few hours or so, makes observations of an additional set of standard stars, and on through the night. Figure 4 indicates the steps. In the reduction process, each set provides a mean Universal Time (UT) of observation, together with an average deviation, for the group, from published magnitudes or color indices; see Figs 5 and 6. Look at the deviations in average magnitude and color index as a function of time as shown in Fig. 7. Straight lines connect each pair of points. The time of observation is known for each program star. One goes to the plot for a given time of observation, reads off the correction, and applies it to the measure. Figure 8 shows that the changes are small, usually on the order of a few hundredths magnitude over a night. The "proof of the validity of the process" is that final magnitudes and color indices for program stars have appreciably smaller errors when such corrections are applied as compared to when they are not applied. Figure 8, then, shows evidence of a change in the average deviation of standard stars from catalog values as a night progresses. Evidence over the years points to the sky, and not the equipment, as the cause for these small changes.

Transformation relations, going from the instrumental magnitudes corrected for extinction, to placing the magnitudes and color indices onto some standard star photometric system, take the form, for magnitudes:

$$V = v + z + f(B - V) \tag{3}$$

where V is the transformed magnitude, v is the instrumental magnitude corrected for extinction, z is the zero point, and f is the slope. For color indices, e.g., $B - V$ and $U - B$, one has:

$$B - V = a + b\ C_y \tag{4}$$

$$U - B = c + d\ C_u \tag{5}$$

where $B - V$ and $U - B$ are the transformed color indices, now on a standard photometric system, a and c are zero points, and b and d are slopes. C_y and C_u are the instrumental extinction corrected color indices. Similar relations may be written for the other color indices.

No more will be said about the basic data reduction steps since there exist many excellent references in the literature which describe photometric reduction procedures, including Schulte & Crawford (1961), Hardie (1962), Golay (1974), Henden & Kaitchuk (1982), Sterken & Manfroid (1992), Massey & Jacoby (1992), Craine, Tucker, & Barnes (1999), and Howell (1992, 2000).

Something does need to be said about non-linear transformations. After having reduced and transformed the data to the standard photometric system the best that one can, using linear relations, there on occasion appear non-linearities as a function of color index. The problems in $(B - V)$ and in $(U - B)$ are most severe. These non-linear effects are illustrated in Figs. 7–12 in Landolt (1992a). The calculation of non-linear transformation coefficients based upon the data in those figures, similar in appearance to Figures 2 and 3 above, leads to relations similar to those comparing the two different photomultipliers earlier in this chapter. Application of such non-linear coefficients leads to results similar to those in Fig. 3 above.

Nearly six hundred stars were examined as possible candidates for broadband *UBVRI* standard stars on the Johnson-Kron-Cousins photometric system in preparation for what became Landolt (1992a). The observations were obtained at the 1.5-m telescope at CTIO. Those observations established a 143 star subset from the initial 600 as new standard stars in the approximate magnitude range $11 < V < 15$ and color index range $-0.3 < B - V < +2.3$. Those stars were observed on an average of 11 different nights and more than 20 times

Table 2. KPNO extinction coefficients, 1994–1995.

	V	$B-V$		$U-B$		$V-R$		$R-I$		$V-I$		
UT Date	Q_y	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	Telescope
013094	+0.151	+0.117	−0.025	+0.247	−0.026	+0.042	+0.002	+0.048	−0.004	+0.086	+0.000	0.9-m
013194	+0.127	+0.111	......	+0.220	......	+0.032	......	+0.052	......	+0.093	......	0.9-m
032894	+0.183	+0.104	−0.013	+0.222	+0.033	+0.046	+0.001	+0.044	−0.004	+0.101	−0.010	0.9-m
033194	+0.201	+0.136	......	+0.231	......	+0.052	......	+0.055	......	+0.110	−0.007	0.9-m
040194	+0.197	+0.111	−0.034	+0.292	+0.000	+0.033	+0.007	+0.045	−0.008	+0.088	−0.007	1.3-m
040294	+0.208	+0.122	......	+0.292	......	+0.015	......	+0.045	......	+0.088	−0.007	1.3-m
040394	+0.195	+0.133	......	+0.290	......	+0.039	......	+0.044	−0.011	+0.080	−0.015	1.3-m
040594	+0.187	+0.101	......	+0.293	......	+0.043	......	+0.049	−0.008	+0.096	−0.007	1.3-m
061194	+0.217	+0.133	−0.022	+0.315	−0.007	+0.049	−0.001	+0.038	−0.007	+0.078	−0.002	1.3-m
061294	+0.227	+0.124	......	+0.327	......	+0.040	......	+0.034	......	+0.070	......	1.3-m
061394	+0.220	+0.120	......	+0.323	......	+0.041	......	+0.029	......	+0.084	......	1.3-m
061494	+0.199	+0.113	......	+0.310	......	+0.052	......	+0.034	......	+0.063	......	1.3-m
091594	+0.140	+0.104	−0.005	+0.183	−0.002	+0.062	−0.013	+0.028	−0.014	+0.089	−0.013	0.9-m
091694	+0.165	+0.105	......	+0.307	......	+0.044	......	+0.049	......	+0.091	......	0.9-m
102994	+0.160	+0.105	−0.020	+0.313	−0.013	+0.035	+0.000	+0.049	+0.005	+0.073	−0.001	1.3-m
103194	+0.160	+0.107	......	+0.301	......	+0.039	......	+0.059	......	+0.095	......	1.3-m
110194	+0.158	+0.117	......	+0.292	......	+0.035	......	+0.035	......	+0.070	......	1.3-m
120294	+0.138	+0.116	−0.026	+0.300	−0.011	+0.041	+0.006	+0.018	−0.010	+0.065	−0.002	1.3-m
120394	+0.142	+0.113	......	+0.294	......	+0.030	......	+0.034	......	+0.072	......	1.3-m
												1.3-m
032995	+0.192	+0.107	−0.018	+0.297	−0.008	+0.039	+0.005	+0.041	−0.010	+0.091	−0.002	1.3-m
033095	+0.197	+0.108	......	+0.309	......	+0.043	......	+0.041	......	+0.089	......	1.3-m
033195	+0.220	+0.105	......	+0.315	......	+0.044	......	+0.046	......	+0.096	......	1.3-m
040195	+0.201	+0.109	......	+0.307	......	+0.048	......	+0.050	......	+0.096	......	1.3-m
040295	+0.174	+0.112	......	+0.317	......	+0.040	......	+0.028	......	+0.074	......	1.3-m

Table 3. CTIO extinction coefficients, 1999–2001.

