Estimation Of Extinction and Transformation Coefficients of Standard Star

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Abstract - Accurate photometric calibration is essential for reliable astronomical observations, particularly in determining stellar magnitudes and colors. In this paper, we use observations of standard stars from Landolt's catalogue to determine atmospheric extinction and transformation coefficients. Using a CCD-equipped telescope and common UBVRI filters, observations were made under photometric circumstances. Whereas transformation coefficients were determined by linear regression between instrumental and standard magnitudes and colour indices, primary extinction coefficients were calculated from the airmass-dependent fluctuations in instrumental magnitudes. Our results show stable extinction behavior consistent with the atmospheric conditions of the observing site, and well-constrained transformation coefficients that allow precise calibration of instrumental data to the standard photometric system. These coefficients are crucial for reducing observational data and ensuring consistency in long-term photometric monitoring programs.

***Key Words*:** Extinction Coefficient, Transformation Coefficient, Standard Star

1.INTRODUCTION *(Size 11, Times New roman)*

1.1 Atmospheric Extinction

The intensity of star light is decreased by the Earth's atmosphere. This is due to the scattering and absorption of air molecules and aerosols in the environment. The reduction in intensity is determined by the height of the star over the horizon (elevation), the wavelength of observation, and the prevailing atmospheric conditions at the location of observation. The star appears weak toward the horizon when compared to the zenith. To determine the magnitude of the star above the earth's atmosphere, we must correct the ground-based measured magnitudes and colors for atmospheric extinction. (Henden & Kaitchuck 1990).

Extinction correction on observed magnitude (m_λ) is done using the formula-

$$m_{\lambda 0} = m_\lambda - k_\lambda.sec(z)$$

Where k_λ is principal extinction coefficient, $sec(z)$ represents the airmass and z being zenith angle (i.e. 90° - elevation). This equation can be written as-

$$m_\lambda = m_{\lambda 0} + k_\lambda.sec(z)$$

This is an equation of a straight line with slope of kλ. Hence to obtain the value of extinction coefficient we need to make a plot between mλ and sec(z).

Extinction is measured in unit of magnitude per airmass. The amount of air directly over- head is called one airmass.

If elevation of star is greater than 30◦ then we can ignore the curvature of the earth's atmosphere and plane parallel slab approximation gives-

$$sec(z) = (sin\varphi.sin\delta + cos\varphi.cos\delta.cosH)^{-1}$$

Where
φ = observer latitude
δ = declination of star
H = hour angle in degree

1.2 Transformation to a standard system

A system of magnitude and colors, such as the UVB system, is defined by a set of standard star measured by a particular detector and filter set. In order for observers at different observatories to be able to compare observations must be transformed from the instrumental system to a standard system. If M_λ is the standard magnitude and $m_{\lambda 0}$ is the observed extinction corrected magnitude and c is the standard color index (*e.g.* $M_B - M_V$) then they are related by the equation (Henden & Kaitchuck 1990)-

$$M_\lambda = m_{\lambda 0} + \alpha_\lambda . c + \beta_\lambda$$

Where
α_λ = Color coefficient
β_λ = Zero point coefficient

Transformation relations for standard $UBVRI$ system are given below-

$$V = v_0 + \alpha_v(B - V) + \beta_v$$

$$(B - V) = \alpha_{bv}(b - v)_0 + \beta_{bv} \tag{6}$$

$$(V - R) = \alpha_{vr}(v - r)_0 + \beta_{vr} \tag{7}$$

$$(R - I) = \alpha_{ri}(r - i)_0 + \beta_{ri} \tag{8}$$

$$(V - I) = \alpha_{vi}(v - i)_0 + \beta_{vi} \tag{9}$$

$$(U - B) = \alpha_{ub}(u - b)_0 + \beta_{ub} \tag{10}$$

$$(V - v)_0 = \alpha'_v(V - R) + \beta'_v$$

$$(B - b)0 = \alpha b(B - V) + \beta b$$

$$(R - r)_0 = \alpha_r(V - R) + \beta_r$$

$$(I - i)0 = \alpha' i(V - I) + \beta i$$

$$(I - i)_0 = \alpha'_i(R - I) + \beta'_i$$

$$(U - u)0 = \alpha u(U - B) + \beta u$$

Where capital/small letters denote magnitudes and colors in standard/instrumental system. Above equations represent equation of a straight line with slope and intercept of α and β respectively. Hence to obtain the values of these coefficients we *need* to fit straight lines in the above transformation relations.

