Extinction and Transform Observations

There's nothing like planning ahead. So far, you've picked your target but are you really ready? If you're going to be doing filtered images and planning to transform to standard magnitudes, you'll need some images to establish the nightly extinction and zero-point values to transform to a standard system. If you haven't done the transforms yet, this is as good a time as any to get that done. It's not hard and if you use the Hardie method, you can use the same images that you get for the nightly zero-points.

If you're working with a group, especially one of the specialty variable star groups, they may have their own procedures for determining nightly values. *Use those procedures*. In all probability, they are well tested and produce uniform results among a number of observers. Using another method may yield results that are not otherwise consistent and may make your data difficult to use. If you're not sure if there are set procedures, be sure to ask *before* you start observing.

This brings up the point that not all groups require transforms or air mass corrections. I wonder why this is the case. This leads to a hodgepodge of values with no certainty of what's what. That just makes for more headaches for those maintaining databases or researches using the data. The point of this book is to show you how to do lightcurves and the best way to do those is to put your data on a standard system whenever it makes sense and is possible. If you are consistent in what you do and how you do it, then it'll be like the old line of never telling a lie: you don't have to remember what you said. I understand it doesn't always make sense or is possible. All I'm saying is that you should not use the bit of extra time and effort required to do the transforms be an excuse and that you have good reasons not to do transforms.

When are Extinction and Transform Observations Needed?

Let me expand on the point of getting extinction and nightly zero-points. If you're working all-sky photometry, nightly extinction and zero-points are mandatory. Working differential photometry doesn't always relieve you of this requirement.

For variable star observers, who are always working the same targets and are often using the same set of comparisons for a given target as every other observer, the requirement for zero-point can be dropped. The same can be said for extinction – assuming, as I've mentioned before, that one is not working at higher air masses, i.e., staying above 30° altitude.

If you're working two colors and your intent is to transform to the standard system, you really should determine both values. Given that you've already gone through the trouble to get multicolor images, there's no reason not to take the small extra step and transform your values from instrumental to standard magnitudes. It seems penny-wise and pound-foolish not to do transforms after a certain point.

For those working asteroids, where the reference fields used for determining transforms or calibrating comparison stars and the target field are sometimes many degrees apart, then extinction and zero-points are again mandatory – if you're to get accurate transforms to the standard system. As I cover elsewhere, you can get by without transforms when doing lightcurve period analysis but, as I also mention, that "simple" task can become difficult if your

data spans several weeks or you're combining data from a number of observers. If your intent it to provide data of the most scientific value, you need to get your data on a standard system. With today's software – even a simple spreadsheet will do – getting good transforms is not that difficult.

I understand if you want to start simple – just as long as you start. If you can, try at some point to build on what you've learned and take the steps, big or small, one at a time, until you have mastered the required techniques that allow you to provide the best possible data.

Hardie

Hardie mentioned this technique for getting the nightly extinction values only briefly in his chapter in Astronomical Techniques edited by W.A. Hiltner. The book is out of print but you may be able to find it in some used/rare bookstores. It's pretty outdated overall but there's always something to be learned from the masters.

Hardie realized that time at the telescope was precious. One could spend a good part of the night taking images just to get the extinction values needed to transform instrumental magnitudes into a standard band. So, he developed a plan that required a minimal amount of time and one that can serve the dual purpose of getting images of a standard field so you can determine the complete transforms or just the nightly zero-points.

> *What follows is a bit technical, but not too much. If you want to glance over it for now or prefer to use the more popular, and easier, comparison star method, then jump on down.*

1. Locate a standard field that is about 30° above the horizon. If you want to get solidly on the Johnson-Cousins system, this should be of the Landolt fields, usually found near the equator.

2. Shoot at least one image through each of the filters that you're planning to use that night. This includes the Clear filter, which you can convert to standard V if you have a minimum number of observations in V and R as well. It's better if you shoot two or three images through each filter. This allows you to average the values for each star and so reduce scatter (noise).