	V	$B-V$		$U-B$		$V-R$		$R-I$		$V-I$		
UT Date	Q_y	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	Telescope
012199	+0.188	+0.115	−0.013	+0.290	−0.013	+0.053	+0.003	+0.048	−0.013	+0.090	−0.002	0.9-m
012299	+0.170	+0.128	......	+0.271	......	+0.037	......	+0.057	......	+0.090	......	0.9-m
012339	+0.142	+0.137	......	+0.275	......	+0.037	......	+0.043	......	+0.099	......	0.9-m
012499	+0.148	+0.107	......	+0.267	......	+0.042	......	+0.042	......	+0.098	......	0.9-m
012599	+0.152	+0.124	......	+0.270	......	+0.037	......	+0.027	......	+0.091	......	0.9-m
012699	+0.150	+0.120	......	+0.278	......	+0.047	......	+0.005	......	+0.066	......	0.9-m
012799	+0.124	+0.136	......	+0.287	......	+0.038	......	+0.019	......	+0.071	......	0.9-m
032499	+0.125	+0.128	−0.020	+0.265	−0.021	+0.034	−0.005	+0.047	−0.002	+0.094	−0.005	0.9-m
032799	+0.244	+0.164	......	+0.308	......	+0.062	......	+0.077	......	+0.135	......	0.9-m
032899	+0.120	+0.129	......	+0.267	......	+0.048	......	+0.043	......	+0.064	......	0.9-m
032999	+0.140	+0.124	......	+0.281	......	+0.050	......	+0.047	......	+0.093	......	0.9-m
061299	+0.118	+0.142	−0.032	+0.297	−0.016	+0.035	+0.009	+0.026	−0.011	+0.077	−0.001	0.9-m
072099	+0.099	+0.126	−0.022	+0.264	−0.034	+0.031	+0.008	+0.028	−0.004	+0.068	−0.002	0.9-m
072199	+0.093	+0.126	......	+0.276	......	+0.035	......	+0.034	......	+0.074	......	0.9-m
101099	+0.158	+0.145	−0.022	+0.295	−0.035	+0.038	+0.005	+0.069	+0.004	+0.104	+0.005	0.9-m
101199	+0.150	+0.135	......	+0.303	......	+0.035	......	+0.028	......	+0.084	......	0.9-m
101299	+0.144	+0.105	......	+0.301	......	+0.044	......	+0.045	......	+0.073	......	0.9-m
121099	+0.128	+0.142	−0.021	+0.287	−0.019	+0.026	+0.007	+0.025	−0.018	+0.076	−0.004	0.9-m
121199	+0.137	+0.134	......	+0.298	......	+0.044	......	+0.022	......	+0.085	......	0.9-m
121299	+0.140	+0.138	......	+0.290	......	+0.031	......	+0.026	......	+0.075	......	0.9-m
121399	+0.168	+0.131	......	+0.295	......	+0.032	......	+0.016	......	+0.066	......	0.9-m
121499	+0.134	+0.138	......	+0.286	......	+0.037	......	+0.022	......	+0.073	......	0.9-m
												0.9-m
031000	+0.223	+0.149	−0.018	+0.307	−0.005	+0.052	+0.006	+0.041	−0.007	+0.101	+0.000	0.9-m
031100	+0.140	+0.139	......	+0.294	......	+0.032	......	+0.054	......	+0.104	......	0.9-m
031200	+0.141	+0.118	......	+0.288	......	+0.034	......	+0.051	......	+0.088	......	0.9-m
031400	+0.177	+0.145	......	+0.297	......	+0.038	......	+0.059	......	+0.107	......	0.9-m
031500	+0.179	+0.145	......	+0.313	......	+0.043	......	+0.050	......	+0.096	......	0.9-m
031600	+0.225	+0.147	......	+0.305	......	+0.055	......	+0.046	......	+0.119	......	0.9-m
031700	+0.160	+0.107	......	+0.295	......	+0.038	......	+0.063	......	+0.115	......	0.9-m
031800	+0.123	+0.124	......	+0.284	......	+0.037	......	+0.038	......	+0.093	......	0.9-m
031900	+0.171	+0.134	......	+0.298	......	+0.050	......	+0.067	......	+0.114	......	0.9-m

Table 3. CTIO extinction coefficients, 1999–2001 (continued).

	V	$B-V$		$U-B$		$V-R$		$R-I$		$V-I$		
UT Date	Q_y	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	Telescope
052300	+0.167	+0.150	−0.023	+0.298	−0.024	+0.033	+0.012	+0.058	+0.000	+0.095	+0.003	0.9-m
052400	+0.137	+0.117	......	+0.288	......	+0.031	......	+0.031	......	+0.079	......	0.9-m
052900	+0.139	+0.131	......	+0.280	......	+0.040	......	+0.048	......	+0.093	......	0.9-m
071900	+0.126	+0.118	−0.022	+0.274	−0.023	+0.032	+0.005	+0.029	−0.001	+0.083	+0.002	0.9-m
072000	+0.118	+0.128	......	+0.308	......	+0.038	......	+0.033	......	+0.075	......	0.9-m
072300	+0.055	+0.125	......	+0.319	......	+0.050	......	+0.049	......	+0.092	......	0.9-m
072400	+0.138	+0.129	......	+0.288	......	+0.037	......	+0.043	......	+0.077	......	0.9-m
072500	+0.105	+0.129	......	+0.285	......	+0.035	......	+0.038	......	+0.079	......	0.9-m
082500	+0.132	+0.140	−0.026	+0.269	−0.007	+0.023	+0.008	+0.028	+0.000	+0.076	+0.004	0.9-m
082600	+0.134	+0.123	......	+0.272	......	+0.032	......	+0.036	......	+0.085	......	0.9-m
082700	+0.167	+0.126	......	+0.267	......	+0.043	......	+0.062	......	+0.096	......	0.9-m
082800	+0.113	+0.142	......	+0.280	......	+0.039	......	+0.051	......	+0.075	......	0.9-m
082900	+0.133	+0.129	......	+0.270	......	+0.030	......	+0.043	......	+0.079	......	0.9-m
101900	+0.154	+0.147	−0.025	+0.290	−0.029	+0.040	+0.001	+0.049	−0.001	+0.098	+0.005	0.9-m
102000	+0.142	+0.147	......	+0.294	......	+0.054	......	+0.053	......	+0.087	......	0.9-m
102100	+0.140	+0.152	......	+0.309	......	+0.036	......	+0.034	......	+0.088	......	0.9-m
102200	+0.158	+0.117	......	+0.292	......	+0.060	......	+0.034	......	+0.086	......	0.9-m
102300	+0.144	+0.126	......	+0.297	......	+0.033	......	+0.060	......	+0.093	......	0.9-m
121400	+0.166	+0.130	−0.018	+0.326	+0.005	+0.042	+0.001	+0.063	+0.001	+0.088	+0.001	0.9-m
121500	+0.179	+0.149	......	+0.300	......	+0.045	......	+0.082	......	+0.101	......	0.9-m
121600	+0.119	+0.161	......	+0.320	......	+0.030	......	+0.010	......	+0.057	......	0.9-m
121700	+0.152	+0.139	......	+0.308	......	+0.031	......	+0.025	......	+0.081	......	0.9-m
121900	+0.210	+0.138	......	+0.309	......	+0.058	......	+0.072	......	+0.122	......	0.9-m
122000	+0.141	+0.120	......	+0.292	......	+0.052	......	+0.033	......	+0.093	......	0.9-m
												0.9-m
021801	+0.129	+0.129	−0.026	+0.278	−0.008	+0.021	+0.004	+0.019	−0.016	+0.073	−0.005	0.9-m
021901	+0.127	+0.134	......	+0.292	......	+0.030	......	+0.019	......	+0.076	......	0.9-m
022001	+0.181	+0.146	......	+0.303	......	+0.038	......	+0.044	......	+0.090	......	0.9-m
022101	+0.189	+0.172	......	+0.330	......	+0.055	......	+0.041	......	+0.100	......	0.9-m
022201	+0.312	+0.216	......	+0.370	......	+0.088	......	+0.033	......	+0.145	......	0.9-m
022301	+0.186	+0.158	......	+0.307	......	+0.053	......	+0.054	......	+0.098	......	0.9-m

