Chapter 6: Transforming your data

Why is transformation necessary?

The AAVSO International Database is composed of data collected from many different observers, at different times, from around the globe. The beauty of such a system is that it allows all interested observers to contribute to the archive, thus it has a great deal of potential to expand the duration and breadth of coverage for the target stars. Unlike data collected through surveys, which can experience coverage gaps due to bad weather conditions, equipment failures or discontinuation of funding, the AAVSO approach reduces the effect of such problems. On the other hand, the fact that each observer is using different equipment and procedures can introduce offsets which makes it difficult to reconcile from one observer to another.

Assuming that the procedures outlined in this guide have been followed carefully, and no mistakes have been made along the way, the largest remaining differences between measurements reported by two different observers looking at the same star with the same filter at the same time is likely caused by differences in the color response of each observer's equipment. Each telescope, filter and CCD combination has its own unique characteristics, which, depending on the color of the star being measured and the filters used, can result in magnitude differences of anywhere from several hundredths of a magnitude to several tenths of a magnitude from one observer to another. Even two photometric filters purchased from the same vendor will have a slightly different spectral response that will affect your measurements!

By transforming your data to a standard system, these differences can be greatly reduced if not eliminated. This will have the effect of not only bringing your observations more in line with those of other observers who have transformed their data, but it will make the whole database more scientifically useful. It is the goal of the AAVSO to get all CCD observers to transform their data as a matter of course.

How do I transform my data?

There are two parts to the process of transforming your data. The first is to determine your transformation coefficients. The second is to apply these coefficients to your observations.

At first, you may find the whole process a little daunting and certainly there has been much confusion and little guidance available in the past. With this guide, the AAVSO hopes to change this by explaining the process clearly and by covering only the simplest, most straightforward cases. By following this procedure, you will achieve most if not all of the corrections necessary to convert your data to the standard system. If you wish to delve deeper, please check out the references listed at the end of this guide.

General overview and assumptions

For the sake of simplicity and to be consistent with other material given in this guide, the explanation that follows assumes that you are performing differential aperture photometry. The magnitudes you derive and ultimately include in your report to the AAVSO are differential magnitudes, that is to say, they are derived by measuring the difference in brightness between the variable and a comparison star.

For example, if you measure two stars of true equal brightness in the bandpass of a standard filter, you will derive two different measured magnitudes for these stars with your own system if the two stars are not equal in color. Our goal will be to transform these measurements to a *standard system*, such that the resulting magnitudes you report will be the same.

In order to make this transformation to a standard system, you need to know two things: the color of the stars you are measuring — known as *differential instrumental color* — and the effect of that color on the differential magnitude you obtained — the *differential instrumental magnitude*.

By relating the differential instrumental color to the *differential true color* of standard stars for which the colors have been very carefully determined, you will be able to come up with a term called a *color transform*. In a similar way, by relating the differential instrumental magnitude to the *true differential magnitude* of this same set of standard stars you can derive a *magnitude transform*. Applying these two transforms to observations you make of variable stars where the color and magnitude is not accurately known will enable you to "correct" your measurements and convert them to a standard system which in theory can be matched by fellow observers.

In astronomy, the color of a star (or color index) is generally expressed as the difference in magnitude resulting from measurements made with two different filter colors. You can do this with different combinations of filters, but since the most widely used measure is b-v (i.e. the magnitude as measured using a Johnson B filter minus the magnitude as measured using a Johnson V filter), it will be assumed that you have these two color filters at least. As you will see later, there is a way in which you can transform your data even if you have only one photometric filter, but generally your results will be better if you have at least two. If you use more than two filters, you will need to come up with color and magnitude transformation coefficients for each of them.

Determining your transformation coefficients

Step 1 – Image a standard field and calibrate the images

The first step in determining your transformation coefficients is to image a "Standard Field" using each of your filters. Standard fields are star fields for which the magnitudes of selected stars are

known very precisely in several colors. For your convenience, the AAVSO has prepared standard sequences for six star clusters, which were selected on the basis of several factors including their range of colors and quantity of stars that will conveniently fit into one CCD image.

