

Calibration of the BATC Survey: Methodology and Accuracy

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ABSTRACT. We describe in detail the extinction correction procedures used for the Beijing-Arizona-Taiwan-Connecticut Sky Survey (BATC Survey). The survey covers the spectral range 3200–9900 Å by utilizing a set of 15 intermediate-band filters. These filters are specifically designed to exclude most of the bright and variable night-sky emission lines. We also present extinction coefficients for the filter passbands for typical photometric nights at the Xinglong Observing Station, Beijing Astronomical Observatory (where the observations of the survey are being carried out). Time-dependent, low-amplitude ($\sim 1\%$), nightly extinction variation has been observed. Such variation is demonstrably independent of filter bandpass and air mass, with amplitudes ranging from ~ 0.01 to ~ 0.03 mag. The variation is plausibly caused by slowly varying (at $\sim 1\%$) atmospheric extinction, possibly related to changes in air pressure/temperature/humidity that occur during the night. An iterative fitting scheme has been developed to take this time-varying component into account. We conclude that the survey can achieve its stated observational goal, namely, an absolute photometric calibration that is tied to the AB_s system to an accuracy of 1% in all filters.

1. INTRODUCTION

For any large photometric project done with one telescope, it is wise to establish the photometric behavior of the site + telescope combination. In this paper, we use the data we have collected with the 60/90 cm Schmidt telescope of the Beijing Astronomical Observatory (BAO) to establish the photometric behavior of the observing site, the Xing-

long Observing Station (longitude: $-117^{\circ}34'42''$; latitude: $40^{\circ}23'47''$; altitude: 970 m).

Our methodology for establishing the photometric behavior of this site has been influenced by the experience of one of us (D. B.), who has found nightly, gray (i.e., independent of passband), air-mass-independent changes to occur in atmospheric extinction on otherwise well-established photometric nights. This has been seen on several different sites (Kitt Peak, Cerro Tololo, La Palma; Burstein et al. 1987; Colless et al. 1993; Saglia et al. 1997). As we show here, the nightly atmospheric extinction variations we see are also independent of passband and air mass. If adequately monitored, such “diurnal” changes in nightly atmospheric extinction can be removed from the data to produce $\sim 1\%$ photometry. Thus, we made monitoring such effects an integral part of our observing procedure on nights anticipated to be photometric in the Beijing-Arizona-Taiwan-Connecticut (BATC) Color Survey of the sky (cf. Fan et al. 1996; Shang et al. 1998; Zheng et al. 1999). In this paper we present the first results of such monitoring and, with these data, the mean extinction coefficients from 3200 to 9900 Å for the Xinglong Observing Station.

Section 2 of this paper describes the survey’s photometric system, which is primarily determined by the BATC intermediate-band filter transmissions, and the systematic problems for which we will test in this paper. Section 3

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TABLE 1
PARAMETERS OF THE 15 BATC FILTERS

FILTER NO.	CODE	λ_{eff} (Å)		FWHM (Å)	
		Wavelength Weighted	Frequency Weighted	Measured	Gaussian Fit
1	a	3371.5	3360.0	359	271
2	b	3906.9	3897.6	291	260
3	c	4193.5	4179.6	309	327
4	d	4540.0	4531.9	332	259
5	e	4925.0	4916.4	374	280
6	f	5266.8	5258.2	344	290
7	g	5789.9	5784.9	289	231
8	h	6073.9	6068.6	308	245
9	i	6655.9	6645.5	491	359
10	j	7057.4	7054.9	238	179
11	k	7546.3	7544.7	192	151
12	m	8023.2	8019.7	255	228
13	n	8484.3	8482.6	167	166
14	o	9182.2	9180.2	247	182
15	p	9738.5	9736.3	275	200

explains the extinction correction procedures in full detail and explicitly tests for these problems. Section 4 states our conclusions.

2. PHOTOMETRIC SYSTEM

The BATC Color Survey's photometric system is defined by 15 intermediate-band filters (cf. Fan et al. 1996). Two, 2

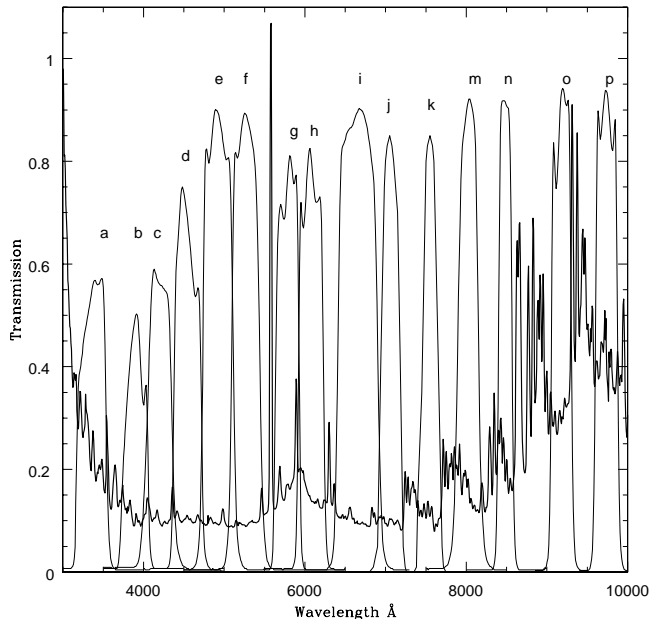


FIG. 1.—Transmissions of the 15 BATC filters. The filter codes (see Table 1) are labeled on top of each filter. Also superposed is a typical night-sky emission-line spectrum. The filter design avoids most of the bright night-sky emission lines.