each. The average mean error of the mean is better than $0\overset{m}{.}005$ for the magnitude and color indices, except for $(U - B)$ where the error is perhaps twice as large. All these data were tied into the author's previous standard star work (Landolt 1983).

A summary of the characteristics of the author's published standard star sequences is given in Table 6. The stars in Landolt (1973a, 1983) nearly all are located within one degree of the celestial equator, in the celestial equatorial Selected Areas, thereby providing a set of photometric standards easily accessible to telescopes from both geographic hemispheres. While the magnitude and color range was adequate, there were few stars of extreme color. And, stars of extreme color are a necessity if one wants to derive the best color transformations. The second and fifth columns in Table 7 indicate the accuracies achieved in the 1973a paper. These errors represent the mean error of the mean for the 350 or so stars with five or more individual measures. Stars known to be variable were not included in the determination.

Order of Observing

Group 1	Group 2	Group 3	Group 4	Group 5
standard stars	program stars	standard stars	program stars	standard stars

Figure 4. The sequence in which standard and program observations were inter-dispersed.

Table 4. Extinction coefficients at CTIO, 1977–1990.

	Coefficient Symbol	Average coefficient value	Range in coefficient values
V	Q_y	+0.152	+0.099 to +0.250
$B - V$	k_1	+0.124	+0.074 to +0.184
	k_2	−0.023	−0.046 to +0.013
$U - B$	k_3	+0.315	+0.251 to +0.448
	k_4	−0.022	−0.080 to +0.057
$V - R$	k_5	+0.044	+0.007 to +0.084
	k_6	+0.007	−0.013 to +0.021
$R - I$	k_7	+0.045	+0.002 to +0.078
	k_8	−0.006	−0.024 to +0.021
$V - I$	k_9	+0.091	+0.040 to +0.141
	k_{10}	+0.003	−0.011 to +0.017

The lack of stars of extreme color in the 1973a paper was addressed to some extent in Landolt (1983). That paper also added intensity measures at the

Table 5. A comparison of extinction at KPNO and CTIO.

	Coefficient Symbol	Coefficient Value CTIO	KPNO
V	Q_y	+0.172	+0.162
$B - V$	k_1	+0.111	+0.102
	k_2	−0.026	−0.021
$U - B$	k_3	+0.318	+0.322
	k_4	−0.020	−0.017
$V - R$	k_5	+0.042	+0.040
	k_6	0.000	0.000
$R - I$	k_7	+0.046	+0.042
	k_8	0.000	0.000
$V - I$	k_9	+0.087	+0.085
	k_{10}	0.000	0.000

		observed			catalogue			o−c		
Name	**UT**	**V**	**(B−V)**	**(U−B)**	**V**	**(B−V)**	**(U−B)**	**ΔV**	**Δ(B−V)**	**Δ(U−B)**
Group 1										
Star 1										
Star 2										
Star 3										
Average										
Group 2										
Star 1										
Star 2										
Star 3										
Average										
Group 3										
Star 1										
Star 2										
Star 3										
Average										

Figure 5. A comparison of the recovered magnitudes and color indices for standard stars with their catalogue values.

R (6800Å) and I (8250Å) effective wavelengths as defined by Cousins (1976), following the pioneering work of Kron, White & Gasciogne (1953). Cousins had set up $UBVRI$ photometric sequences in the Harvard E-regions at declination $-45°$. The author's 1983 RI measures were tied into those Cousins E-region sequences; the 1983 UBV measures were tied into the Johnson (1963) original standards via Landolt (1973a). Most of these stars again were in the celestial equatorial Selected Areas. The characteristics of these data, obtained over a five

Group	UT	ΔV	Δ(B−V)	Δ(U−B)
1	$(\overline{UT})_1$	$\Delta\overline{V}_1$	$\Delta(\overline{B-V})_1$	$\Delta(\overline{U-B})_1$
2	$(\overline{UT})_2$	$\Delta\overline{V}_2$	$\Delta(\overline{B-V})_2$	$\Delta(\overline{U-B})_2$
3	$(\overline{UT})_3$	$\Delta\overline{V}_3$	$\Delta(\overline{B-V})_3$	$\Delta(\overline{U-B})_3$

Figure 6. The average amount by which each standard star group deviates from the catalogue value as a function of time.

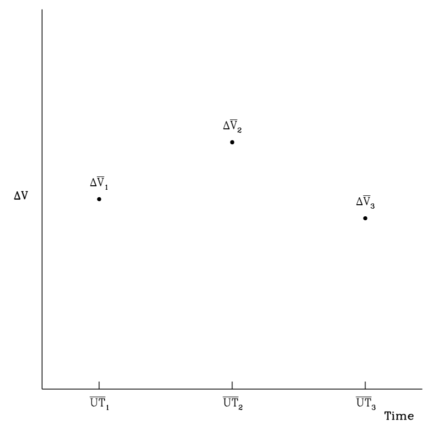

Figure 7. An example plot of the deviations in average V magnitude as a function of Universal Time.

Table 6. Summary of Landolt's past standard star efforts.