3. Locate a field near the meridian that is higher in the sky. Specifically, you want the two fields to have air masses that differ by at least one-half air mass and preferably more. Remember that a field about 30° high has an air mass of about 2.0. A field directly overhead has an air mass of 1.0. If you're also using this field for the transforms, you'll get better results if you pick a field that has stars with a fairly good range of colors, i.e., some blue and red stars. If the stars are almost nearly the same color, the transforms will not be of the best quality.

4. Shoot the second field using the same filters as you did with the first field.

The Hardie routine relies on the fact that if two stars of different magnitudes in the same color band are observed at different air masses, then were it not for extinction, the difference between the instrumental magnitudes would be identical to the difference in the standard magni-

tudes. For example, if Star 1 is in a field with an air mass of 1.0 and Star 2 is a star in a field with air mass 2.0 and

Star1 Catalog Mag = 14.000
Star2 Catalog Mag = 13.000

Then, without extinction, the difference between the instrumental magnitudes should be exactly 1.000. In reality, the difference is a bit larger because Star2 is a fainter than it should be because it's seen through a longer path through the atmosphere than is Star1. Don't let this little bit of math that's coming scare you. It's really pretty easy. In general, the formula is

```
K = (CM1 – CM2) – (IM1 – IM2)
              DM


where IM1 = instrumental magnitude of Star1
      IM2 = instrumental magnitude of Star2
      CM1 = catalog magnitude of Star1
      CM2 = catalog magnitude of Star2
      DM  = difference in air mass between field 1 and 2
      K   = extinction in magnitudes/air mass
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Plugging in some numbers for our example

```
K = (14.00 – 13.00) – (–6.70 – (–8.000))
              (1.00 – 2.00)