Table 6.1 – Standard clusters

Name	RA	Dec	Mag Range	Diameter(arc min)
NGC 1252	03:10:49	-57:46:00	8 – 15	300+
M67	08:51:18	+11:48:00	7 – 16	74
NGC 3532	11:05:39	-58:45:12	8 – 13.5	30
Coma Star Cluster	12:22:30	+25:51:00	5 – 10	450
M11	18:51:05	-06:16:12	8.5 – 17	20
NGC 7790	23:58:23	+61:12:25	10 – 20	7

You can produce a chart for one of these fields using the AAVSO Variable Star Plotter (VSP) by typing in the RA and Dec of the cluster you wish to image and selecting the FOV and limiting magnitude appropriate to your system, as you would with any other chart. Be sure also to select "Yes" to the question, "Would you like a standard field chart?" This should result in a chart similar to the one in Figure 6.1 on the next page. You may also wish to print out the associated Photometry Table containing the published magnitudes of all the Standard stars, which will come in handy if your software does not load the comparison star photometry for you (see Figure 6.2, page 55).

Now use the same good practices you would follow with any imaging. Try to image the clusters when they are high in the sky and set your exposure time so that you can get as many counts as reasonable without saturating the brighter stars. Take several images with each filter and stack them to increase the SNR. Then calibrate your images with bias, darks and flat frames.

To minimize the effects of spurious problems or atmospheric effects, it is a good idea to repeat the entire process of imaging the standard field and computing your coefficients over several nights. Your results from each of the nights can then be averaged together to get one better set of coefficients.

Step 2 – Measure the images to obtain instrumental magnitudes

Using your photometry software, measure as many stars as you can to obtain their instrumental magnitudes. There is no need to select a specific target star or check star. As with any crowded field, be careful not to measure any stars that are so close together that their images are "blended." Also be very careful with star identification and in the case of multiple stars with the same identifier, check the RA and Dec to be sure you know which is which.

Figure 6.1 – M67 chart

This sample chart was produced using the AAVSO's Variable Star Plotter (VSP) using the RA and Dec for M67 given in Table 6.1 with a FOV of 15' and magnitude limit of 13.8. The stars circled in red were used in the example given in this Guide.
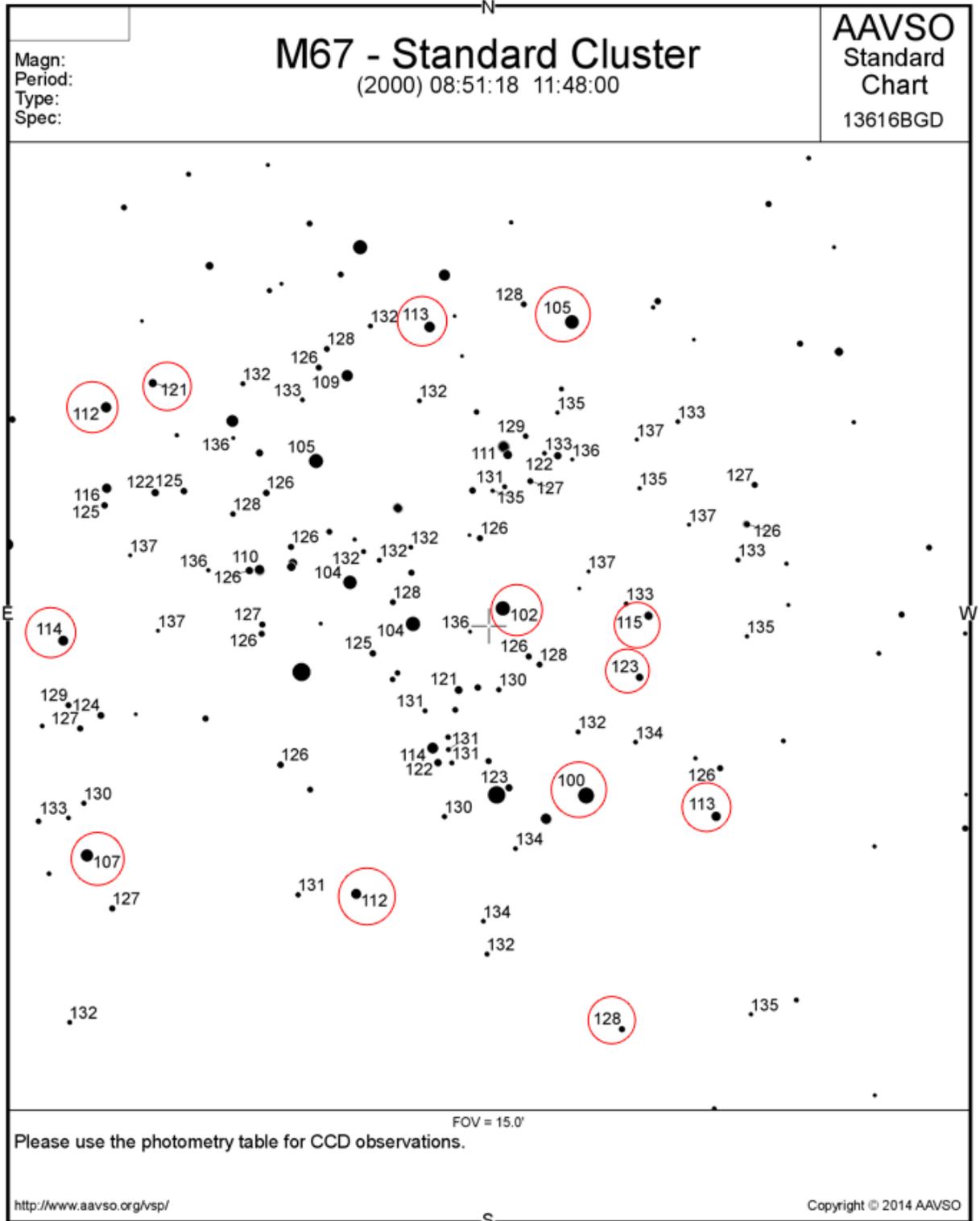