Year of Pub.	# of Stds.	V range	$B-V$ range	measures per star
1973a	335	10.5 12.5	$-0.25+2.0$	11
1983	223	7.0 12.5	$-0.30+2.0$	20
1992a	217	11.5 16.0	$-0.30+2.3$	29

year period, also appear in Table 6. The accuracies achieved in the 1983 paper are in Table 7.

The time interval of 1977 to 1991 saw the continued acquisition of data approximately in the magnitude range $11.5 < V < 16.0$. Although the equatorial Selected Areas were pushed to fainter limits, the shortage of stars of extreme color was addressed by searching out stars of extreme color primarily through literature searches. One good source of blue stars proved to be the Palomar-Green (PG) list of objects (Green, Schmidt & Liebert 1986). Searches were

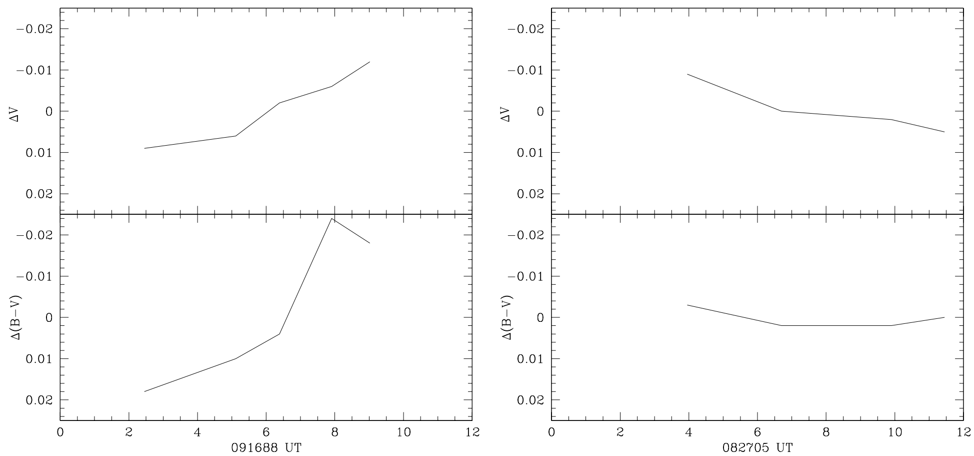

Figure 8. A plot of the deviations in average V magnitude and $B-V$ color index as a function of Universal Time for the nights indicated. The error of the ordinate typcially is on the order of one percent (0.01 mag).

Table 7. Photometric accuracies in Landolt's published efforts.

	Mean Errors of a Single Obs.			Mean Errors of the Mean		
	1973a	1983	1992a	1973a	1983	1992a
V	0.0153	0.0134	0.0160	0.0046	0.0029	0.0039
$B-V$	0.0159	0.0124	0.0195	0.0048	0.0027	0.0048
$U-B$	0.0250	0.0228	0.0439	0.0075	0.0050	0.0125
$V-R$		0.0090	0.0126		0.0020	0.0031
$R-I$		0.0095	0.0182		0.0021	0.0044
$V-I$		0.0116	0.0228		0.0025	0.0055

conducted, with some small success, in the vicinities of these PG stars for red objects.

The just discussed data appeared in Landolt (1992a). The initial 526 stars tested as candidate standard stars yielded a subset of 298 stars with sufficient data to deem them to be useful as $UBVRI$ standard stars. The exclusion of 81 stars, which also appeared in Landolt (1983), from that subset of 298 stars, left 217 entirely new standard stars. The numerical size of the average mean error of a single observation of a V magnitude or a color index for the 217 new standard stars is given in the fourth and seventh columns of Table 7. Readers should note that the 1992a mean errors of the mean are somewhat higher than for the 1973a and 1983 material, since the faintness of the stars being made into standards increased relatively more rapidly than did the size of the telescope with which the data were collected. Hence, the poorer average accuracy, as the telescope was pushed to its photoelectric limit.

It should be noted, for completeness, that a companion paper to Landolt (1992a) contained *UBVRI* magnitudes and colors for the Baldwin-Stone southern hemisphere spectrophotometric standard stars (Landolt 1992b).

A later section of this paper will describe the status of standard star sequences currently in production.

5. Positive and Negative Procedures in Doing Good Photometry

The following paragraphs are meant to call the observer's attention to a variety of situations which can affect the resulting single-object photometry as the observer works to attain the most accurate photometric results. Less severe constraints may apply if one only is undertaking a survey whose goal is *"just see what kind of object"* exists in a certain area of the sky.

- There cannot be too much emphasis of the statement, beginning with Johnson (1955), that "*when one establishes a standard photometric system, the data acquisition should be limited to one telescope, one photometer (detector), one set of filters, one mountain top (elevation), and the cooling of the detector to a standard stable temperature*" (Johnson 1962; Bessell 1979).

- Remember that even with the greatest of care, two photomultipliers of the same brand will deliver magnitudes and color indices of different zero point and color terms. One photomultiplier will need to be chosen as the *base*, to which the other photomultiplier's magnitudes and colors must be transferred. In other words, one just cannot, must not, average the two data sets.

- The same problem occurs if an observer is forced to switch filter sets during a project. The two filter sets will provide results different in zero point and color, and the astronomer will have to decide which filter set's results are the "best", and then transform the first to the second.

- One must obtain extinction measures every night; experience indicates that best results are obtained if the difference between the high and low air mass measurements are near one air mass. At an air mass difference of 0.5 or less, the accuracy of the extinction coefficients rapidly diminishes.

- In addition to observing standard stars to be used in the determination of transformation coefficients near the meridian, always observe some of these same, and other, stars at air mass values that are at least as large as the air mass for the program objects themselves, that is, the air mass of standard stars observed during a night should encompass the air mass of the program star fields.

- Always begin and end a night's observing with five or so standard stars possessing as large a range in color as possible.

- During a night's observing, intersperse, every two or so hours, program star acquisition with a set of standard stars. These groups of standard stars can be used to calibrate out the changes which occur throughout a night due to atmospheric and equipment variations. At CTIO, one of the best photometric sites on Earth, many times one can look out over the surrounding valleys and see the top of the atmospheric inversion layer well below the mountain tops. Later in the night, one might see movement of the inversion layer either higher or lower. At times it rises above the mountain tops, in the worst case making its presence known as an atmospheric haze. One can use the groups of standard stars observed at various times during the night to calibrate out (see Fig. 8), or at least minimize, such changes. Such phenomena occur at all sites; however, such atmospheric changes usually are subtle.

- Go out several times a night to look at the sky. An observational astronomer just must know the quality of the night from which the data came. With experience, one almost can smell the quality of the night. Keep good notes; when one returns to the data in the future, an apparent errant datum may have an explanation recorded in the logbook.