Observation, Data Reduction and Analysis

In this study, Extinction and Transformation coefficients are estimated using the data obtained from 2-meter Himalayan Chandra Telescope (HCT) at Indian Astronomical Observatory (IAO), Hanle on 2016-05-14. For this purpose standard star fields SA110-504 and PG 1633+099 from Landolt (1992) were observed using Himalaya Faint Object Spectrograph Camera (HFOSC) attached to the backend of HCT. The CCD chip used in HFOSC has dimension of $2K \times 4K$ pixles. The central $2K \times 2K$ pixles region was used in the observation. Gain and Read out noise of CCD chip are 1.22 electrons ADU^{-1} and 4.87 electrons per pixle respectively. SA110-504 was monitored from airmass $sec(z)$ = 1.198 to 1.919 to estimate the extinction coefficient. For calibration of HCT-HFOSC system SA110-504 and PG1633+099 fields (observed at $sec(z)$ = 1.3 and 1.1) were used. Finding chart for these fields are shown in Fig. 1.

We have used IRAF package for Reduction and Analysis of CCD Data. The process is given below-

[1] The multiple bias frames obtained are median combined to get the master bias. This master bias is subtracted from all other frames.

[2] A master flat for each filter is created by median combining and normalizing. All the bias-subtracted frames are divided by master flat in the same filter.

[3] Aperture photometry was performed on eight field stars (marked in Fig. 1) to calculate their instrumental magnitude using *phot* task of *DAOPHOT* package within IRAF.

[4] A plot between magnitude and airmass was made and a straight line was fit for each star in all bands. The slope gives the value of extinction coefficient.

[5] After this we estimated color coefficients (α) and zero points (β) by fitting straight lines to the transformation relations mentioned above (section 1.2).

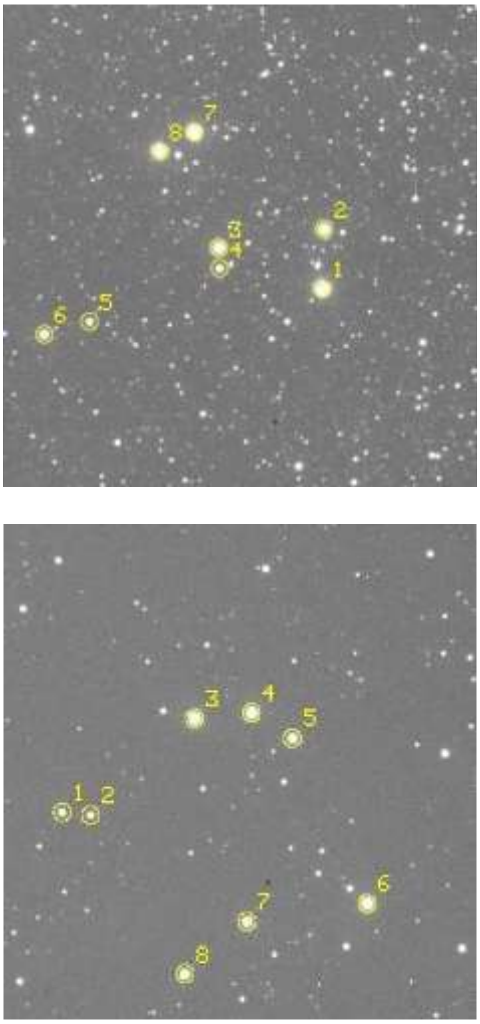


Fig -1: Identification chart for SA110-504 (top). The stars marked were used to estimate Extinction and Transformation coefficients. Identification chart for PG1633+099 (bottom). The marked stars in the field were used for cross verification of estimated coefficients.