inch sets of these filters are now being used by various members of our collaboration. For completeness, the filter transmissions published in Fan et al. (1996) are reproduced here in Figure 1, with one minor revision. The previous filter 10 has been replaced by two narrower filters (*j* and *k*) to further exclude strong and variable night-sky lines. Also superposed is a typical night-sky emission-line spectrum (from Mount Hopkins, Arizona), so one sees that the filter design avoids most of the known bright and variable night-sky emission lines. One of the advantages of these filters is that the sky background is greatly suppressed in the red, as demonstrated by the discovery of a ring of very faint surface brightness ($R \sim 28 \text{ mag arcsec}^{-2}$) around the edge-on

TABLE 2
BATC MAGNITUDES OF THE FOUR PRIMARY STANDARD STARS

Band	HD 19445 (C001)	HD 84937 (C002)	BD +26°2606 (C003)	BD +17°4708 (C005)
a	9.234	9.486	10.933	10.726
b	8.653	8.800	10.299	10.057
c	8.447	8.626	10.095	9.841
d	8.294	8.505	9.962	9.693
e	8.187	8.429	9.848	9.592
f	8.072	8.338	9.743	9.488
g	7.969	8.259	9.652	9.396
h	7.935	8.232	9.617	9.365
i	7.885	8.205	9.576	9.318
j	7.851	8.171	9.541	9.273
k	7.826	8.165	9.522	9.255
m	7.800	8.150	9.501	9.238
n	7.790	8.144	9.489	9.226
o	7.784	8.149	9.489	9.226
p	7.801	8.173	9.507	9.244