- Work in a console room with subdued lights. Incandescent bulbs are best, since fluorescent lights emit more blue light. Subdued lighting and the warmer more yellow radiation from an incandescent bulb allows one's eyes to adapt much more quickly to darkness when making the necessary treks during the night to review the quality of the night sky. One needs good dark adaption to see thin cirrus or airplane contrails.

- Always time all measurements. One never knows when an object will prove variable. The time of observation will permit the calculation of a heliocentric Julian Day.

- Be suspicious of, be knowledgeable about, algorithms which clip errant data points. Look at all data intensely. You may be throwing away your Nobel Prize!

- For photoelectric photometry, use diaphragms large enough to encompass the anticipated seeing. For CCD photometry, for the determination of the transformation relations, use a software diaphragm of the same size as was used to define the standard stars being used to calibrate your data. Stetson (2006) shared with the author a communication from a student whose results differed by up to $0\overset{m}{.}05$ from Landolt (1992a), depending upon which standard stars were used. It turned out that the offending standard star had a close and quite faint companion which had been included in the diaphragm of the photoelectric photometer, but which had not been included in the point spread function fitting used with the CCD data. Bessell (1993) makes the same point.

- One should not mix standard stars from different authors' papers if the greatest accuracy is required for a project. Otherwise, one will most assuredly incur small zero point and or color term differences.

- Do not use non-photometric data when making standards. More important, why would an observer want to contaminate beautiful data with data of lesser quality, upon any occasion?

- Do not use standard stars that were observed at high air masses for extinction purposes, also in the derivation of transformation relations. One is throwing away accuracy.

6. Current Status of Ongoing Standardization Work in *UBVRI*

The author currently has in preparation for publication photoelectrically determined *UBVRI* standard star sequences, centered around the sky, both at the celestial equator (Landolt 2007a) and approximately at $-50°$ declination (Landolt 2007b). The sequences at the equator are both an update of and additional stars added to the celestial equatorial sequences in the 1992a paper.

Observations are underway for additional sequences around the sky approximately at $+50°$ declination. With the advent of CCD imaging, observers need standard stars situated close together on the sky to minimize the time that it takes to obtain sufficient standardization frames. The task is considerably more difficult than it might at first appear to be, just because nature did not produce a proliferation of small areas on the sky that contain stars of a wide range in color. Of course, the magnitudes cannot be too different either, as some stars would be saturated for a given exposure time, and other stars might not be detectable with sufficient signal to noise.

There have been some standard sequences established in cluster or other crowded regions. That method of sometimes locating stars of a reasonable range in color has the negative aspect of crowded star images, and hence related problems in data reduction. And, really, star clusters do not as a rule contain stars of a very wide range in color index, anyway. The author prefers to avoid crowded fields when it comes to standard star sequences. The author reminds the reader of the correspondence with Stetson (2006).

6.1. Celestial Equatorial Sequences

The Landolt (1992a) *UBVRI* sequences around the sky at the celestial equator are in the process of being updated (Landolt 2007a). Not only will 32 stars have improved magnitudes and color indices, but 41 new standards will expand the color range of many of the sequences. Table 8 lists these equatorial fields. The coordinates, equinox 2000, are for the field centers. The sequence name is taken from the blue star within the field.

Table 8 illustrates the magnitude and color index characteristics for stars in the updated celestial equatorial sequences. Figure 9 shows the magnitude and color distributions of the equatorial sequences in intervals of $0\overset{\text{m}}{.}25$ and $0\overset{\text{m}}{.}1$, respectively. Figure 10 illustrates the $[U-B, B-V]$ and $[V-R, R-I]$ diagrams.

6.2. Southern Hemisphere Sequences

The new *UBVRI* photometric sequences centered approximately at $-50°$ are identified in Table 9. The fields, with the exception of the T Phe field, are named after a blue star whose presence caused the field to be chosen as a candidate standard field. T Phe is a long-period variable star. The coordinates are for the equinox 2000, and represent the center of the sequence field. Each sequence star in each sequence field will have accurate modern coordinates, based on the UCAC2, in the final publication (Landolt 2007b).

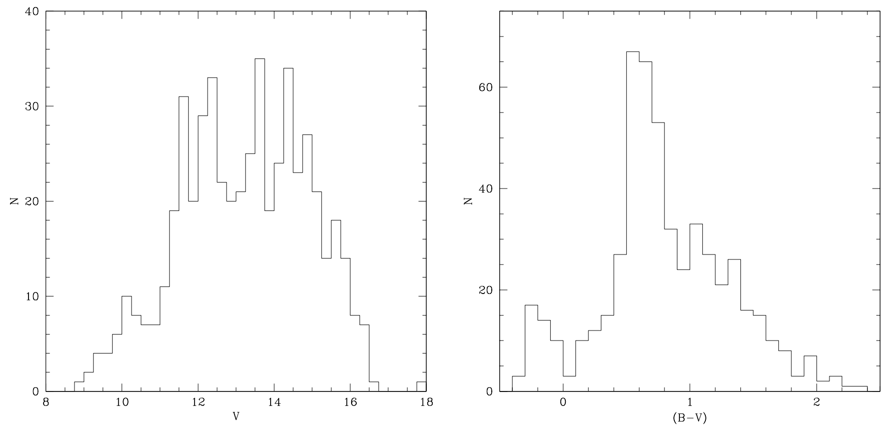

Figure 9. V and $B-V$ distributions of the updated equatorial standards.

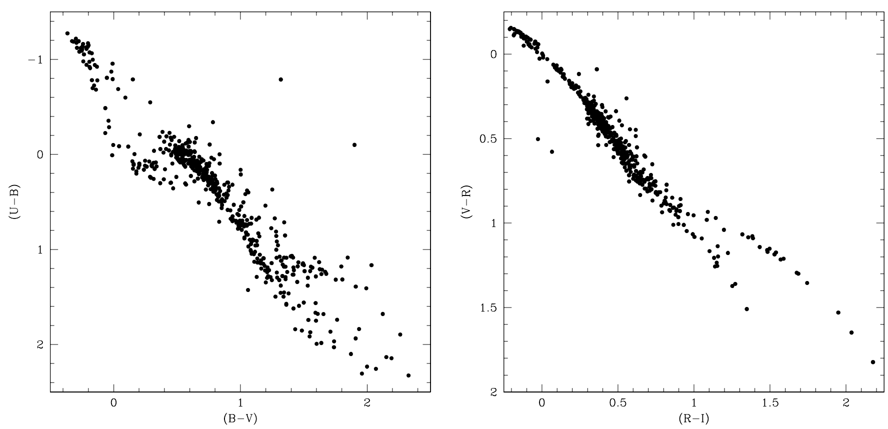

Figure 10. Color-color diagrams for the updated equatorial standards.