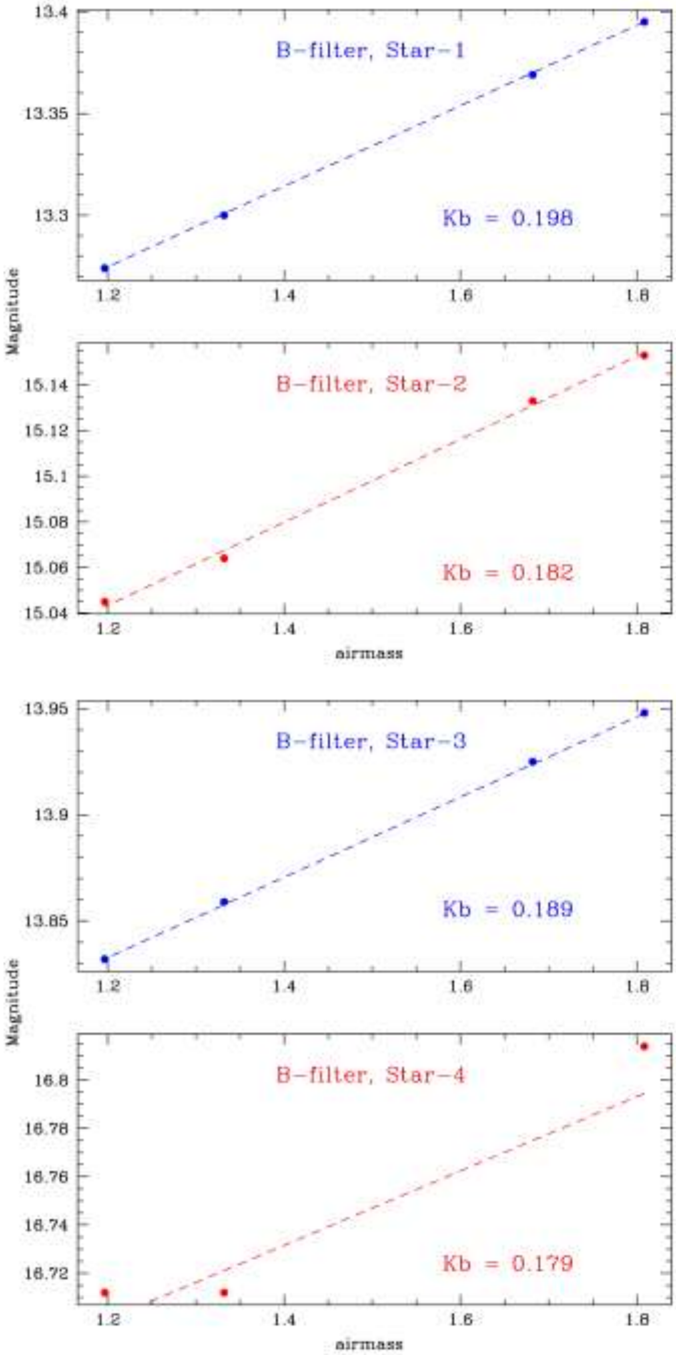
Results

[1] The straight line fit on data to estimate extinction coefficients in *UBV RI* bands are shown in Fig. 2, 3, 4, 5 and 6. Estimated values of extinction coefficients are listed in Table 1.

[2] Plots for various Transformation Relations are shown in Fig. 7. Estimated values of transformation coefficients are listed in Table 2.

Cross Verification

The estimated values were cross verified using PG1633+099 field. For this purpose aperture pho- tometry was performed on eight field stars (marked in Fig. 1, *right*) to extract their instrumental magnitudes. The calculated magnitudes were corrected for extinction using the extinction coef- ficients derived, after that the magnitudes were transformed to standard system using α and β derived. The transformed/calibrated magnitudes are given in Table 3 and has been compared with the magnitudes listed in Landolt (1992).



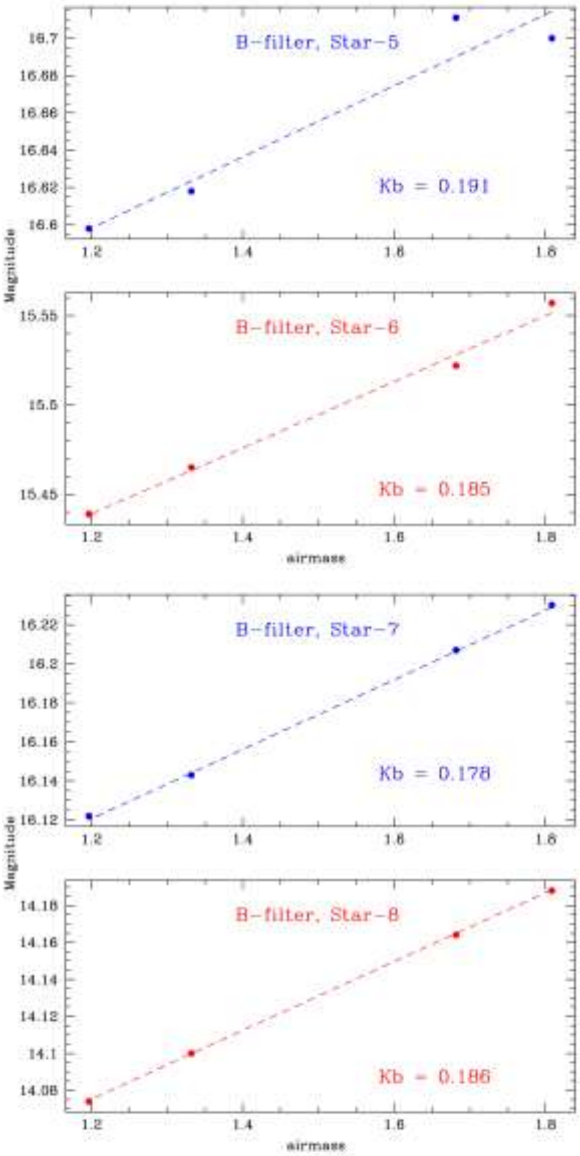
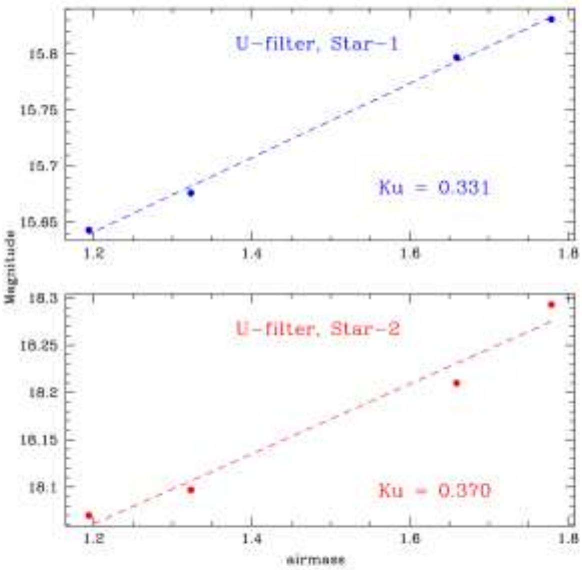