M67 - Standard Cluster
(2000) 08:51:18 11:48:00

AAVSO Standard Chart
13616BGD

Magn:
Period:
Type:
Spec:

FOV = 15.0'
Please use the photometry table for CCD observations.

http://www.aavso.org/vsp/

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Figure 6.2 – M67 photometry table

This is an *excerpt* of the photometry table associated with the chart in Figure 6.1 showing the 10 brightest stars used for computing the transformation coefficients in the example. They are the same stars as those circled on the chart.

Variable Star Plotter (VSP)

■ Printable Version   ■ Return & Replot

Field Photometry From the AAVSO Variable Star Database

Data includes all comparison stars within 0.12500° of RA: 08:51:18 (132.82500) & Decl.: 11:48:00 (11.80000).

AUID	RA.	Dec.	Label	U	B	V	B-V	Rc	Ic	J	H	K	Comments
000-BLG-879	8:51:11.82 [132.79926d]	11:45:21.7 [11.75602d]	100	-	9.978 $(0.050)^{10}$	10.040 $(0.029)^{10}$	-0.062 (0.058)	10.059 $(0.040)^{10}$	10.086 $(0.049)^{10}$	-	-	-	STD_FIELD
000-BLG-886	8:51:17.12 [132.82133d]	11:48:16.4 [11.80455d]	102	12.915 $(0.038)^{10}$	11.553 $(0.023)^{10}$	10.289 $(0.016)^{10}$	1.264 (0.028)	9.626 $(0.021)^{10}$	9.063 $(0.027)^{10}$	-	-	-	STD_FIELD
000-BLG-887	8:51:22.83 [132.84512d]	11:48:02 [11.80056d]	104	12.583 $(0.031)^{10}$	11.562 $(0.018)^{10}$	10.453 $(0.014)^{10}$	1.109 (0.023)	9.886 $(0.016)^{10}$	9.386 $(0.020)^{10}$	-	-	-	STD_FIELD
000-BLG-888	8:51:26.87 [132.86194d]	11:48:40.7 [11.81131d]	104	11.118 $(0.022)^{10}$	11.064 $(0.016)^{10}$	10.489 $(0.013)^{10}$	0.575 (0.021)	10.149 $(0.015)^{10}$	9.822 $(0.021)^{10}$	-	-	-	STD_FIELD
000-BLG-890	8:51:29.01 [132.87090d]	11:50:33.3 [11.84260d]	105	12.703 $(0.030)^{10}$	11.656 $(0.018)^{10}$	10.533 $(0.012)^{10}$	1.123 (0.022)	9.952 $(0.014)^{10}$	9.438 $(0.017)^{10}$	-	-	-	STD_FIELD
000-BLG-889	8:51:12.71 [132.80298d]	11:52:42.6 [11.87850d]	105	12.620 $(0.032)^{10}$	11.617 $(0.023)^{10}$	10.524 $(0.016)^{10}$	1.093 (0.028)	9.961 $(0.020)^{10}$	9.471 $(0.022)^{10}$	-	-	-	STD_FIELD
000-BLG-891	8:51:43.58 [132.93156d]	11:44:26.7 [11.74076d]	107	13.003 $(0.029)^{10}$	11.898 $(0.019)^{10}$	10.763 $(0.016)^{10}$	1.135 (0.025)	10.185 $(0.020)^{10}$	9.657 $(0.023)^{10}$	-	-	-	STD_FIELD