Table 9 illustrates the magnitude and color index characteristics for stars in the $UBVRI$ photometric sequences around the sky, at about $-50°$ declination. Figure 11 shows the magnitude and color distributions in intervals of $0^{\rm m}.25$ and $0^{\rm m}.1$, respectively. Figure 12 illustrates the $[U-B,\ B-V]$ and $[V-R,\ R-I]$ color-color diagrams.

6.3. Northern Hemisphere Sequences

A series of photometric sequences around the sky centered approximately at $+50°$ declination was begun at KPNO in the mid-1990s. This work came to a halt with the closure of the KPNO 1.3-m. Only recently has the opportunity arisen to finish the northern hemisphere sequences at the Lowell Observatory. Photoelectric data are being taken in some 24 sequences, which contain approximately 211 stars. The observational program is estimated to be roughly 50% complete as of mid-2006. The stars fall in the magnitude range $9.5 < V < 15.5$.

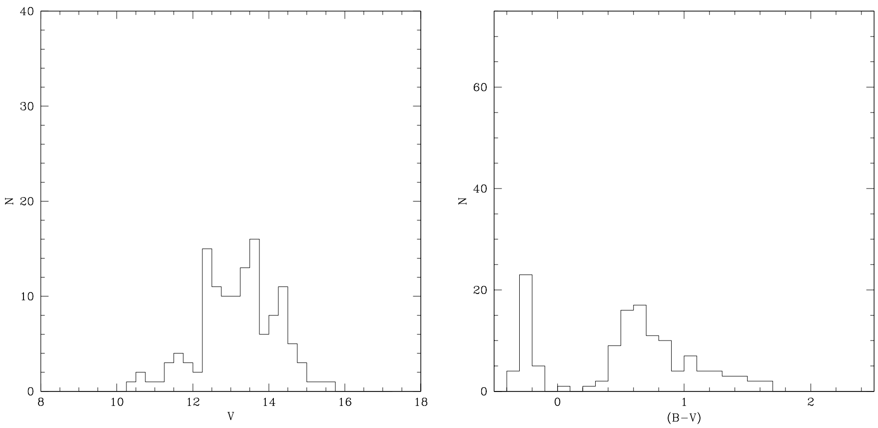

Figure 11. V magnitudes and $B - V$ color distributions for the sequence stars around the sky at $-50°$ declination.

Coordinates for a subset of the sequences undergoing observation are listed in Table 10. It should be noted that the listed coordinates are indicative only. Coordinates for the center of each field, as well as accurate coordinates for each star will be provided in the final journal publication. The Selected Areas (SA) sequences contain more stars. The sequences with the fewest number of stars tend to have the greatest color index range. It should be emphasized that some of these proposed sequences might not make the final publication.

Table 10 illustrates the magnitude and color index characteristics for stars in the $UBVRI$ photometric sequences around the sky, at about $+50°$ declination.

6.4. Faint Standard Fields for CCDs

A number of faint equatorial sequences, identified in Table 11, are in the process of being established through use of CCDs. At the faint end of the sequences are potential red-blue pairs, originally identified by Prof. David Turnshek (Turnshek et al. 1990, Table II), after massaging data digitized by Dr. David Morgan in Scotland from AAT plates of selected Kapteyn Selected Areas (SA) wherein photometric sequences had been developed (Landolt 1973a). Additional candidate sequence fields to aid in filling in gaps in right ascension were supplied to the author by Dr. Michael Irwin through scans of Palomar Observatory Sky Survey (POSS) plates. These fields are prefixed by "SF", which means only standard field (SF). The coordinates in Table 11 are equinox 2000, and again represent the field center.

Statements earlier in this Section were made to the effect that the most consistent and systematically accurate data sets come from a dedicated telescope-photometer-detector-filter set combination. Since such ideal arrangements long-term are rare, much more so in this era of CCDs than in the time of photomultipliers, an observer has to be cognizant of a variety of potential problem areas, and try to avoid them, or take them into account. Problems faced by everyone using CCDs include concern about both the wavelength and long-term stability of each chip, its spectral characteristics, band-pass variations across the chip,

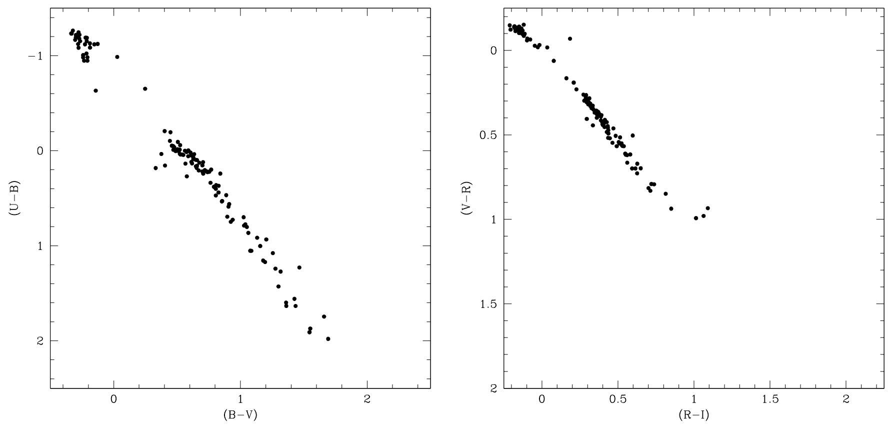

Figure 12. Color-color diagrams for the sequence stars at -50° declination.

focus variations, point spread function variations, non-linearities in transforming the CCD data onto a standard photometric system, and so on. The *modus operandi* is to check out potential problems, and to the extent possible handle all data reductions and analysis in a consistent fashion. Most likely, the most important word is consistency!

The decades-long history of the *UBVRI* photometric system, together with standard sequences available, soon, around the sky at three widely spaced declinations would seem to assure its continued usefulness. The spectral location of the *U* filter does have its problems, but that fact has been known and worked around for more than fifty years. One could add to *BVRI* the Strömgren *u* as Kinman, Suntzeff, & Kraft (1994) have done, or the Thuan-Gunn *u* as Bond (2005) and Siegel & Bond (2005) have done. The *UBVRI* photometric system provides a strong thread to the past, through its *V* magnitude. Standard stars of more extreme color index still are needed. Fainter sequences to 20th magnitude around the sky at the celestial equator, available soon, will fill a need for the largest ground-based telescopes, most of which are found within 30° of latitude of the earth's equator. Every time someone invents a new photometric system, new sets of standard stars are required. The necessary effort at the telescope is immense. Are all the photometric systems really necessary? Does everyone with a new spacecraft or telescope need to "re-invent the wheel?" A very major problem which arises is the task of being able to convert from one system to another. Colleagues have been lamenting the task of combining data from the SDSS survey with data from the HST with data from the Gemini telescopes, as one example. One really wonders just what are the accuracies of such final photometric products.

