Making a Transformation : The Relationship between the Johnson V-Band and the USNO Catalogue

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The current photometric system being used to estimate sky surface brightness values at the Hobby-Eberly Telescope (HET) at the University of Texas McDonald Observatory is the United States Naval Observatory Catalogue's Blue and Red magnitudes. It is difficult to understand this system. Therefore, we must transform it into a photometric system we do understand: the Johnson V-band system. Not only is this system used throughout the astronomical community, but it was also founded by Johnson at the McDonald Observatory's 82-inch telescope in the 1950's.

The first step in this transformation process is to look at photometric images of the sky. On the night of July 13, 2007, I took images using the prime focus camera on the observatory's 30-inch telescope. These images were of Landolt Selected Areas 109, 110, and 112 using the Johnson BVR bands at different exposure times. After astronomer Steve Odewahn reduced these images, I analyzed the average flux (Equation A) of the sky and the flux of the Landolt stars (Equation B) by using Image Reduction Analysis Facility (IRAF) and DS9.

Equation A $\langle F_{sky} \rangle = \Sigma(flux) / N$

Equation B $F_{star+sky} - \langle F_{sky} \rangle = F_{star}$

Taking the flux of the star into Pogson's equation (Equation C), the zero point (ZP) was calculated to calibrate the image.

Equation C $m = ZP - \log(F_{star})$

The standard V magnitudes from Landolt's 1992 paper on the UBVRI system[1] were plugged in for the magnitude (m) in Pogson's equation. Then, the zero point can be calculated for each selected area using Landolt stars (See Table 1).

Table 1: Zero Points for V-Band Images from the Prime Focus Camera

Observed Field	Image # *	Exposure Time (sec)	<Zero Point>	Zero Point (1 Sec)
SA_100	41†	10	23.29 +/- 0.01	20.79
SA_101	42†	5	22.54 +/- 0.03	20.79
SA_109	1	15	23.75 +/- 0.02	20.81
SA_109	4	45	24.91 +/- 0.02	20.78
SA_109	7	135	25.83 +/- 0.05	20.50
SA_109	10	15	23.96 +/- 0.03	21.01
SA_109	12	15	23.95 +/- 0.03	21.01

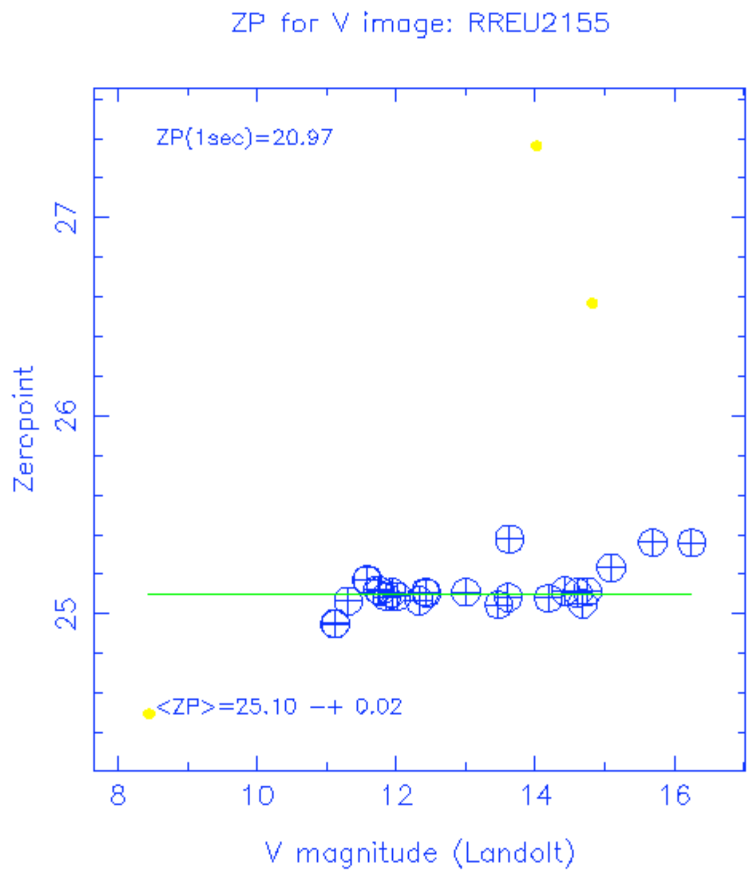
SA_109	**15**	**45**	**25.14 +/- 0.04**	**21.01**
SA_109	**44**[†]	**10**	**23.33 +/- 0.02**	**20.83**
SA_110	**40**[†]	**20**	**24.11 +/- 0.01**	**20.86**
SA_110	**17**	**15**	**23.90 +/- 0.02**	**20.96**
SA_110	**20**	**45**	**25.07 +/- 0.02**	**20.94**
SA_110	**23**	**135**	**26.08 +/- 0.03**	**20.75**
SA_110	**26**	**15**	**23.92 +/- 0.02**	**20.98**
SA_110	**29**	**45**	**25.10 +/- 0.02**	**20.97**
SA_112	**32**	**15**	**23.89 +/-0.00**	**20.95**
SA_112	**38**	**135**	**25.99 +/- 0.03**	**20.66**