000-BLG-892	8:51:27.04 [132.86266d]	11:51:52.8 [11.86467d]	109	11.117 $(0.030)^{10}$	11.042 $(0.021)^{10}$	10.946 $(0.019)^{10}$	0.096 (0.028)	10.902 $(0.022)^{10}$	10.844 $(0.024)^{10}$	-	-	-	STD_FIELD
000-BLG-893	8:51:32.62 [132.88593d]	11:48:52.3 [11.81454d]	110	11.416 $(0.027)^{10}$	11.283 $(0.019)^{10}$	11.064 $(0.017)^{10}$	0.219 (0.025)	10.948 $(0.020)^{10}$	10.820 $(0.024)^{10}$	-	-	-	STD_FIELD
000-BLG-894	8:51:17.07 [132.82111d]	11:50:46.7 [11.84630d]	111	13.192 $(0.029)^{10}$	12.221 $(0.018)^{10}$	11.132 $(0.014)^{10}$	1.089 (0.023)	10.560 $(0.017)^{10}$	10.059 $(0.021)^{10}$	-	-	-	STD_FIELD
000-BLG-895	8:51:26.46 [132.86024d]	11:43:51 [11.73083d]	112	11.474 $(0.027)^{10}$	11.391 $(0.019)^{10}$	11.263 $(0.016)^{10}$	0.128 (0.025)	11.215 $(0.017)^{10}$	11.146 $(0.023)^{10}$	-	-	-	STD_FIELD
000-BLG-896	8:51:42.39 [132.92662d]	11:51:23.3 [11.85648d]	112	13.307 $(0.032)^{10}$	12.342 $(0.016)^{10}$	11.266 $(0.012)^{10}$	1.076 (0.020)	10.697 $(0.016)^{10}$	10.187 $(0.020)^{10}$	-	-	-	STD_FIELD
000-BLG-897	8:51:21.78 [132.84074d]	11:52:38.1 [11.87724d]	113	12.060 $(0.025)^{10}$	11.911 $(0.020)^{10}$	11.305 $(0.013)^{10}$	0.606 (0.024)	10.945 $(0.018)^{10}$	10.609 $(0.020)^{10}$	-	-	-	STD_FIELD
000-BLG-898	8:51:03.54 [132.76474d]	11:45:03 [11.75083d]	113	11.727 $(0.028)^{10}$	11.604 $(0.020)^{10}$	11.314 $(0.017)^{10}$	0.290 (0.026)	11.149 $(0.021)^{10}$	10.988 $(0.025)^{10}$	-	-	-	STD_FIELD
000-BLG-899	8:51:21.59 [132.83995d]	11:46:06.4 [11.76845d]	114	13.463 $(0.031)^{10}$	12.500 $(0.017)^{10}$	11.427 $(0.014)^{10}$	1.073 (0.022)	10.867 $(0.016)^{10}$	10.376 $(0.020)^{10}$	-	-	-	STD_FIELD
000-BLG-900	8:51:45.10 [132.93793d]	11:47:46.2 [11.79617d]	114	13.451 $(0.026)^{10}$	12.546 $(0.016)^{10}$	11.494 $(0.011)^{10}$	1.052 (0.019)	10.941 $(0.014)^{10}$	10.442 $(0.017)^{10}$	-	-	-	STD_FIELD
000-BLG-901	8:51:07.84 [132.78265d]	11:48:09.5 [11.80264d]	115	11.912 $(0.025)^{10}$	11.949 $(0.017)^{10}$	11.544 $(0.014)^{10}$	0.405 (0.022)	11.293 $(0.017)^{10}$	11.050 $(0.021)^{10}$	-	-	-	STD_FIELD
000-BLG-902	8:51:42.37 [132.92653d]	11:50:07.9 [11.83554d]	116	13.599 $(0.029)^{10}$	12.686 $(0.017)^{10}$	11.636 $(0.012)^{10}$	1.050 (0.021)	11.081 $(0.015)^{10}$	10.580 $(0.020)^{10}$	-	-	-	STD_FIELD