K = (1.000 – (1.30)) / –1.000
K = –0.3 / –1.00
K = 0.3
```

This says that for every unit of air mass, light is dimmed by 0.3 magnitudes in the given filter, getting brighter as the star rises higher above the horizon. This value can never be negative – things do not get brighter as they get *closer* to the horizon. I'll give an example of working through this later on in the analysis section.

Comp Star

When you shoot the same field all night, you have a ready set of data that can be used for determining the nightly extinction values. As the field rises and then sets the air mass is constantly changing. It's largest when nearer the horizon and smallest when the field is at its maximum altitude above the horizon.

1. Select a star that you'll measure in each image. You can use several and use the average if you like. Try to pick a star similar in color and brightness to the target. This minimizes color dependency and sensitivity errors.

2. Measure the raw instrumental magnitude of the star or stars in each image. Be sure to record the air mass for each image as well. The imaging and/or measuring software should do this for you automatically.

3. Plot the magnitudes against the air mass and determine the linear least squares solution for the data. The slope of the line is the extinction. *Be sure to plot the data to confirm the solution.*

If you're observing through more than one filter, you must perform this method for images in each filter. You can't mix and match. Figure 17 shows a typical example of a comparison star extinction plot.

You should use the same field as the target, not only for the technical reason that extinction *differences* are usually insignificant, but it saves time moving from one field to another. However, if you have a reliable automation system, you could go to a nearby field of standard stars periodically through the night for the extinction images. These could serve the multiple purposes of getting additional data for primary transforms and/or a red-blue pair for second order transforms. You are the best judge of what your system can do and how to meet your observing requirements. I prefer to keep the observing program as simple as possible – Murphy knows my address all too well.
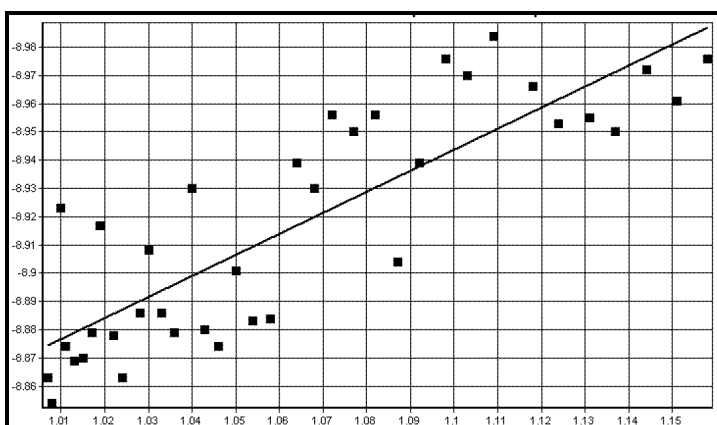

Figure 17. Finding first order extinction The plot shows instrumental magnitudes of a selected comparison star over various air masses. The least squares solution to the data is the first order extinction. In this case, the range of air mass values was really too small to get a good estimate of the extinction. See the text for more.

Actually, this plot does not show a very good solution. I included it to make a point. If you remember, I said earlier that you should view the results from a computer with at least a little suspicion and that when possible you should plot the data and see if it makes sense.

The program reported the slope of the line as 0.744. That may be valid for the given data but that's an excessively large value for V extinction, 0.2 to 0.4 would make more sense. Of course, there may have been a volcanic eruption, deep haze, or some other factor that lead to the result. However, the plot gives a more likely answer.

Look at the range of values on both axes. You can't control the range of magnitudes; they are a function of the air mass and star. You *can* control the range of air mass values. In this case, the combination of a small range of magnitudes and a small range of air mass values gives an artificially high extinction value. A least squares solution is very sensitive to the range of data

on both axes. This is why, when finding the transforms to convert to a standard magnitude system, you should use a field with as large a range of colors as possible. If all the stars are similar in color, you don't get the range you need and the solution is easily thrown out of kilter. In math terms, interpolation is always better than extrapolation.

Second Order Transforms

Except for the B-V transform, the second order term in the transformation equations is considered insignificant for all but the most critical cases. If you're going to make observations in B and V, you really should get some images of a field that contains a red and blue star that have well-established B-V magnitudes. That is not easily accomplished. The good news is that you don't have to do transforms often, maybe two to four times a year.

1.   Locate a field that has a red-blue pair. Some of the Landolt fields charted in the appendices fit the bill.

2.   Shoot the field through B and V filters periodically through the night.

3.   Plot the difference of the instrumental color index (b-v) for the two stars against the air mass times that same difference. Figure 18 shows an example plot. The slope of the line is the second order extinction. It is usually a small negative number, indicating that blue stars fade faster than red stars as they get closer to the horizon. See the example in the appendices for determining the second order value.
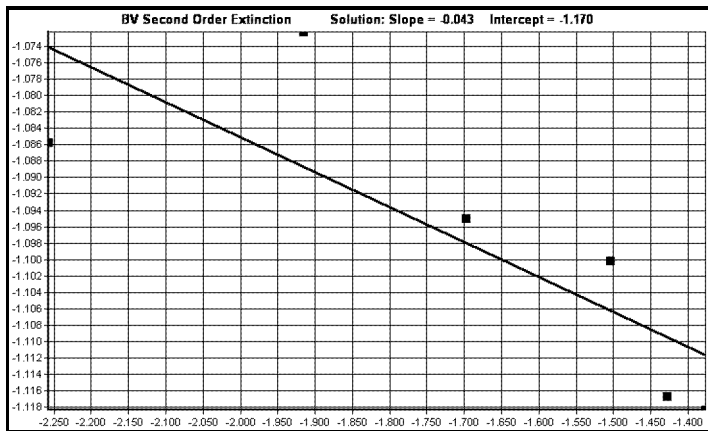

Figure 18. Finding the second order extinction. The plot shows the difference of the instrumental and catalog B-V color index (Y-axis) against (B-V * air mass). The slope of the line is the second order extinction.

To Filter or Not to Filter

Are filtered observations absolutely required? No, but they are certainly preferred, especially if you're collaborating with other observers or observing a target over a long period of time – several weeks or months. They are more mandatory when working variable stars, though some useful work can be done without filters on cataclysmic variables and eclipsing binaries. When you use filters designed to match the CCD to one or more of the standard magnitude bands, e.g., the Johnson V and Cousins R, all of your observations can be directly matched to those who also reduce their observations to the same bands.