** : Image # is a part of the Astronomical IMage TOOL (AIMTOOL) program to keep track of the different images.*

† : *These are fields taken on the 30-inch prime focus camera by Steve Odewahn in April 2004.*

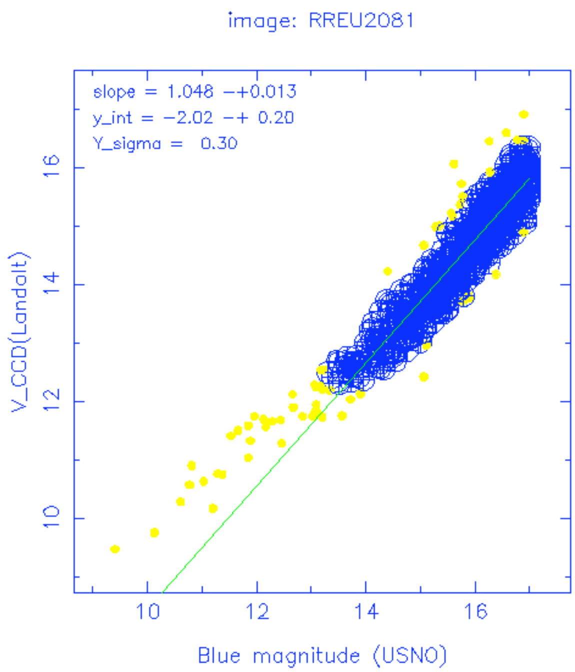
Now we have calculated a zero point for each field, we can go to any star and find its Johnson V magnitude. Graph 1 is an example of calculated zero points from different Landolt stars in SA_110. The zero point trend shows a tight relationship and a small error. Those stars that were too bright or too faint in magnitude were rejected and are represented by yellow markings.

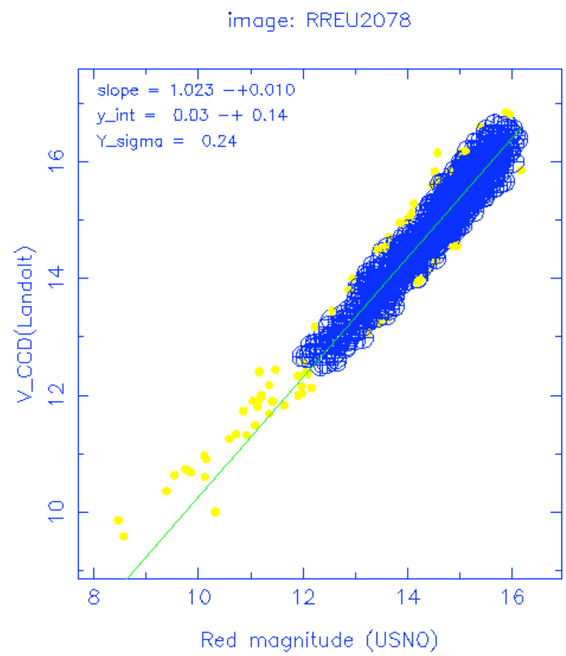
Graph 1: Zero Point fit example from SA_110



The Landolt stars were then cross-matched to the USNO Blue and Red Catalogues (See Graph 2 and Graph 3; examples from Selected Area 109). The reasons for rejected stars (yellow markings) could be from either positional cross-match errors, photometry errors in USNO catalogue and/or CCD, or the inaccurate measurements of bright magnitudes in the USNO Blue and Red magnitudes.