Table 8. A characterization of sequences at the celestial equator.

Region Name	α (2000) h m s	δ (2000) ° ′ ″	V range	ΔV	$(B-V)$ range	$\Delta(B-V)$	$(U-B)$ range	$\Delta(U-B)$	# stars
Feige 11	01:04:22	+04:13:37	12.06 14.47	2.41	−0.24 +0.84	1.08	−0.98 +0.45	1.43	3
PG 0231+051	02:33:41	+05:18:40	12.77 16.10	3.33	−0.33 +1.45	1.78	−1.19 +1.34	2.53	6
Feige 24	02:35:08	+03:43:57	11.76 13.81	2.05	−0.20 +1.12	1.32	−1.17 +1.00	2.17	4
GD 71	05:52:28	+15:53:15	12.32 13.64	1.32	−0.25 +1.17	1.42	−1.11 +0.90	2.01	6
Rubin 149	07:24:15	−00:32:55	11.48 14.50	3.02	−0.13 +1.12	1.25	−0.78 +1.02	1.80	8
Rubin 152	07:29:55	−02:06:18	11.08 15.02	3.94	−0.19 +0.88	1.07	−1.07 +0.49	1.56	7
PG 0918+029	09:21:28	+02:46:03	12.27 14.49	2.22	−0.27 +1.04	1.31	−1.08 +0.82	1.90	5
PG 0942−029	09:45:12	−03:09:24	13.71 14.99	1.28	−0.29 +0.78	1.07	−1.18 +0.34	1.52	5
GD 108	10:00:47	−07:33:31	13.56 15.02	1.46	−0.22 +0.86	1.08	−0.94 +0.46	1.40	5
PG 1047+003	10:50:18	−00:00:23	12.45 14.75	2.30	−0.29 +0.69	0.98	−1.12 +0.17	1.29	4
G163-50/51	11:08:04	−05:11:36	11.30 14.47	3.17	+0.04 +1.51	1.47	−0.69 +1.23	1.92	7
PG 1323−086	13:25:39	−08:49:18	12.08 14.00	1.92	−0.14 +0.76	0.90	−0.68 +0.26	0.94	4
PG 1407−013	14:10:26	−01:30:13	12.50 15.22	2.72	−0.26 +1.16	1.42	−1.12 +1.00	2.12	6
PG 1525−071	15:28:11	−07:16:27	13.51 16.26	2.75	−0.20 +1.10	1.30	−1.15 +1.03	2.18	5
PG 1633+099	16:35:24	+09:47:50	12.97 15.26	2.29	−0.19 +1.13	1.32	−0.97 +1.14	2.11	8
PG 1657+078	16:59:32	+07:43:31	14.03 16.14	2.11	−0.15 +1.07	1.22	−0.94 +0.73	1.67	6
Mark A	20:43:59	−10:47:42	13.26 15.91	2.65	−0.24 +0.94	1.18	−1.16 +0.65	1.81	5
G 26-7	21:31:16	−09:47:28	12.00 13.46	1.46	+0.56 +1.67	1.11	+0.04 +1.24	1.20	4
G 93-48	21:52:25	+02:23:20	12.42 13.66	1.24	−0.01 +1.32	1.33	−0.79 +1.22	2.01	5
PG 2213−006	22:16:28	−00:21:15	12.64 15.11	2.47	−0.22 +0.78	1.00	−1.12 +0.30	1.42	6
GD 246	23:12:35	+10:50:27	12.97 14.38	1.41	−0.32 +0.92	1.24	−1.19 +0.69	1.88	4

Table 9. A characterization of sequences at −50° declination.

Region Name	α (2000) h m s	δ (2000) ° ′ ″	V range	ΔV	$(B-V)$ range	$\Delta(B-V)$	$(U-B)$ range	$\Delta(U-B)$	# stars
JL 163	00:10:30	−50:15:00	12.64 15.56	2.92	−0.23 +1.60	1.29	−1.04 +1.03	2.07	7
T Phe field	00:30:16	−46:27:55	10.44 14.91	4.47	−0.30 +1.55	1.85	−1.22 +1.91	3.13	10
MCT 0401−4017	04:03:04	−40:09:42	10.63 14.40	3.77	−0.23 +0.91	1.14	−1.24 +0.59	1.83	7
LB 1735	04:31:11	−53:35:25	12.76 15.20	2.44	−0.14 +1.27	1.41	−0.61 +1.24	1.85	8
MCT 0550−4911	05:52:02	−49:11:22	13.02 14.71	1.69	−0.24 +1.31	1.55	−1.25 +1.13	2.38	6
LSS 982	08:10:32	−40:33:10	11.29 13.36	2.07	−0.30 +1.67	1.97	−1.28 +1.69	2.97	8
WD 0830−535	08:31:51	−53:40:45	12.60 14.49	1.89	−0.20 +1.29	1.49	−1.18 +1.01	2.19	12
WD 1056−384	10:58:20	−38:44:51	12.38 14.03	1.65	−0.17 +1.16	1.33	−1.11 +1.04	2.15	5
WD 1153−484	11:56:14	−48:40:42	12.60 14.24	1.64	−0.21 +1.35	1.56	−1.05 +1.59	2.64	9
LSE 44	13:52:42	−48:08:07	12.02 13.74	1.72	−0.25 +1.43	1.68	−1.18 +1.56	2.74	7
LSE 259	16:53:54	−56:02:00	10.86 14.14	3.28	−0.12 +1.69	1.81	−1.14 +2.25	3.39	9
MCT 2019−4339	20:19:23	−43:39:52	12.44 13.95	1.51	−0.26 +1.02	1.28	−1.21 +0.78	1.99	7
JL 82	21:36:06	−72:49:00	11.22 13.50	2.28	−0.20 +1.06	1.26	−0.96 +0.87	1.83	5
JL 117	22:54:38	−72:23:10	12.55 14.96	2.41	−0.34 +0.81	1.15	−1.23 +0.47	1.70	5

Table 10. A characterization of sequences at +50° declination.