Figure 2: Plot between magnitude and airmass in *B*-filter for stars from *SA*110–Landolt field. Values of Extinction coefficient obtained are shown.



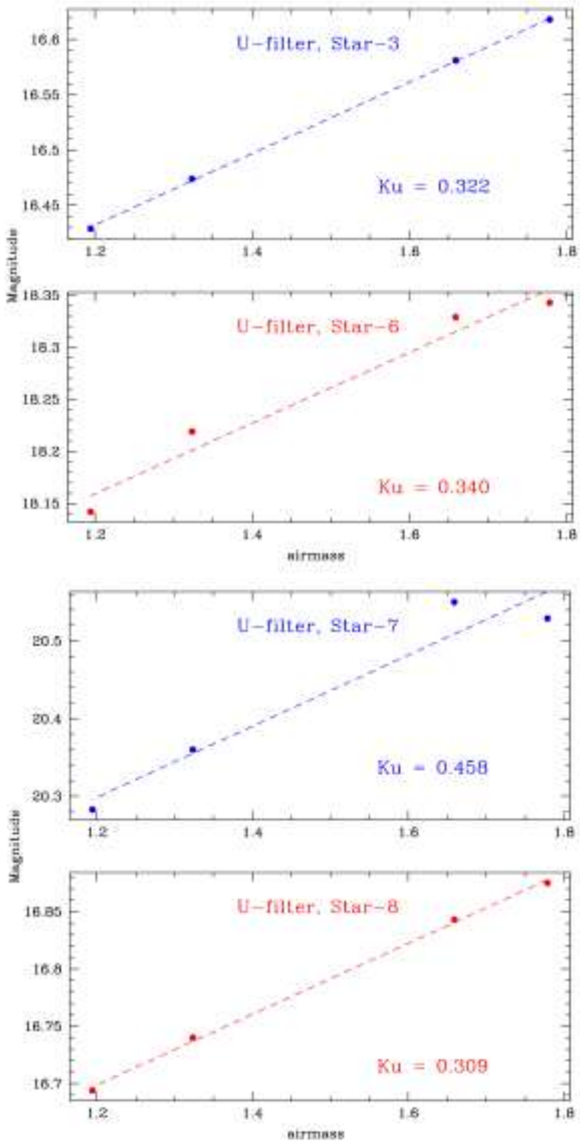
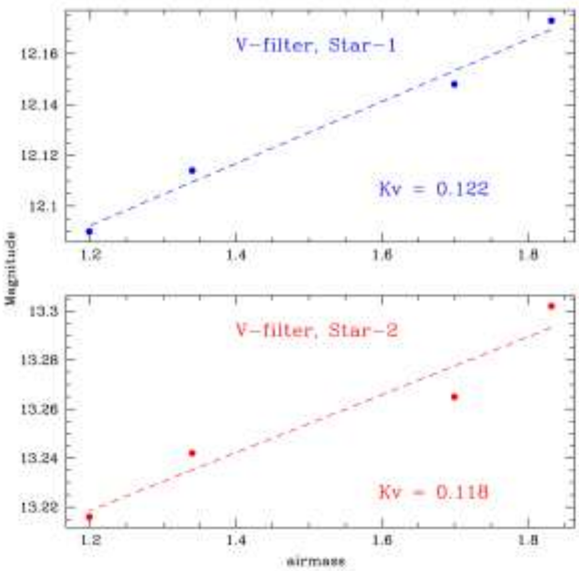


Figure 3: Plot between magnitude and airmass in *U*-filter for stars from *SA*110–Landolt field. Values of Extinction coefficient obtained are shown.