Graph 2: USNO Blue vs V magnitude **Graph 3: USNO Red vs V magnitude**





Hundreds to thousands of stars were measured which was possible because of the wide field of view of the prime focus camera. When I plot the color Blue minus Red versus the V magnitude minus Red, I get a linear regression. The slope of that regression is called the color term (See Graph 4; example from Selected Area 109). All color term and y-intercept data collected is in Table 2.

Graph 4: Color Term and Y-Intercept

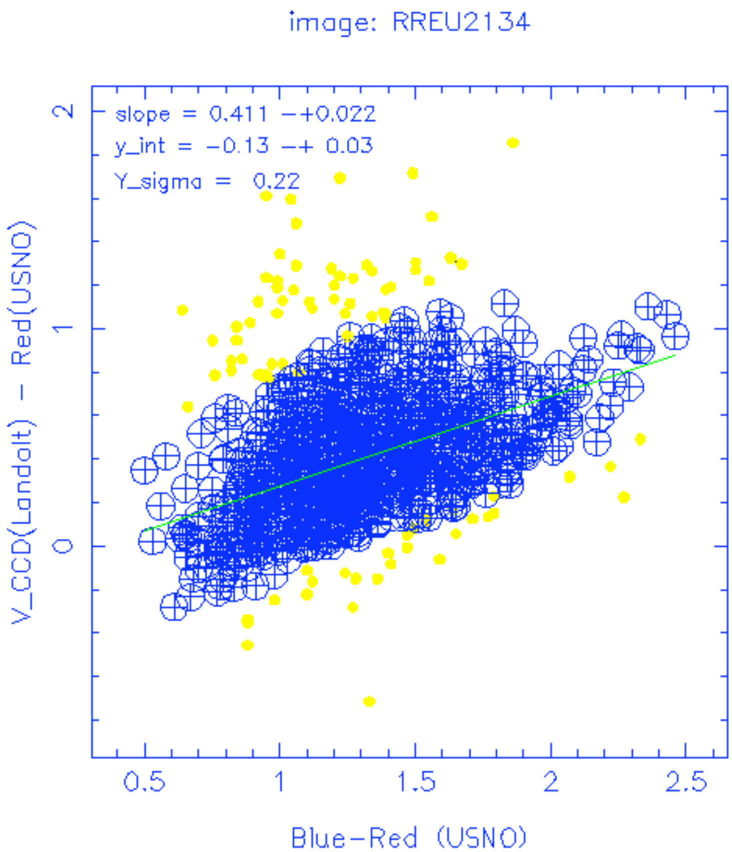


Table 2: Color Term and Y-Intercepts for V-Band Images							
Observed Field	Image* #	Exposure Time (sec)	Color Term	Color Term Error	Y-Intercept	Y-Int Error (+/-)	Y-Sigma
SA_100	41†	10	0.424	0.027	0.14	0.02	0.12
SA_101	42†	5	0.457	0.036	-0.02	0.05	0.12
SA_109	1	15	0.358	0.022	-0.05	0.03	0.21
SA_109	4	45	0.368	0.021	-0.11	0.03	0.19
SA_109	7	135	0.392	0.021	-0.46	0.03	0.20
SA_109	10	15	0.411	0.022	-0.13	0.03	0.22
SA_109	12	15	0.387	0.022	-0.12	0.03	0.21
SA_109	15	45	0.398	0.022	-0.16	0.03	0.20
SA_109	43†	5	0.362	0.026	-0.10	0.04	0.22
SA_109	44†	10	0.407	0.023	-0.15	0.03	0.21
SA_112	32	15	0.437	0.020	-0.41	0.03	0.11
SA_112	35	45	0.417	0.020	-0.43	0.03	0.10

SA_112	**38**	**135**	**0.438**	**0.022**	**-0.73**	**0.04**	**0.12**

Mean Color Term	**STDV**	**Mean Error**	**Mean Y-Intercept**	**STDV**	**Mean Error**
0.404	**0.031**	**0.009**	**-0.210**	**0.232**	**0.067**

** : Image # is a part of the Astronomical IMage TOOL (AIMTOOL) program to keep track of the different images.*
† : *These are fields taken on the 30-inch prime focus camera by Steve Odewahn in April 2004.*

I can use the mean color term and the mean y-intercept in the color transformation equation (Equation D) and use the USNO Blue and Red magnitudes to get a Johnson V magnitude.