If your goal is simply to determine the period and amplitude of the lightcurve during a given month, then unfiltered observations are acceptable, especially if you're working by yourself. Unfiltered observations can be combined with data based on a standard system. It's sometimes difficult but it can be done. The disadvantage to filtered observations is that they reduce the amount of light reaching the detector. That means your limiting magnitude isn't as faint and, in most cases, the SNR goes down. That's not always the case for the latter, however.

An experienced observer I know who worked very faint asteroids often included a reddish Wratten filter in the optical path. He was using an ST-6, which had a decided preference for the red end of the spectrum. While the filter dimmed the light of the asteroid, it dimmed the light of the bluish sky even more and so the asteroid signal, relative to the sky, went up. This technique, along with cooling the camera as much as possible allowed him to reach fainter objects than might have been possible otherwise. One can't take this idea to infinity. With an exposure long enough, the sky background takes over no matter how much it is filtered.

Many of those doing period work where all the sessions are within a short time span can merge the various sessions by factoring in a different zero-point for each session. Sometimes this is difficult because just a small difference in the zero-points can change the results dramatically.

The next two sections cover methods of standardizing your observations. I put them here because if you are going to use one of the methods, you need to plan your observing program around what's required. If you're not worried about getting more exact zero-points from session to session, you can skip to the next section.

At some point, come back to these two sections and try your hand at one method or the other. It will make your life easier in the long run.

Clear to Visual Conversions

First, and most important, it must be made clear that it is very unlikely one can get a perfect match of an unfiltered system to the V. Don't expect precision on the order of millimags. However, 0.01m-0.02m is not unreasonable. The passband of the system will most likely not match the peak or shape of the V passband, therefore, the unfiltered system will have color dependencies that cannot be easily factored if using just a V filter to calibrate your system. Yet, the situation is not hopeless.

Arne Henden performed an experiment using unfiltered images of M67 to determine if it was possible to make a clear to V transform of reasonable precision and accuracy. The finding was

that some popular chips were very close matches to either B or V while others were in be-tween. Still, within reason, it was possible to find a transform that allowed instrumental mag-nitudes to be converted to standard magnitudes. These data were the result of using only unfil-tered cameras. If one takes the process a step further, measuring the V-R color dependency of the system, then getting good Clear to V transforms is very possible.

The details of how to do the Clear to V (CtoV) transforms are covered later in this book. For now, here is a brief summary so that you have a general idea of the process.

1. Shoot a standard field close to the target field through C, V, and R filters. Take three images through each filter so you can use an average value for the stars being measured.

2. Shoot the target field through the same filters, again shooting three images through each filter to get a smoothed average for the comparison stars and the target.

3. If the fields are more than a degree or two apart, you'll need to determine the nightly first order extinction values *for all filters including Clear*.

4. Shoot the target field through C only for the majority of the night. If you're using the comp star method for extinction, you should get several more CVR series of the target field through the night so you can determine the extinction in each filter.

   You cannot use the Hardie method to determine the C extinction, since there are no catalogs with C magnitudes. You must use the comp star method to get the C first order extinction.

5. Use the v-r values instead of the traditional V-R catalog values when determining the transforms based on the images of the standard field.

6. Determine the instrumental v-r color index for the target and comparisons since the transform is based on these instead of the V-R catalog values.

If you're working a field with well-calibrated stars, you could use the V-R values, assuming the target's V-R value is also known. Using the v-r instrumental color index makes for a more general solution, which is often required when working asteroids.

This procedure was used in experiments on M67 using a camera with a Kodak 1001E (blue enhanced) chip and Schuler V/R filters. Using MPO PhotoRed for the process, C observations were reduced to standard V with a mean error (Vm – Vc) of < 0.01m with a standard devia-tion on the order of 0.01m and maximum errors of 0.02m.

One could use the same approach based on the B-V or V-I color dependencies, too. I used V and R because those were the filters I had.

A Non-standard Standard

The method described above puts all the data onto the Johnson-Cousins standard. There's no doubt about the zero-point, save due to the possible small errors in getting your data into that standard. What if you don't care which standard you're using just as long as it's a standard? After all, the Johnson-Cousins standard is just one of many. There's no rule that says you can't create your own and that it be overly difficult. If you're merging data with other observers, it does help if the standard is closely tied to an accepted standard.