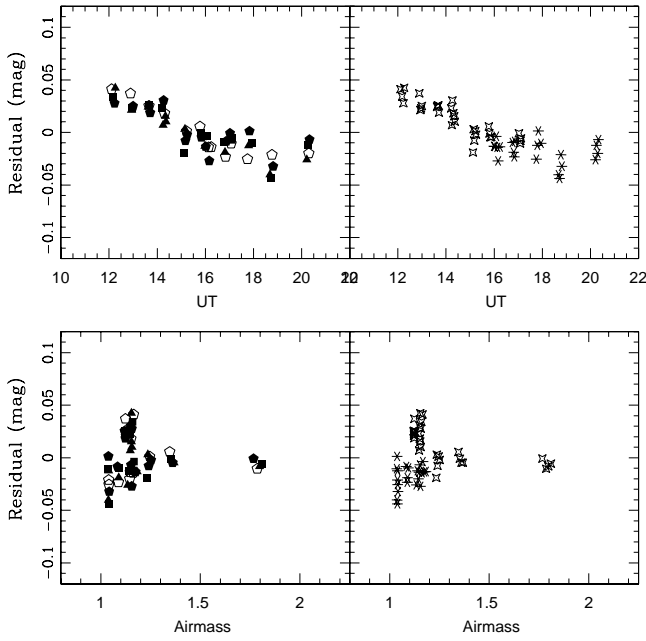


FIG. 2a

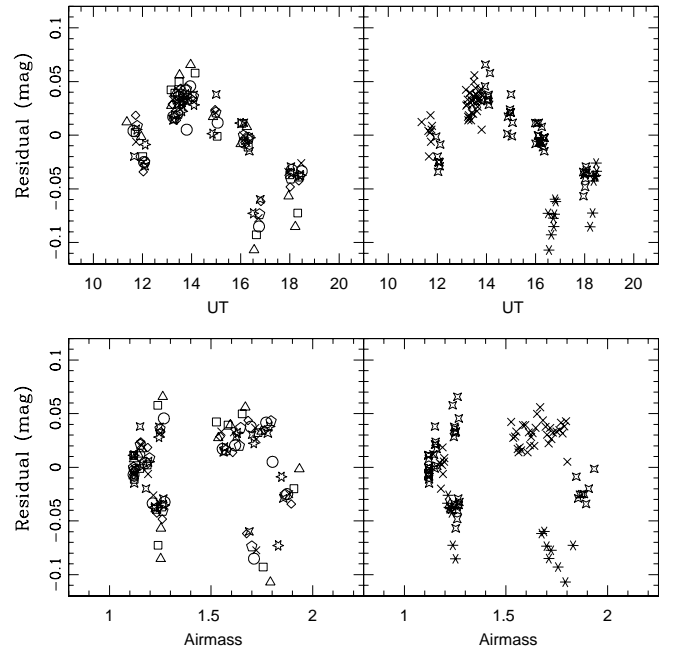


FIG. 2b

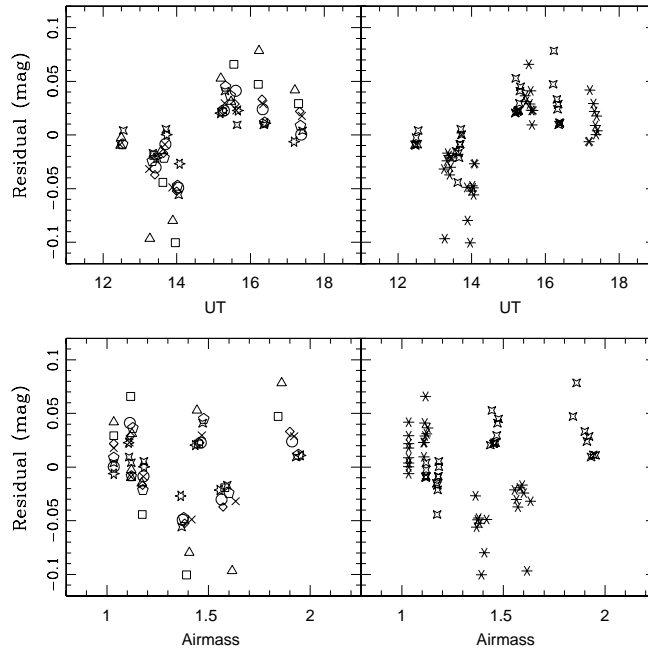
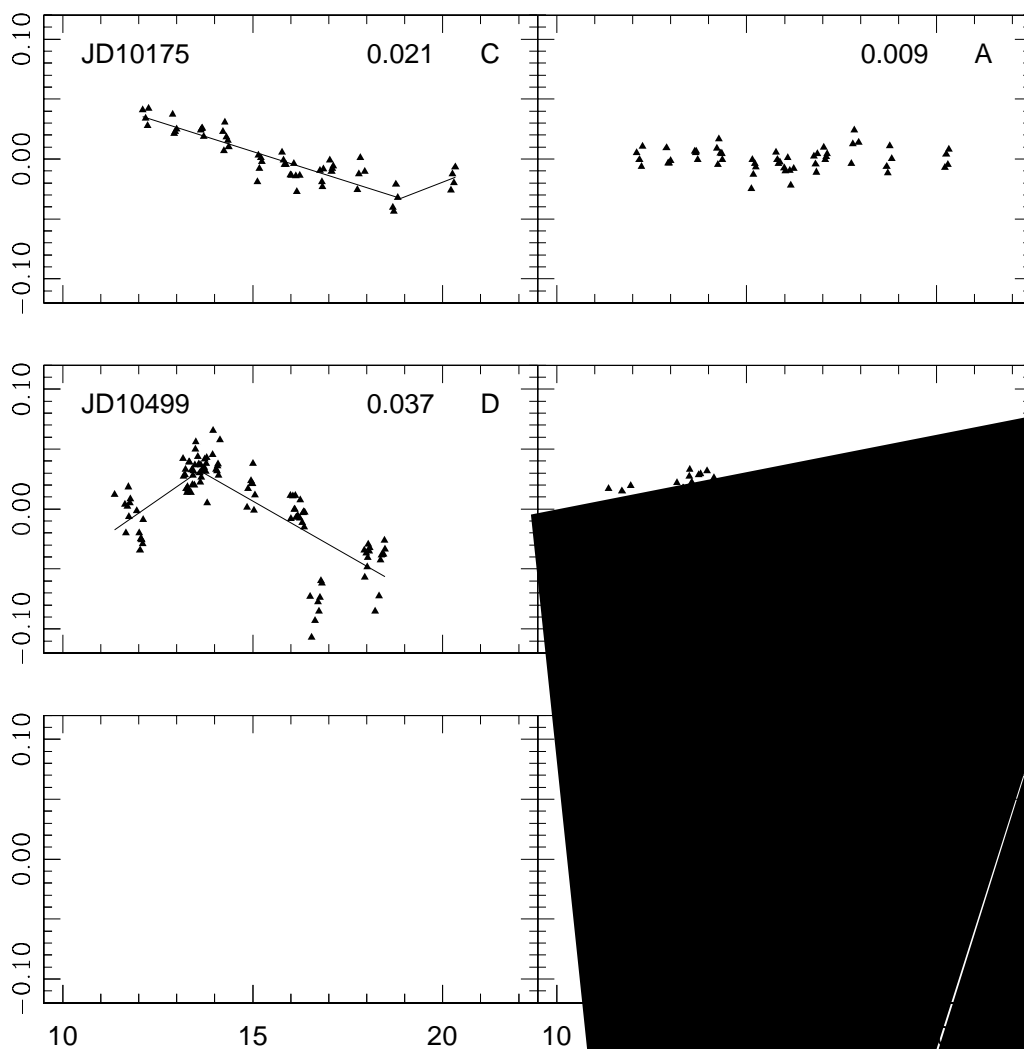


FIG. 2c

FIG. 2.—(a) For JD 10,175. First-order fitting residuals show strong correlation with both time and air mass. A grade A [after taking off $f(UT)$ term, see text] night is shown here, with upper panels used for residual vs. time and lower panels used for residual vs. air mass. In either panel different symbols are used to indicate different filters in the left figure and to indicate different standard stars in the right figure. The passbands used at this night are g (*open pentagons*), m (*filled triangles*), o (*filled squares*), and p (*filled pentagons*). The stars used for this night were C002 (*four-pointed stars*) and C003 (*six-pointed stars*). It is clear that the residuals do not depend on color or on use of different standard stars. (b) For JD 10,499. Same as (a), but with a grade B night. The passbands used are b (*triangles*), d (*squares*), f (*diamonds*), g (*pentagons*), h (*circles*), i (*crosses*), j (*four-pointed stars*), and k (*six-pointed stars*). The stars used for this night were C001 (*crosses*), C002 (*four-pointed stars*), and C003 (*six-pointed stars*). (c) For JD 10,555. Same as (b), but with a grade C night. The passbands used are b, d, f, g, h, i, j, and k. Symbols are the same as in (b).