Step 3 – Compute the transformation coefficients

AAVSO volunteers have developed software tools to assist you with both computing transformation coefficients and the next step — applying the coefficient to transform your data *(see http://www.aavso.org/transform* to download the programs and read useful information about them). In order to understand the principles, this guide uses the "spreadsheet method" so that you can see what is being done more clearly.

The easiest way to explain the process of transforming your data is to give an example using real data. This will enable you to see how it works without getting into a lot of theory and messy equations. You can then substitute your own data into the appropriate tables and derive your own results.

In the example that follows, it has been assumed that you are following the most common practice and imaging in just two colors – Johnson B and Johnson V. For simplicity, just 13 stars in the standard field of M67 were measured. In reality, it is better to include more like 30–50 stars covering a wide range of colors. Our sample data has been entered in the columns marked "My Data". In all cases, the instrumental magnitudes you obtain are given in lower case letters while the Standard (published) magnitudes are given in upper case letters. Your goal is to compute one color transform (T_{bv}) and two magnitude transforms (T_{b_bv} and T_{v_bv}) from this data set.

Start by entering the identifier(s) of each star you measured along with its instrumental magnitude from images made using each filter you use. Add the published magnitudes of the same stars for each color:

Table 6.2 – Sample data for M67

M67		My Data (inst. mags)			Standard Data		
Star ID	AUID	b	v	i	B	V	I
100	000-BLG-879	-7.981	-8.298	-7.501	9.978	10.040	10.086
102	000-BLG-886	-6.575	-7.983	-8.462	11.553	10.289	9.063
105	000-BLG-889	-6.487	-7.761	-8.102	11.617	10.524	9.471
107	000-BLG-891	-6.194	-7.503	-7.866	11.898	10.763	9.657
112	000-BLG-895	-6.591	-7.040	-6.421	11.391	11.263	11.146
112	000-BLG-896	-5.725	-7.000	-7.337	12.342	11.266	10.187
113	000-BLG-897	-6.111	-7.001	-6.960	11.911	11.305	10.609
113	000-BLG-898	-6.364	-6.982	-6.562	11.604	11.314	10.988
114	000-BLG-900	-5.511	-6.763	-7.072	12.546	11.494	10.442
115	000-BLG-901	-6.054	-6.753	-6.493	11.949	11.544	11.050
121	000-BLG-904	-4.929	-6.120	-6.400	13.138	12.138	11.122
123	000-BLG-908	-4.709	-5.894	-6.121	13.359	12.380	11.409
128	000-BLG-929	-4.508	-5.494	-5.497	13.541	12.812	12.033

Next, create the plot used to determine the color transform by plotting the instrumental color (b-v) versus the Standard color index (B-V). The advantage of actually plotting your data is that you can see how your observations fit the line and remove outliers so they will not negatively impact your results.