Region Name	α (2000) h m s	δ (2000) ° ′ ″	V range	ΔV	$(B-V)$ range	$\Delta(B-V)$	$(U-B)$ range	$\Delta(U-B)$	# stars
GD 2	00:07:34	+33:19:00	13.28 15.19	1.91	−0.29 +0.92	1.21	−1.18 +0.68	1.86	6
GD 8	00:39:45	+31:34:50	13.30 14.68	1.38	−0.27 +0.82	1.09	−1.18 +0.46	1.64	4
SA 20	00:45:52	+45:53:09	8.95 14.88	5.93	+0.08 +1.10	1.02	−0.05 +0.98	1.03	23
GD 010	01:06:59	+39:31:20	13.68 15.46	1.78	+0.20 +0.84	0.64	−0.63 +0.45	1.08	4
GD 277	01:29:27	+51:09:18	13.53 14.53	1.00	−0.10 +1.27	1.37	−0.90 +1.02	1.92	3
GD 421	01:51:00	+67:41:50	12.15 14.56	2.41	−0.21 +2.59	2.80	−1.08 +2.63	3.71	5
GD 279	01:52:03	+47:01:15	10.40 14.16	3.76	+0.08 +1.12	1.04	−0.63 +0.99	1.62	9
SA 23	03:44:55	+45:19:59	9.44 15.44	6.00	+0.17 +1.86	1.69	−0.47 +2.21	2.68	21
GD 64	04:57:18	+41:55:10	11.53 14.44	2.91	+0.06 +1.81	1.75	−0.56 +2.18	2.74	7
SA 26	06:43:50	+44:38:13	8.51 15.35	6.84	+0.12 +1.69	1.57	−0.36 +1.73	2.09	18
GD 91	08:30:16	+45:19:50	12.44 15.07	2.63	+0.19 +1.02	0.83	−0.52 +0.85	1.37	3
PG 0837+401	08:41:01	+39:56:30	12.17 15.47	3.30	−0.23 +0.93	1.16	−1.00 +0.69	1.69	4
GD 98	08:57:20	+40:17:25	13.47 14.81	1.34	−0.12 +0.92	1.04	−0.92 +0.62	1.54	3
SA 29	09:44:32	+44:15:45	8.29 15.43	7.14	+0.48 +1.22	0.74	−0.08 +1.20	1.28	20
GD 300	09:55:18	+51:38:25	12.65 12.99	0.34	−0.32 +0.68	1.00	−1.19 +0.15	1.34	3
KU 348−13	10:04:00	+40:33:45	12.50 14.70	2.20	−0.32 +0.70	1.02	−1.13 +0.16	1.29	3
GD 310	11:29:24	+38:07:45	13.92 14.97	1.05	−0.17 +0.98	1.15	−1.02 +0.82	1.84	4
GD 314	12:04:33	+60:34:50	10.84 13.56	2.72	−0.33 +0.93	1.26	−1.23 +0.66	1.89	3
PG 1210+533	12:13:22	+53:03:14	11.50 14.46	2.96	−0.30 +0.65	0.95	−1.22 +0.15	1.37	3
SA 32	12:56:52	+44:12:54	8.96 16.36	7.40	+0.40 +1.16	0.76	−0.11 +1.13	1.24	24
PG 1314+442	13:16:33	+43:58:45	15.24 15.39	0.15	−0.13 +0.70	0.83	−1.00 +0.14	1.14	2
GD 325	13:36:23	+48:29:30	11.98 14.10	2.12	+0.03 +0.88	0.85	−0.96 +0.52	1.48	4
GD 336	14:31:55	+37:06:00	12.99 15.28	2.29	−0.25 +0.65	0.90	−1.17 +0.14	1.31	4
PG 1430+427	14:32:35	+42:31:00	11.42 14.23	2.81	−0.14 +0.90	1.04	−0.67 +0.67	1.34	4
SA 35	15:31:07	+44:40:21	9.03 16.10	7.07	+0.37 +1.52	1.15	−0.09 +1.89	1.98	19
KU 433−03	16:38:27	+35:00:00	14.88 15.58	0.70	−0.24 +1.24	1.48	−1.15 +1.25	2.40	2
GD 358	16:47:05	+32:27:47	12.57 13.60	1.03	−0.13 +0.95	1.08	−1.04 +0.76	1.80	6
PG 1648+536	16:50:00	+53:29:16	12.25 15.16	2.91	−0.21 +0.97	1.18	−1.02 +0.74	1.76	6
GD 363	17:38:37	+41:53:18	12.91 15.27	2.36	−0.10 +1.16	1.26	−0.92 +0.98	1.90	5
SA 38	18:49:12	+45:15:37	8.57 15.46	6.89	+0.28 +1.29	1.01	−0.09 +1.44	1.53	26
GD 391	20:29:50	+39:15:59	11.46 15.00	3.54	−0.15 +1.01	1.16	−1.00 +0.54	1.54	9
SA 41	21:49:38	+44:57:26	9.98 14.99	5.01	+0.23 +1.74	1.51	−0.19 +2.06	2.25	19
GD 556	23:14:04	+55:28:27	15.27 15.70	0.43	+0.16 +1.41	1.25	−0.56 +1.72	2.28	3

7. The Future

A final comment is that the work of those who establish standard photometric systems never is completed. Standard systems always need stars of a greater range in color index, as well as ever fainter stars as larger telescopes are built and as detectors become more sensitive.

Table 11. CCD photometric sequences in preparation at the celestial equator.

Region Name	RA (J2000) h m s	Dec (J2000) ° ′ ″
SA 95 Field 1	03:40:05	+01:47:01
SA 95 Field 2	03:37:52	+00:34:19
SA 95 Field 3	03:46:52	−00:37:37
SA 95 Field 4	03:41:49	+01:38:26
SF 0841−022	08:43:55	−02:25:27
SA 101 Field 1	09:57:34	−00:22:29
SF 1253−001	12:55:54	−01:24:08
SF 1403−011	14:06:23	−01:22:54
SA 107 Field 1	15:35:28	+00:03:08
SA 107 Field 2	15:44:19	+00:17:36
SF 1615−013	16:17:57	−01:27:55
SF 1615+001	16:18:01	−00:01:04
SF 2118+007	21:20:47	+00:53:44
SA 113 Field 1	21:36:07	−00:29:41
SA 113 Field 2	21:35:03	+00:31:27
SA 113 Field 3	21:40:02	+01:32:58

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Discussion

Kidger: One of my possessions is the IR observing manual for a particular (well-known) observatory, which recommends "saving time" by observing a large number of standard stars in twilight. We've found that more than 95% of nights show variable near-IR extinction. From long experience, observers prefer to risk losing a full night of data rather than spend a little of their precious observing time on calibration. What can Commission 25 do to try to encourage good calibration practices and to sensitize the community to the need to do things correctly even if it costs a little extra time?

Landolt: Commission 25 could discuss the topic of calibration practices during its meeting at the Prague IAU General Assembly in August 2006. An appropriately worded resolution may be effective in calling the community's attention to the problem.