Residual



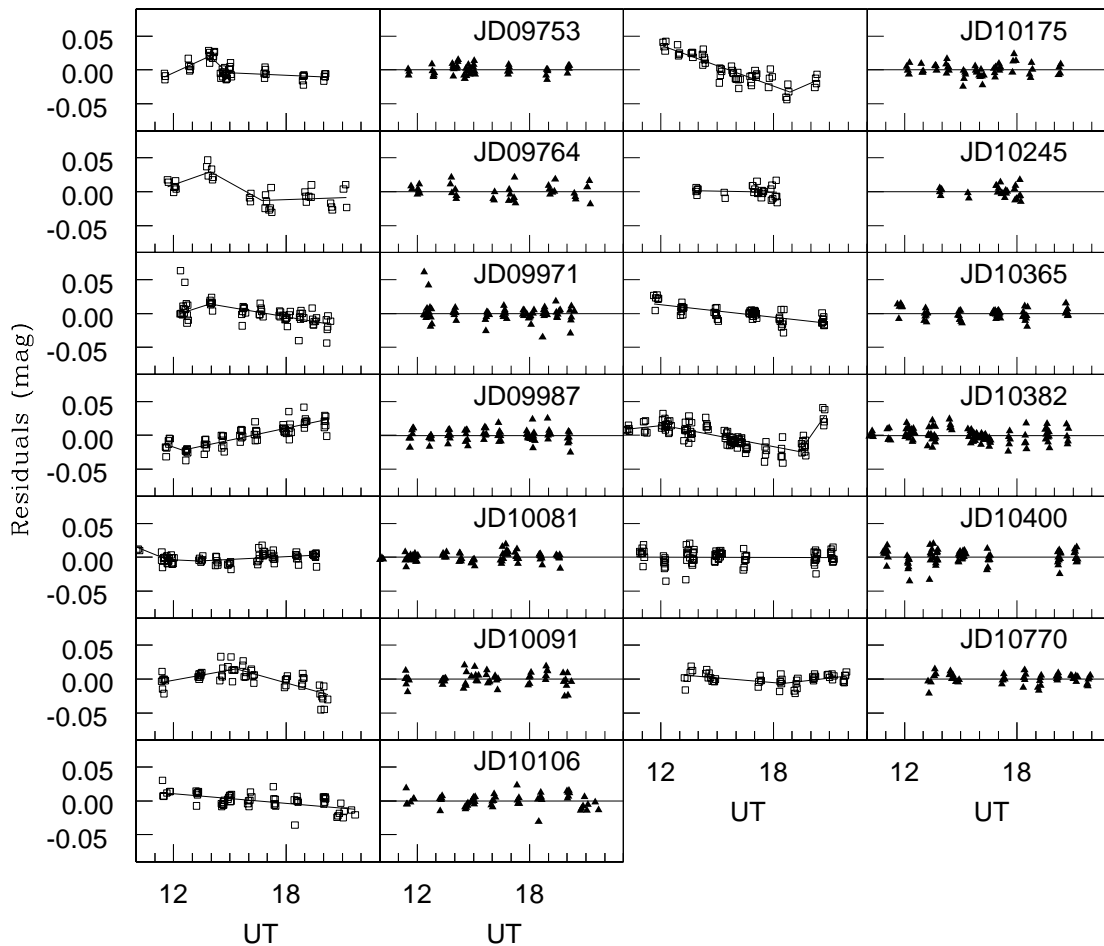


FIG. 4a

FIG. 4.—(a) $f(\text{UT})$ fitting results for all the 13 A nights. The residuals both before (*left*) and after (*right*) the fit are shown. Note that the vertical scale on this figure is different from those used for B and C nights. Each night uses filters with as wide a wavelength range as in Figure 2. (b) Same as (a), but for all the 15 B nights. Note that the vertical scale on this figure is different from those used for A and C nights. Each night uses filters with as wide a wavelength range as in Fig. 2. (c) Same as (b), but for all the four C nights. Note that the vertical scale on this figure is different from those used for A and B nights. Each night uses filters with as wide a wavelength range as in Fig. 2.

energy distribution of the source, and λ_1 and λ_2 are the lower and upper cutoff wavelengths of the passband, respectively (cf. Fan et al. 1996). We noticed that for a photon-count detector such as a CCD, \tilde{F}_v can be more naturally written as

$$\begin{aligned} \tilde{F}_v &= \frac{\int d(\log v) f_v R_v}{\int d(\log v) R_v} \\ &= \frac{\int dv R_v f_v / hv}{\int dv R_v / hv}, \end{aligned}$$

which ties the magnitude to the number of photons detected by the CCD, rather than to the input flux (cf. Fukugita et al. 1996). The difference for the BATC filters is trivial (at the ~ 0.001 mag level), due to the relative narrowness of the BATC passbands.

The system response $R(\lambda)$ actually used to relate f_v and \tilde{F}_v includes *only* the filter transmissions. Other effects, such as the quantum efficiency of the CCD, the response of the telescope's optics, the transmission of atmosphere, etc., are ignored. This makes the BATC system filter-defined. We can do this because the bandwidths are intermediate in size and all the other responses vary little within a specified passband. This issue will be fully addressed in a separate paper, through photometry of stars with a wide range of color. To give a rough idea of to what extent our assumption is true, we note that the effective wavelengths are affected only at the ~ 6 Å level after taking CCD quantum efficiency and aluminum reflection into account.

The primary standard stars used by the survey to define the photometric zero point are four of the five spectrophotometric standard stars of Oke & Gunn (1983): BD + 17°4708, BD + 26°2606, HD 19445, and HD 84937.