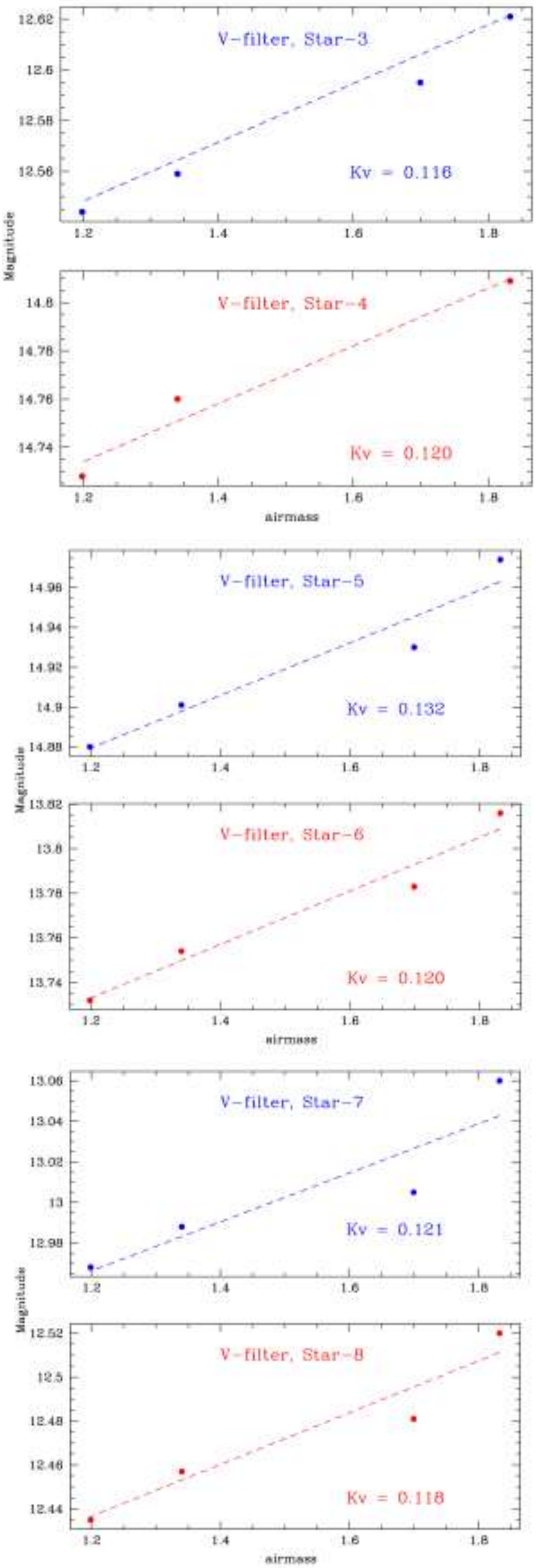


Figure 4: Plot between magnitude and airmass in *V*-filter for stars from *SA*110–Landolt field. Values of Extinction coefficient obtained are shown.

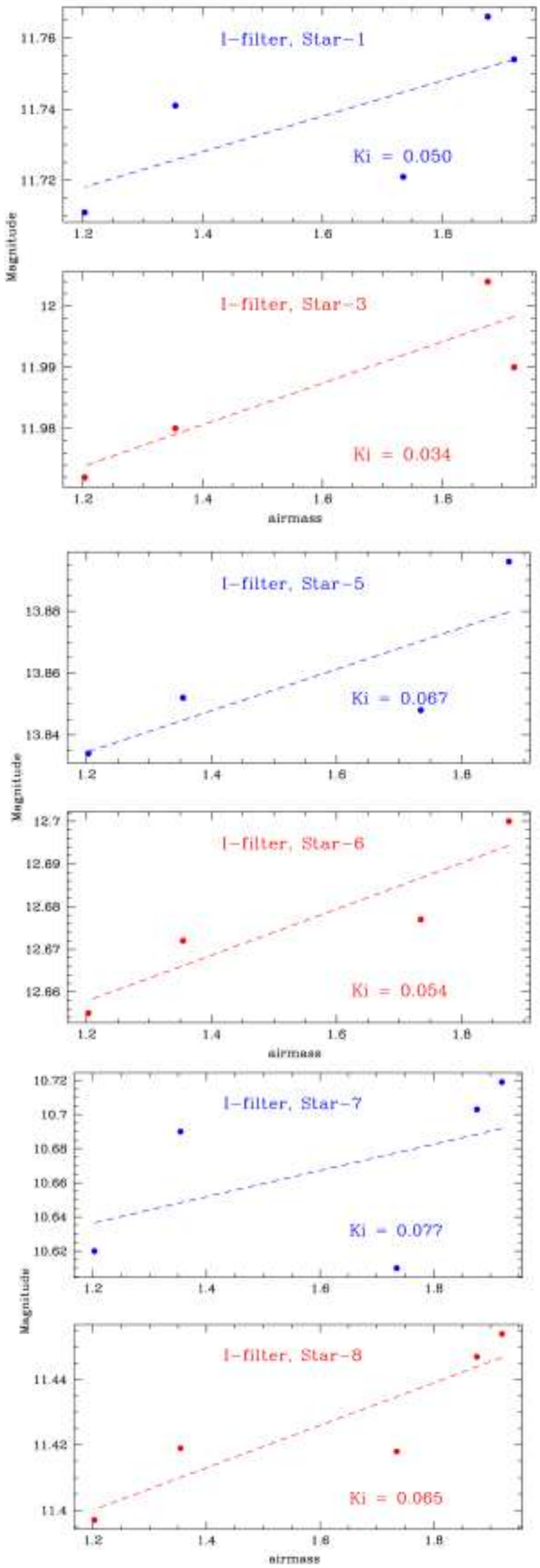


Figure 5: Plot between magnitude and airmass in *I*-filter for stars from *SA*110–Landolt field. Values of Extinction coefficient obtained are shown.