Figure 6.3 – Plotting the color transform

B-V	b-v
-0.062	0.317
1.264	1.408
1.093	1.274
1.135	1.309
0.128	0.449
1.076	1.275
0.606	0.890
0.290	0.618
1.052	1.252
0.405	0.699
1.000	1.191
0.979	1.185
0.729	0.986

The color transform (b-v versus B-V)

slope = 0.8351
T_{bv} = 1.1974
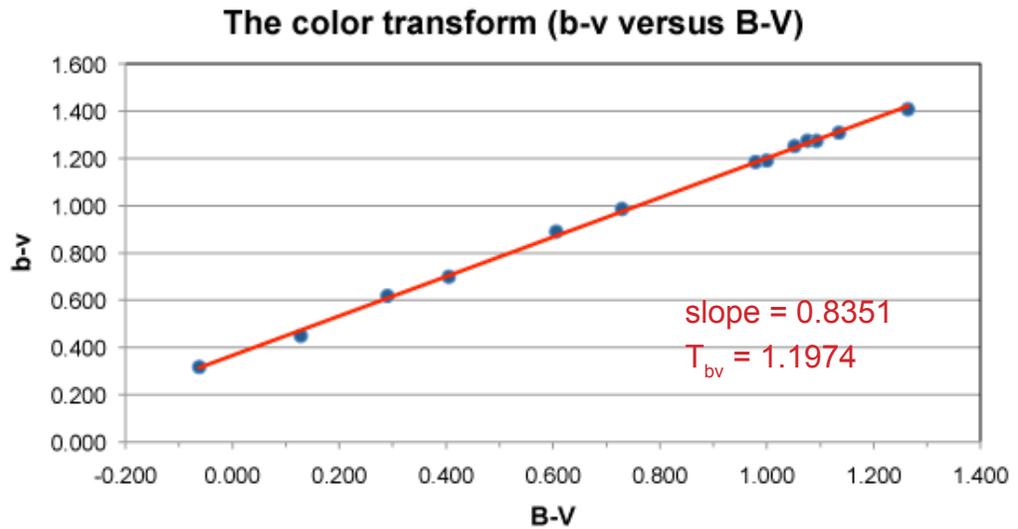
Note that a least square fit trend line was added and its slope computed to be 0.8351 in this example. Since the color transform is defined as the inverse of this slope or 1/0.8351, T_{bv} = 1.1974.

To compute the B and V magnitude transforms, start with the same data as in Table 6.2, but this time plot the difference between the standard magnitude and the instrumental magnitude (B-b) or (V-v) versus the standard color index (B-V) as shown:

Figure 6.4 – Plotting the B–magnitude transform

The B-mag transform (B-b vs B-V)

slope = 0.1181
T_{b_bv} = 0.1181
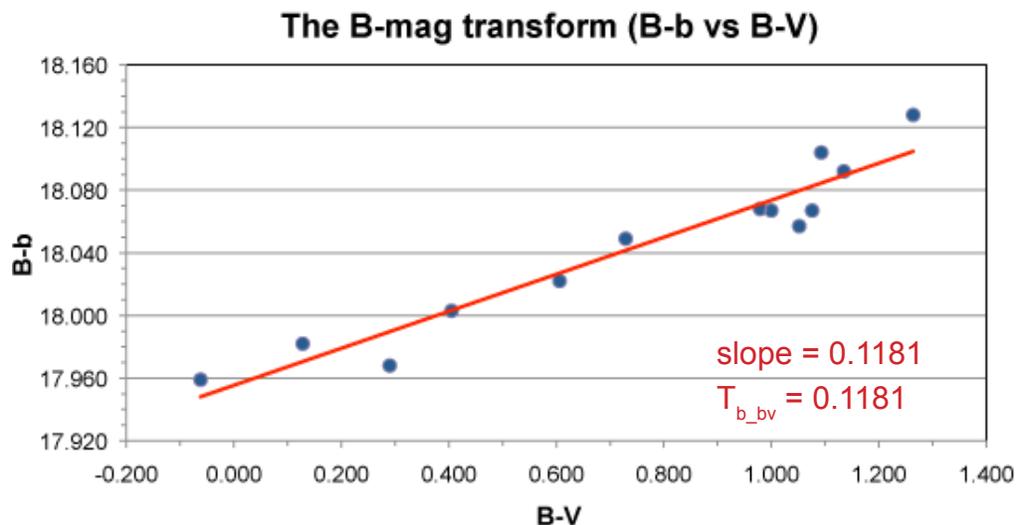
Figure 6.5 – Plotting the V–magnitude transform