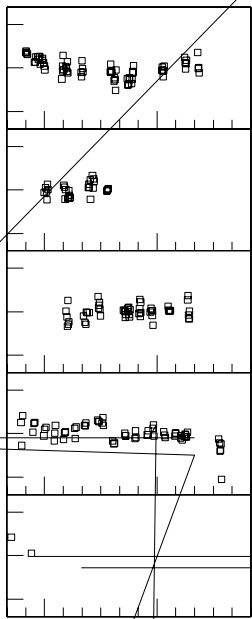


TABLE 3
GRADES OF THE 32 PHOTOMETRIC NIGHTS BEFORE AND AFTER $f(UT)$ FITTING

JD (2,440,000+)		rms			GRADE			rms			GRADE		
		Before $f(UT)$ Fitting	After $f(UT)$ Fitting	Flag ^a	Before $f(UT)$ Fitting	After $f(UT)$ Fitting	Flag ^a	Before $f(UT)$ Fitting	After $f(UT)$ Fitting	Flag ^a	Before $f(UT)$ Fitting	After $f(UT)$ Fitting	
9,681	.....	0.028	0.028		C	C		C	C		C	A
9,753	.....	0.013	0.007	X	B	B		B	A		A	A
9,764	.....	0.019	0.010	X	B	A		A	A		B	A
9,781	.....	0.025	0.025		C	C		C	A		B	A
9,783	.....	0.020	0.013	X	B	B		B	A		A	A
9,833	.....	0.013	0.011		B	B		B	B		B	B
9,971	.....	0.013	0.009	X	B	A		A	B		B	B
9,972	.....	0.015	0.014		B	B		B	B		B	B
9,987	.....	0.016	0.008	X	B	B		B	B		B	B
10,024	.....	0.021	0.016	X	C	C		C	D		D	C
10,049	.....	0.028	0.022	X	C	C		C	D		D	C
10,072	.....	0.018	0.015	X	B	B		B	B		B	B
10,081	.....	0.009	0.006	X	A	A		A	B		B	B
10,091	.....	0.014	0.008	X	B	B		B	B		B	B
10,106	.....	0.011	0.008	X	B	A		A	B		A	A
10,113	.....	0.030	0.018	X	C	B		B	B		B	B
10,175	.....	0.021	0.009	X	C	C		C	C		C	A
10,245	.....	0.008	0.008		A	A		A	A		A	A
10,365	.....	0.011	0.007	X	B	B		B	A		A	A
10,382	.....	0.017	0.009	X	C	C		C	A		A	A
10,400	.....	0.010	0.010		B	B		B	A		A	A
10,402	.....	0.015	0.011	X	B	B		B	B		B	B
10,455	.....	0.018	0.015	X	A	A		A	B		B	B
10,462	.....	0.014	0.013		B	B		B	B		B	B
10,499	.....	0.037	0.017	X	B	D		D	D		D	C
10,555	.....	0.034	0.021	X	C	C		C	D		D	C
10,669	.....	0.015	0.011	X	C	C		C	B		B	B
10,670	.....	0.032	0.027	X	B	C		C	C		C	B
10,694	.....	0.018	0.015	X	A	A		A	B		B	B
10,757	.....	0.013	0.012		A	A		A	B		B	B
10,770	.....	0.008	0.007	X	A	A		A	B		A	A
10,795	.....	0.014	0.012	X	C	B		B	B		B	B

^a An "X" is marked if $f(UT)$ fitting decreases rms significantly.

Their BATC magnitudes are listed in Table 2. The absolute fluxes of these stars are taken from Fukugita et al. (1996), in which the latest flux measurements of these stars (denoted as AB_{9,5}) are given. Note that the magnitudes of these standard stars used in Fan et al. (1996) were on the AB_{7,9} system, which has been superseded by the AB_{9,5} calibration. The new standardization changes the $b-i$ standard colors (3890–6600 color in Fan et al. [1996] notation) by -0.064 mag. These bluer colors remove the discrepancy between the main-sequence colors and predicted reddenings that were found in Fan et al. for the open cluster M67 by using the older standard-star calibration.

3. EXTINCTION CORRECTION

3.1. The Four Observational Issues

The observational goal of the BATC Color Survey is to obtain spectrophotometry in the 15 filters to an accuracy of 1% per passband. To do this, we have to account for four separate observational issues: (1) air-mass dependency of atmospheric extinction; (2) slowly varying atmospheric extinction through the night; (3) possible errors (at the 0.01–0.03 mag level) in either the transformation of the standard-star fluxes to filter-defined magnitudes or the standard-star spectral energy distributions themselves; and (4) determination of the zero point of mean extinction for a given night.

As the first three effects can influence the determination of each other, as well as the value of the fourth, one tries to obtain as many observations as possible in as many filters, over as wide a wavelength region, over as wide an air mass, using as many of the four primary standard stars as possible. Clearly, this is hard to do with just one photometric night (if one also wants to take program observations), but it is possible with many nights, spaced out throughout the year, such as we have for the present analysis.

3.2. The Photometric Observing Procedure

When a night, or a portion of a night, is thought to be photometric by the observers, two or three standard stars are observed seven to nine times with five to nine filters between air masses 1–2. Filters used on a given night span as wide a range as possible in wavelength, modulo bright moon constraints. Only short exposures of the survey program fields are made on photometric nights, so that as many program fields as possible can be observed close their meridians.

The standard stars are put near the CCD center to minimize any systematic errors due to the shutter effect (since only very short time exposures can be made for these stars) or flat fields. The wide dynamic range of the CCD camera ($1.5 \times 10^5 e^-$) makes it possible to always observe these

bright standard stars in focus with a minimum exposure time of 1 s. The photons from the stars are measured within an aperture radius of 15 pixels (25'05 at 1'67 pixel scale). The sky backgrounds are measured within an annulus of 20 pixels (33'40) inner radius and 30 pixels (50'10) outer radius. In this way we include essentially all the light coming from the star, even if the seeing is variable. Because the stars are bright, Poisson photon errors are at a level of ~ 0.0001 mag, negligible for this analysis.

Of the 423 nights of usable observations for the BATC Survey during 1994–1997, 32 nights (7.6%) were deemed to be photometric by the observers, and it is these nights that provide the data we will consider here.

3.3. The First-Order Extinction Correction

To first order the extinction equation for a given filter can be written as

$$m_{\text{inst}} = m_{\text{batc}} + KX + C, \quad (2)$$

where m_{inst} is a star's instrumental magnitude, m_{batc} is its actual magnitude in our system, here termed "BATC magnitude," K is the extinction coefficient for the filter, X is air mass, and C is the instrumental zero point.