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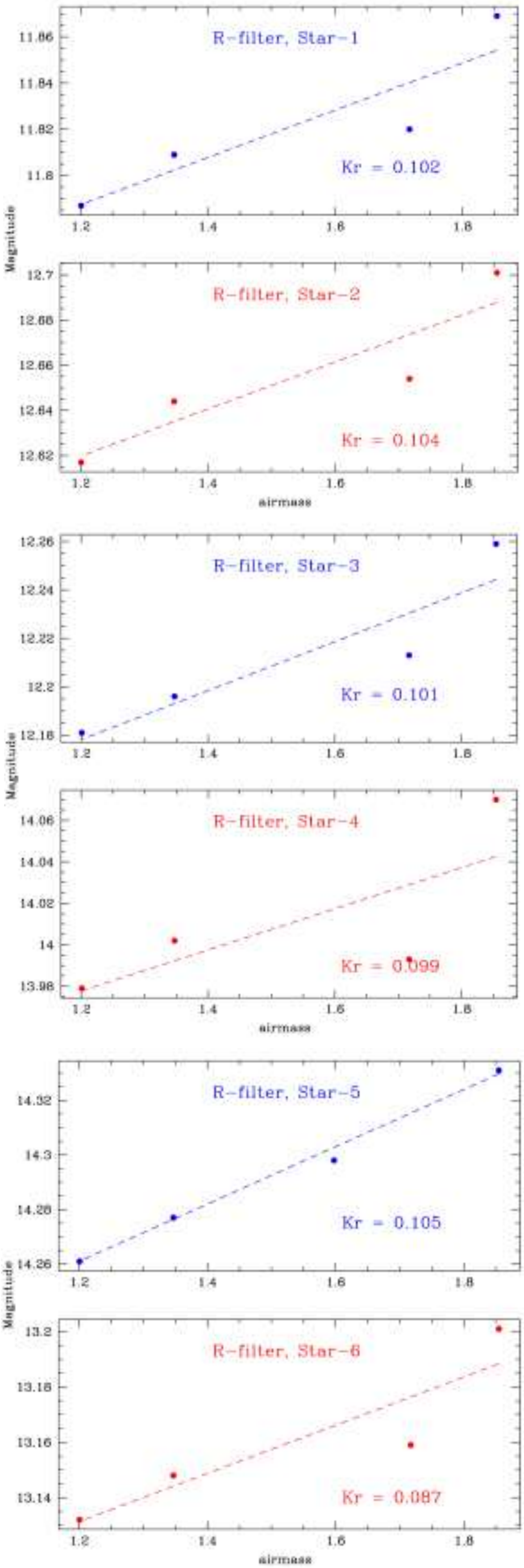