Equation D $V = Red + a\,(Blue - Red) + c$; *where* a *is the color term and* c *is the y-intercept.*

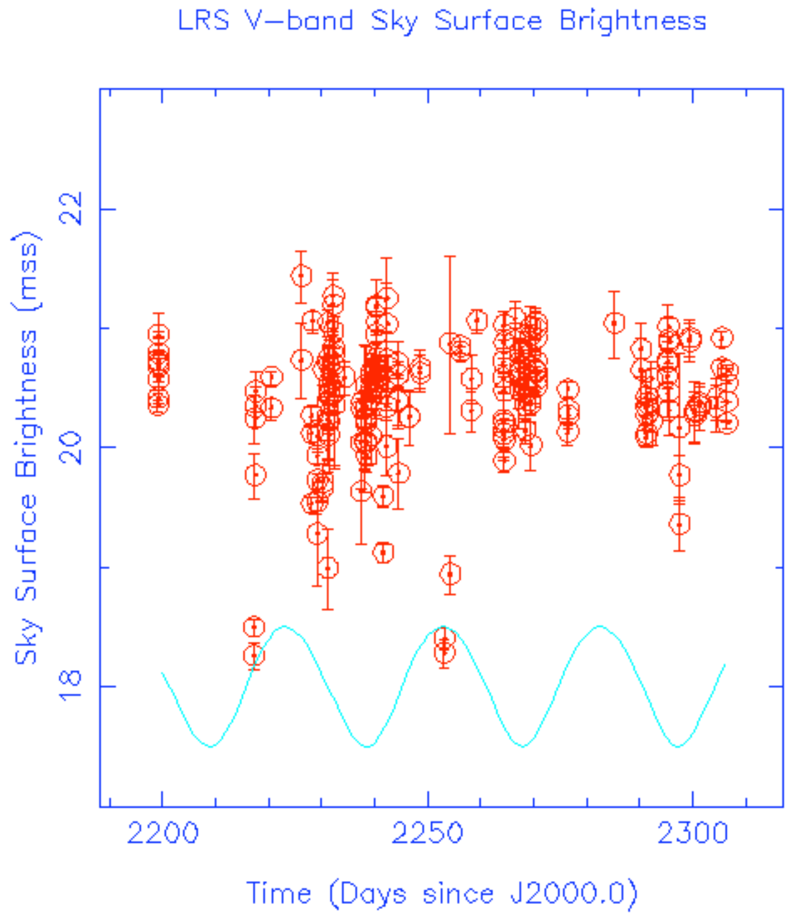
Now, we can use this color transformation on the photometric data from the HET and convert the USNO Blue and Red magnitudes to the Johnson V-band system. From this transformation, we can find the sky surface brightness at the HET. Graph 5 shows five months worth of low-resolution spectrum data. The sinusoidal line represents the phases of the moon where the crest is a full moon and the trough is a new moon. By transforming the magnitudes into the V system, we can calculate the zero point and plug in the values into Equation E.

Equation E: $\mu = ZP - 2.5 \log (F_{sky} / A)$;

where **μ** *is sky surface brightness,* A *is the area of a pixel,*

and F_{sky} *is the average sky in one pixel.*

Graph 5: HET Sky Surface Brightness



All of the data in the graphs were calculated through the programs Zero Point Apertures (ZPAPS) and Astronomical IMage TOOL (AIMTOOL), which Steve Odewahn programmed.

References:

1. Landolt, Arlo U., "UBVRI Photometric Standard Stars in the Magnitude Range 11.5 <V<16.0 Around the Celestial Equator." July 1992