Both K and C in equation (2) are determined nightly. By making the zero point C a free parameter, the nightly determined zero point incorporates any changes in the combined optical response of the detector quantum efficiency, telescope optics, average level of nightly extinction, etc. Although K and C may be determined simultaneously, likely cross-talk between possible air-mass residuals and possible time-dependent extinction variations suggests that an iterative procedure is preferred. By taking the average of both sides, equation (2) gives

$$\begin{aligned} \overline{m_{\text{inst}}} &= \overline{(m_{\text{batc}} + KX + C)} \\ &= m_{\text{batc}} + K\overline{X} + C. \end{aligned} \quad (3)$$

Here we have $C = \overline{C}$ because we define the mean zero point to be held constant for a specified night. Subtracting equation (3) from equation (2), we define the parameter Δ per observation as

$$\begin{aligned} \Delta &= m_{\text{inst}} - \overline{m_{\text{inst}}} \\ &= K(X - \overline{X}), \end{aligned} \quad (4)$$

with K as the only free parameter in this equation. Fitting Δ versus $(X - \overline{X})$ (or effectively just X alone) we get K and bypass the problem of fitting two parameters at the same time.

Now we can substitute K back into equation (3) and determine the average nightly zero point C ,

$$C = \overline{m_{\text{inst}}} - m_{\text{batc}} - K\bar{X}. \quad (5)$$

After K and C have been derived, we can examine the fitting residuals for each night. Substituting K and C into both equations (2) and (3), we define the fitting residual per observation, δ , to be

$$\delta = (m_{\text{inst}} - m_{\text{batc}} - KX) - \overline{(m_{\text{inst}} - m_{\text{batc}} - KX)}.$$

The root mean square (rms) of the residuals, δ , found in determining K for each passband, are averaged over all filter passbands observed on a given night. This rms is our measure of the quality of the photometric nights: nights are graded as ‘‘A’’ [rms ≤ 0.01 mag (air mass) $^{-1}$], ‘‘B’’ [$0.01 < \text{rms} \leq 0.02$ mag (air mass) $^{-1}$], ‘‘C’’ [$0.02 < \text{rms} \leq 0.03$ mag (air mass) $^{-1}$], or ‘‘D’’ [rms > 0.03 mag (air mass) $^{-1}$]. A, B, and C nights are assumed to be photometric; D nights are assumed not to be photometric.

As can be seen from equations (2) and (3), if the extinction behavior were exactly what equation (2) describes, and if there were no error in the photometry, the rms residual would be zero. Typically, however, the residuals on most nights are found to be of low but nonzero amplitude (0.01–0.03 mag), which are much higher than photon statistics for the standard-star data, and show systematic time dependency. We find that the residuals are more positive in the first part of the night, decrease smoothly for much of the night, then become more positive again in the last part of the night. All these time-dependent terms are replicated in all filters observed over the same period of time, at different air masses. This demonstrated lack of passband dependency in the time-dependent terms indicates a gray (i.e., wavelength independent) variation in the observed standard-star magnitudes. This is consistent with what we and others have seen for nightly extinction variations at other observing sites. Figure 2 explicitly shows how this component varies in terms of air mass and time for different filters and different standard stars for three nights of different preliminary (i.e., before time-dependent variations are removed) photometric qualification.

3.4. Iterative Extinction Correction

To incorporate the time-variable gray extinction component, we introduce a time-dependent term into the extinction equation and rewrite equation (2) as

$$m_{\text{inst}} = m_{\text{batc}} + KX + f(\text{UT}) + C, \quad (6)$$

where we define the time dependency of atmospheric extinction on a given night as $f(\text{UT})$. Consequently, equation (4)

becomes

$$\begin{aligned} \Delta &= (m_{\text{inst}} - m_{\text{batc}}) - \overline{(m_{\text{inst}} - m_{\text{batc}})} \\ &= K(X - \bar{X}) + f(\text{UT}) - \overline{f(\text{UT})} \\ &= K(X - \bar{X}) + f(\text{UT}). \end{aligned} \quad (7)$$

Note that we take $\overline{f(\text{UT})} = 0$ because the nonzero part of this component is absorbed into the zero point C . The major contribution to the extinction is still the air-mass term. Using the values of K and C determined from the first-order fit in the previous section, and substituting the revised extinction equation, equation (6), into the definition of δ , we find

$$\begin{aligned} \delta &= (m_{\text{inst}} - m_{\text{batc}} - KX) - \overline{(m_{\text{inst}} - m_{\text{batc}} - KX)} \\ &= f(\text{UT}). \end{aligned}$$