B-V	V-v
-0.062	18.338
1.264	18.272
1.093	18.285
1.135	18.266
0.128	18.303
1.076	18.266
0.606	18.306
0.290	18.296
1.052	18.257
0.405	18.297
1.000	18.258
0.979	18.274
0.729	18.306

The V-mag transform (V-v vs B-V)

slope = -0.0467

T_{v_bv} = -0.0467
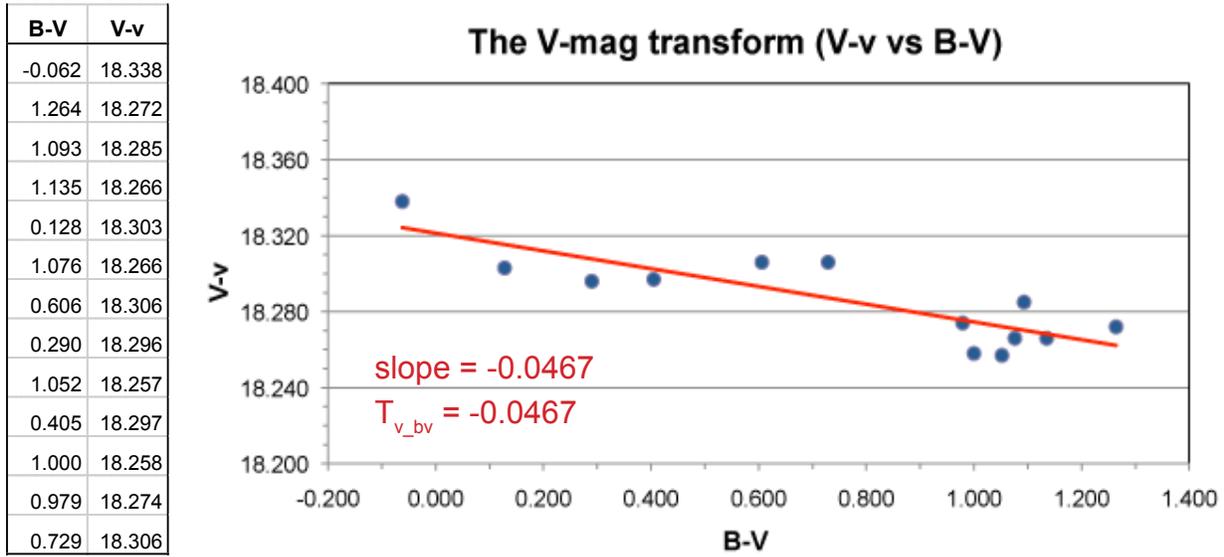
You might wonder why we bother to create plots for each of the transforms when the least–squares fit and slope can be computed without them. The answer is that with a plot, it is easy for you to pick out any points that are outliers and exclude them from the computation.

What happens if I want to use more than two colors or a different set of colors?

Depending on the filter set you use, you may find that you need to find transformation coefficients for your system using an Ic– or Rc–band or some other filter. These would be computed in much the same way as the B and V coefficients described previously.

For example, if you have an Ic–band filter in addition to the B– and V– band ones, you will need to calculate two more coefficients:

$$T_{vi} = 1/\text{slope of the plot for v-i versus V-I}$$
$$T_{i\_vi} = \text{slope of the plot for I-i versus V-I}$$

Similarly if you have a BVR filter set you would need to add these coefficients instead:

$$T_{vr} = 1/\text{slope of the plot for v-r versus V-R}$$
$$T_{r\_vr} = \text{slope of the plot for R-r versus V-R}$$

There is also more than one way to calculate the same coefficients using different colors, which you might find useful. For example, if you are imaging a very red star (like a Mira) which happens

58

to be too faint at minimum to detect using a B–filter, and you have an Ic or Rc filter available, you could use one of these combinations to compute the V magnitude transform:

$$T_{v\_vi} = \text{slope of the plot for V-v versus V-I}$$

or

$$T_{v\_vr} = \text{slope of the plot for V-v versus V-R}$$

How often must I compute my transformation coefficients?