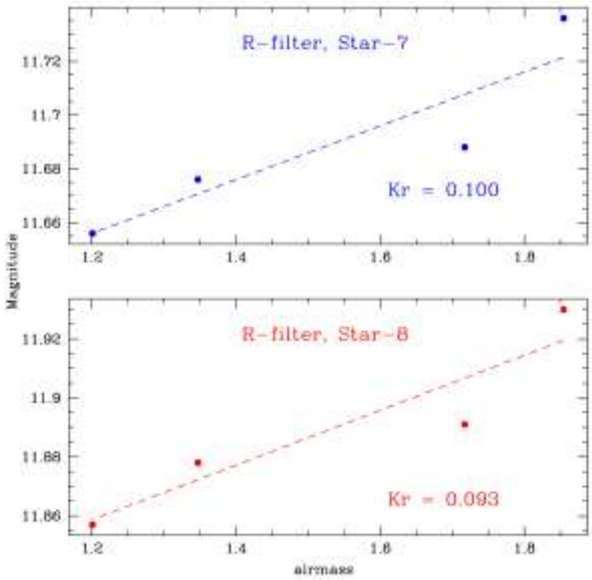
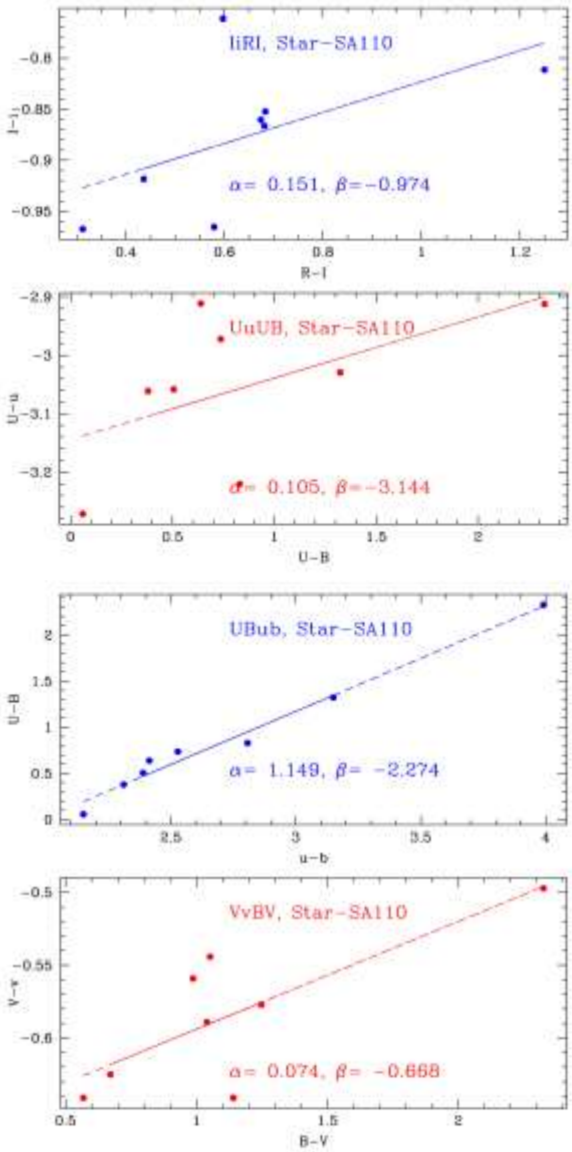


Figure 6: Plot between magnitude and airmass in *R*-filter for stars from *SA*110–Landolt field. Values of Extinction coefficient obtained are shown.



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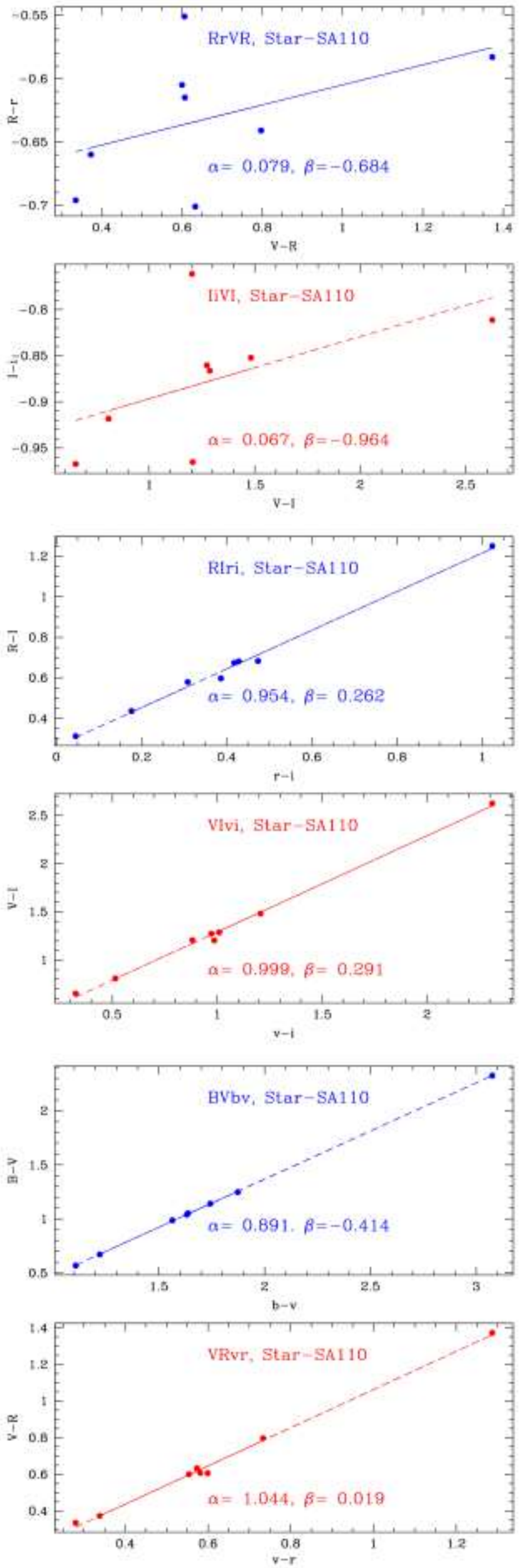