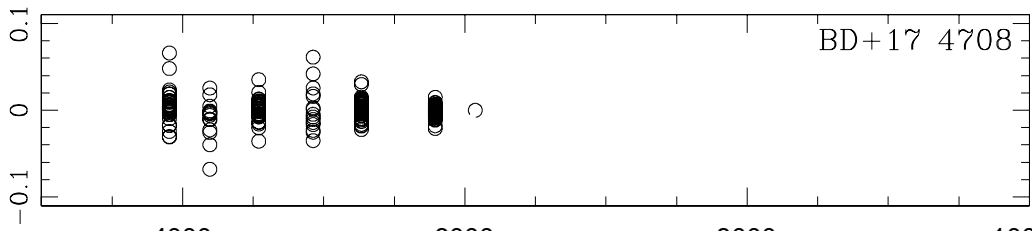
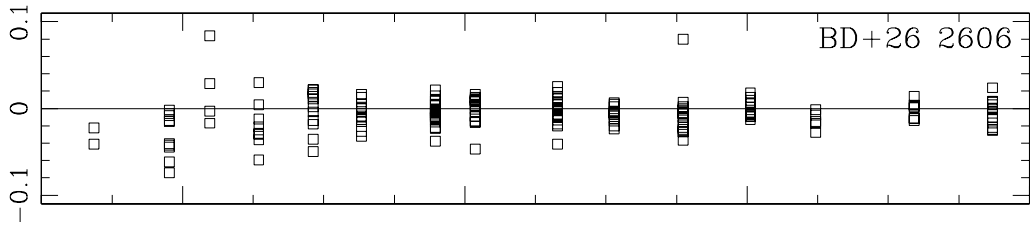
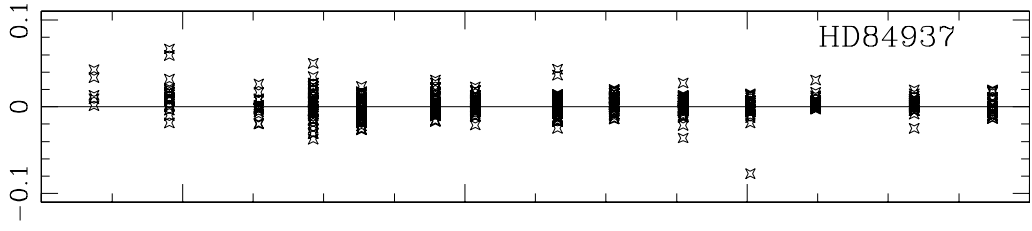
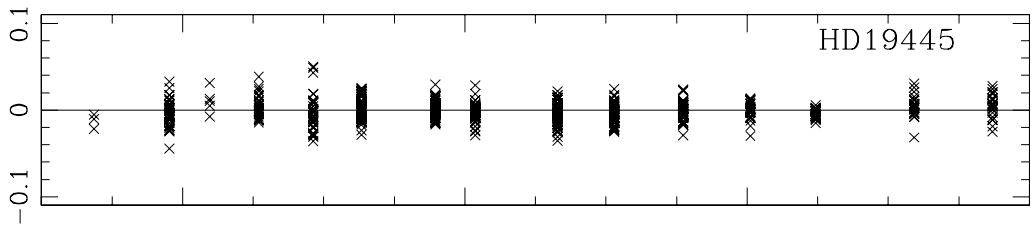
Thus, by examining δ versus UT we can determine $f(\text{UT})$. Examination of the values of δ versus time shows that a whole night can be divided into several time ‘‘segments.’’ A straight-line fit thorough the values of δ within each time segment is sufficient to determine $f(\text{UT})$ for this segment. We therefore express $f(\text{UT})$ as

$$\begin{aligned} f(\text{UT}) &= a_i + b_i \text{UT}, \quad (\text{UT}_{i-1} \leq \text{UT} < \text{UT}_i) \\ &(i = 1, \dots, n), \end{aligned}$$

where a_i and b_i are constants defining each straight-line segment. We substitute this definition of $f(\text{UT})$ into equation (7) and then redetermine K [C remains unchanged because $\overline{f(\text{UT})} = 0$ by definition, cf. eq. (5)]. To increase the reliability of the fits, we take advantage of the gray behavior of the extinctions and combine all δ residuals for all filters together for each night. The whole reduction process is fully automated except that it requires human interaction to determine the beginning and end of each time segment. To avoid a completely arbitrary determination of $f(\text{UT})$, a maximum of four straight-line segments per night is allowed.

In principle, we can iterate this procedure as many times as necessary. In practice, one iteration provides a satisfactory fit. In Figure 3 we show the residuals (δ) ‘‘before’’ and ‘‘after’’ $f(\text{UT})$ corrections for the three nights illustrated in Figure 2. In Figure 4, we show the before and after residuals versus time relationships for each night, divided into A, B, and C quality categories based on ending photometric quality (i.e., no D nights). One can see how the $f(\text{UT})$ correction procedure improves the quality of the photometric calibration for almost every night.

Note that it always takes at least several minutes to complete the observations of each standard star through all



4000

6000

8000

10000

TABLE 4
FILTER-BY-FILTER RESIDUALS AND THEIR ERRORS, BY STAR

BAND	C001			C002			C003			C005		
	Average	rms	<i>n</i>	Average	rms	<i>n</i>	Average	rms	<i>n</i>	Average	rms	<i>n</i>
a	-0.013	0.009	3	0.020	0.017	5	-0.032	0.013	2	...	...	0
b	-0.004	0.015	39	0.014	0.020	21	-0.031	0.025	10	0.005	0.018	37
c	0.010	0.014	5	...	...	0	0.023	0.045	4	-0.010	0.023	14
d	0.003	0.012	35	0.000	0.011	17	-0.019	0.027	8	0.001	0.012	39
e	-0.002	0.022	32	0.001	0.018	41	-0.001	0.024	12	0.002	0.026	15
f	0.001	0.012	65	-0.003	0.012	47	-0.006	0.014	14	0.002	0.011	51
g	0.001	0.009	68	0.002	0.010	61	-0.005	0.013	23	-0.002	0.007	44
h	-0.003	0.009	60	0.003	0.009	43	-0.002	0.016	17	0.001	0.009	45
i	-0.005	0.011	74	0.004	0.019	56	-0.002	0.014	24	0.002	0.012	74
j	-0.005	0.011	64	0.005	0.008	49	-0.007	0.009	12	0.004	0.012	41
k	-0.001	0.010	59	0.001	0.009	62	-0.006	0.026	16	0.002	0.011	33
m	-0.000	0.010	37	-0.002	0.017	28	-0.001	0.009	14	0.002	0.009	39
n	-0.003	0.005	29	0.005	0.007	26	-0.014	0.010	5	0.002	0.014	19
o	0.004	0.012	24	0.002	0.008	25	-0.002	0.010	7	-0.007	0.013	21
p	0.005	0.014	21	0.001	0.010	23	-0.006	0.015	12	-0.002	0.012	20