Transformation coefficients should be computed at least once a year, but if you change anything in your optical train (replacing a filter, adding a field flattener, etc) you will have to compute your coefficients again.

Applying the transformation coefficients

Now that you have computed your transformation coefficients, it is time to use these coefficients to transform real target data to the standard system. For the sake of simplicity, it is assumed that you are using just one comparison star and not an "ensemble" of comparison stars. Note: Transforming observations that were derived using an ensemble of comparison stars is an advanced technique which depends on how the ensemble was calculated. As such, it is best left to software packages.

The basic equation is here:
$$V_{var} = \Delta v + T_{v\_bv} * \Delta(B\text{-}V) + V_{comp}$$

… and here is an explanation of each term:

- Δv is the instrumental magnitude of the variable minus the instrumental magnitude of the comparison star or $v_{var} - v_{comp}$
- V_{comp} is the published V–magnitude of the comparison star
- T_{v_bv} is the V–magnitude coefficient you just calculated
- $\Delta(B\text{-}V)$ is the difference in the standard color of the variable versus the standard color of the comparison star. This should be computed using the formula:

$$\Delta(B\text{-}V) = T_{bv} * \Delta(b\text{-}v)$$

In other words, you can derive $\Delta(B\text{-}V)$ by multiplying your color transform by the measured color difference between the variable and comparison star, $\Delta(b\text{-}v)$. Of course, this assumes that you

actually made images of the target star using both a B filter and a V filter. If for example, you were only able to create an image in one color, it is possible to substitute the published B-V values for the variable and comparison stars (if they exist) for the measured ones in the above equation. Please note that this method is prone to error since in many cases, the color of a variable star may change.

As before, it is easier to understand what is going on using an example based on actual data. Here is some sample data (the instrumental magnitudes are given):

Variable: measured		Comp: measured		Comp: published	
b	v	b	v	B	V
-6.223	-7.855	-6.202	-7.109	11.779	11.166

… and the B and V transformation coefficients computed earlier:

$$T_{bv} = 1.1974$$
$$T_{b\_bv} = 0.1181$$
$$T_{v\_bv} = -0.0467$$

Start by computing Δ(b-v) with the equation:

Δ(b-v) = (b-v)$_{var}$- (b-v)$_{comp}$
(b-v) $_{var}$ = - 6.223 - (-7.855) = 1.632
(b-v) $_{comp}$ = - 6.202- (-7.109) = 0.907
Δ(b-v) = 1.632 - 0.907
Δ(b-v) = 0.725

Now multiply this result by the color transform to get Δ(B-V):

Δ(B-V) = T$_{bv}$ * Δ(b-v)
Δ(B-V) = 1.1974 * 0.725
Δ(B-V) = 0.868

Compute Δv with:

Δv = v$_{var}$- v$_{comp}$
Δv = -7.855 - (-7.109)
Δv = - 0.746

Putting it all together:

$$\mathbf{V_{var} = \Delta v + T_{v\_bv} * \Delta(B\text{-}V) + V_{comp}}$$
$V_{var} = -0.746 + (-0.0467 * 0.868) + 11.166$
$V_{var} = 10.379$

Just for comparison, the un–transformed magnitude would be simply:

$$\mathbf{V_{var} = \Delta v + V_{comp}}$$
$V_{var} = -0.746 + 11.166$
$V_{var} = 10.420$ (untransformed)

Transforming your B measurement would be done in a similar way using this equation:

$$B_{var} = \Delta b + T_{b\_bv} * \Delta(B\text{-}V) + B_{comp}$$

where …

$\Delta b = b_{var} - b_{comp}$
T_{b_bv} = your B magnitude coefficient
$\Delta(B\text{-}V)$ is the same as above
B_{comp} is the published B magnitude of the comparison star

To test your understanding, try working through the example to compute B_{var} using the same sample data as before. You should arrive at a this result:

$B_{var} = 11.861$