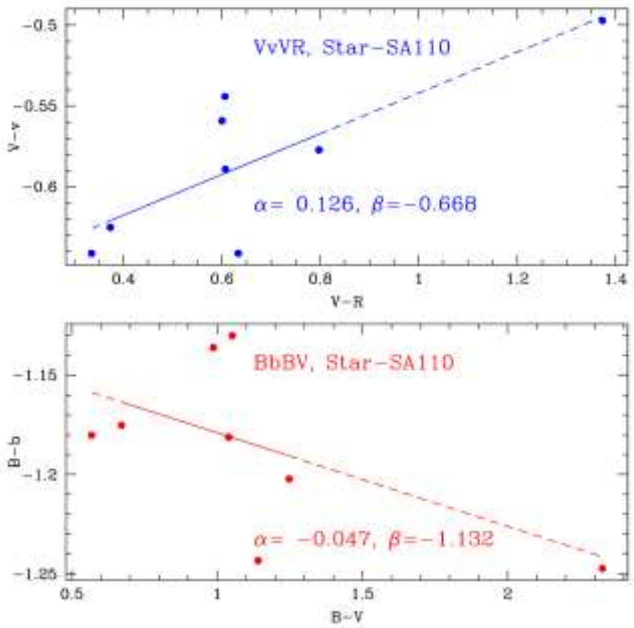

Figure 7: Plot for various Transformation Relations. Values of transformation coefficient are shown.

Table 1: Details of Extinction coefficients estimation

S.No.	U	B	V	R	I
1	0.331	0.198	0.120	0.102	0.050
2	0.370	0.182	0.118	0.104	–
3	0.322	0.189	0.116	0.101	0.034
4	–	0.179	0.120	0.099	–
5	–	0.191	0.132	0.105	0.067
6	0.340	0.185	0.120	0.105	0.054
7	0.450	0.178	0.121	0.100	–
8	0.300	0.183	0.118	0.093	0.054
Avg	0.35 ± 0.053	0.186 ± 0.007	0.120 ± 0.005	0.101 ± 0.004	0.054 ± 0.013

Table 2: Details of Transformation coefficients Estimation

S.No.	Relation	α	β	Corr. coeff.
1	$(B-V) = \alpha_{bv}(b-v)_0 + \beta_{bv}$	0.891	-0.414	0.99
2	$(V-R) = \alpha_{vr}(v-r)_0 + \beta_{vr}$	1.044	0.019	0.99
3	$(R-I) = \alpha_{ri}(r-i)_0 + \beta_{ri}$	0.954	0.262	0.99
4	$(V-I) = \alpha_{vi}(v-i)_0 + \beta_{vi}$	0.999	0.291	0.99
5	$(U-B) = \alpha_{ub}(u-b)_0 + \beta_{ub}$	1.149	-2.274	0.98
6	$(V-v)_0 = \alpha_{vBV}(B-V) + \beta_{vBV}$	0.074	-0.668	0.61
7	$(V-v)_0 = \alpha_{vVR}(V-R) + \beta_{vVR}$	0.126	-0.668	0.63
8	$(B-b)_0 = \alpha_{bBV}(B-V) + \beta_{bBV}$	-0.047	-1.132	0.35
9	$(R-r)_0 = \alpha_{rVR}(V-R) + \beta_{rVR}$	0.079	-0.684	0.23
10	$(I-i)_0 = \alpha_{iVI}(V-I) + \beta_{iVI}$	0.067	-0.964	0.30
11	$(I-i)_0 = \alpha_{iRI}(R-I) + \beta_{iRI}$	0.151	-0.974	0.33
12	$(U-u)_0 = \alpha_{uUB}(U-B) + \beta_{uUB}$	0.105	-3.144	0.31

Table 3: Cross verification of estimated coefficients using PG-1633+099 field

S.No.	V Land	V_{BV} Calc	V_{VR} Calc	B-V Land	B-V Calc	U-B Land	U-B Calc	V-R Land	V-R Calc	R-I Land	R-I Calc	V-I Land	V-I Calc
1	14.396	14.414	14.347	-0.119	-0.154	-0.990	-0.652	0.085	-0.130	-0.114	-0.099	-0.208	-0.226
2	15.259	15.294	15.225	0.871	0.895	0.305	0.422	0.506	0.470	0.506	0.506	1.011	0.972
3	12.968	13.029	12.956	1.081	1.095	1.017	1.173	0.589	0.555	0.503	0.476	1.091	1.022
4	13.224	13.289	13.216	1.114	1.150	1.046	1.300	0.612	0.578	0.524	0.494	1.133	1.063
5	13.689	13.747	13.683	0.535	0.540	-0.021	0.122	0.324	0.296	0.323	0.306	0.649	0.599
6	13.113	13.187	13.120	0.841	0.843	0.337	0.473	0.484	0.455	0.471	0.436	0.953	0.886
7	13.768	13.824	13.762	0.878	0.878	0.254	0.378	0.523	0.514	0.522	0.494	1.035	1.002
8	13.749	13.793	13.727	0.693	0.711	0.079	0.266	0.412	0.381	0.389	0.384	0.804	0.762

REFERENCES

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