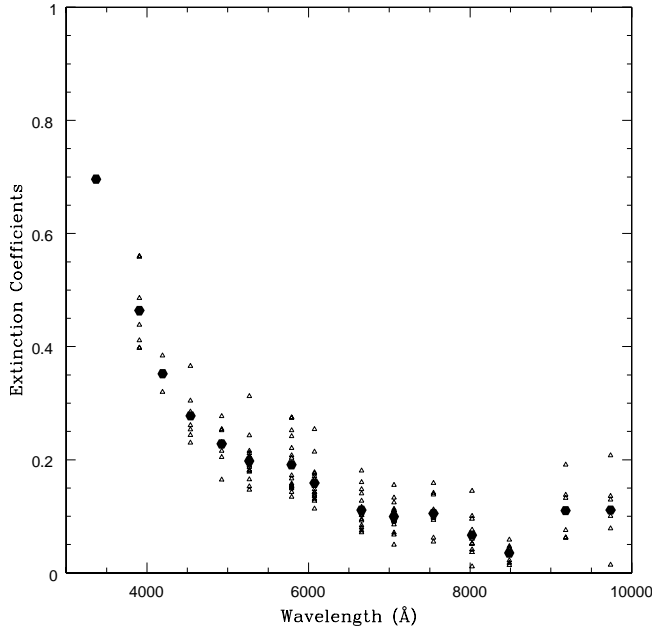


FIG. 6.—The extinction coefficients of Xinglong Observing Station in the 15 BATC passbands, using the data from the 28 A and B nights. The open triangles represent individual measurements (i.e., from each night), while the large solid hexagons represents the averaged values for the specific passbands.

Table 4 gives the mean residuals per filter per standard star as observed on A and B nights, including 1 σ scatter and number of observations. To examine possible star-to-star systematics in m_{BATC} , we again use only the observations from A and B nights. For each filter, we determine the mean value of δ and take the difference between each individual value of δ and this mean. We then group these differences by standard stars. Figure 5 plots these differ-

TABLE 5
AVERAGE EXTINCTION COEFFICIENTS BASED ON THE 28 A AND B NIGHTS

Band	λ_{eff} (Å)	K [mag (air mass) ⁻¹]	δ_K^a	N^b
a	3371.52	0.696	...	1
b	3906.89	0.464	0.021	9
c	4193.50	0.352	0.032	2
d	4539.96	0.278	0.015	8
e	4925.02	0.228	0.011	9
f	5266.84	0.198	0.010	15
g	5789.90	0.191	0.011	18
h	6073.94	0.159	0.008	17
i	6655.93	0.111	0.006	21
j	7057.40	0.099	0.007	15
k	7546.34	0.105	0.007	14
m	8023.16	0.067	0.011	11
n	8484.32	0.035	0.006	8
o	9182.16	0.110	0.021	6
p	9738.48	0.111	0.026	6

^a The error of the mean, defined as $\text{rms}/\sqrt{N_{\text{tot}}}$, where N_{tot} is the total number of observations (not listed).

^b Total number of nights.

ences versus filter effective wavelength for each of the four standard stars. As is evident from both the table and the figure, the scatter per filter per star is consistent with the predicted BATC magnitudes for most filters for these stars to 0.01 mag. There is, however, some indication that the bluest filters for two or three of these stars might need their BATC magnitudes adjusted by 0.01–0.02 mag. Such small differences can occur as a result of the small errors in the AB₉₅ spectrophotometric measurements because of its limited spectral resolution and/or as a result of the small errors in the standard stars' predicted BATC magnitudes

because of the filter transmission convolutions. This is especially true for the spectral region near and below the Balmer jump, where stellar flux varies very strongly with wavelength. However, the present data are too few to make a convincing case that such corrections are needed.

For completeness, Figure 6 plots the atmospheric extinction values versus BATC filter effective wavelength for the 28 A and B nights. These data provide the average atmospheric extinction on photometric nights for the BAO Xinglong Observing Station during the period 1995–1997. The mean extinction coefficients (K in eq. [6]) are given in Table 5. It is possible that the nonmonotonic wavelength dependence of extinction in the near-infrared might be due to the effect of stronger night-sky *absorption* in some filters than in others.

4. SUMMARY

The BATC Color Survey utilizes a set of 15 intermediate-band filters mounted at the 60/90 cm Schmidt telescope at Beijing Astronomical Observatory to do degree-sized CCD imaging down to $V \sim 21$ mag with spectral coverage from 3200 to 9900 Å. Our spectrophotometry is standardized to the AB_v system through the four primary spectrophotometric standard stars of Oke & Gunn, as modified by the study of Fukugita et al. (1996). One of the observational goals of our survey is to obtain spectrophotometry that is tied to AB_v system to a zero-point accuracy of ~ 0.01 mag for all objects in each of our survey fields. We discuss in detail the atmospheric extinction correction procedure used in our survey when a night is expected to be photometric.

From 1994 to 1997, 32 nights (of 423 possible) were selected by the observers at the telescope to be of possible photo-

metric quality. On a typical photometric night we make ~ 50 observations of two or three of these standard stars in five to nine filters, through air masses between 1.0 and 2.0, both east and west of the meridians of the stars. We explicitly show that there is a component in atmospheric extinction which varies smoothly, at low amplitude, throughout each photometric night, in a manner that is independent of passband effective wavelength and air mass. We suggest that these small ($\sim 1\%$), gray, air-mass-independent variations are linked to the changes in atmospheric air pressure, temperature, and humidity known to occur between day and night. By incorporating a time-dependent correction to the atmospheric extinction for each night into the photometric reduction procedure, 13 nights show 0.01 mag or less scatter in their standard-star measures, 15 others have scatter between 0.01 and 0.02 mag, and only four have scatter between 0.02 and 0.03 mag. However, while we can obtain our observational goal of 1% accuracy in our spectrophotometry on photometric nights at the Xinglong Observing Station, the current low percentage of photometric nights (7.6%) means that, for calibration of our survey, we will likely have to provide supplemental observations at other sites.

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