The process I'm about to describe requires filters, but only one – usually V. The number of images required is not as many as when trying to transform to a formal standard and you don't absolutely have to get the images on the same night you shoot your target. It's best if you do only because the Fates and Murphy take advantage of any opportunity you give them.

1. Shoot any field that's near your target field that has a star with a well-known V magnitude. If your target field has such a star, that's even better. You can use a star from one of the Landolt or Henden charts in the appendices or one from the Tyhco2/Hipparcos catalogs. In the latter case, you should convert the Vt magnitude to the Johnson V standard so that it's easier to merge data from different observers. There are several conversion formulae floating about. Do a Google search on "Tycho 2 magnitudes To Johnson V". You'll find a number of messages containing the various possibilities.

    You *must* use this same star to calibrate *all* sessions. This means if you plan on working an asteroid for some time, you should try to pick a field that is a compromise between positions of the first and last fields you shoot. Of course, you don't always know when your last session will be, so at least pick a field that favors the direction in which the asteroid is moving.

2. Shoot the target field through the same filter. As always, shoot two or three images so you can use an average value.

3. If you're going unfiltered for the rest of the night, follow the filtered images with three unfiltered images as soon as possible, to eliminate any errors due to changing conditions.

4. Shoot the field filtered or unfiltered for the duration of the run.

The principle behind this method is to put the comparison stars from each target field on the same arbitrary system by comparing them to a known standard. Even if you shoot through a Johnson V filter, that doesn't put you on the Johnson system because you haven't accounted for color dependencies of your system. However, all measurements through the V filter do put stars on *your* standard system as defined by the filter and your camera. Remember that the detector has as much to say about the definition of a magnitude system as the filters.

In this case, the known star you shoot sets the arbitrary zero-point.

5. From the images you shot in step 2 above, find the average magnitude for each of the comparison stars you'll use *and then find the average of those averages*.

6. Find the average magnitude of the standard star from the images you shot in step 1 above.

7. Find the difference between the comparison and standard star magnitudes.

8. For each session beyond the first, find the difference between the comparison star average for the session and that of first session. Apply that difference to the differential values in the given session. See the example below.

If the value you find in step 7 is for the first session of data, it is the "reference difference." Remember that in differential photometry, the magnitudes you find are the difference between the target's magnitude and that of the comparison star, or average of several stars. If you use a different comparison star or stars for different sessions, then the differential magnitude between the target and comparison may not be the same, even though the asteroid may have the same absolute brightness.

Example

Say that the difference between the standard star and comparison magnitudes is 1.0 for the first session. On the next session, you pick a different set of comparison stars such that the difference between their average and the standard star is 1.5, meaning the comparison average is about 0.5m fainter. In order to put the differential magnitudes of the target against the second set of comparisons on the same scale as the first session, you must add 0.5m to all the differential magnitudes of the target on the second night to be on the same scale as the first. Getting lost? Here's an example:

Night 1
Standard Star: 8.0
Comparison Avg: 9.0
Standard – Comp: –1.0
Target: 12.0
Differential (Target – Comp): 3.0

Night 2
Standard Star: 8.0
Comparison Avg: 10.0
Standard – Comp: –2.0
Target: 12.0
Differential (Target – Comp): 2.0

For the sake of clarity, I've assumed the target doesn't change brightness. Going by the differential magnitude between target and comparison only, i.e., not taking into account a different set of comparison stars was used, the target just got brighter by one magnitude. Of course, this isn't true; it's the same absolute brightness on both nights.

Taking the difference between the two Standard – Comp values:

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(-1.0 - (-2.0)) = +1.0
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Add this value to the differential magnitudes on night 2, i.e.,

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Diff₀ = 2.0 + 1.0 = 3.0
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Where $Diff_0$ is against the arbitrary, but fixed, reference point. Now the target is the same brightness on this arbitrary scale.

You do not have to take the filtered images of the standard star and target field each night. If you keep accurate track of the fields from each session, you can go back on some *photometric night*, one where the sky is perfectly clear and the fields are all well above the horizon. Take images of a standard field and all the different target fields and then determine the corrections

to the differential magnitudes for each session. As I said earlier, the Fates and Murphy do conspire and since this method takes so little extra time, there's no reason not to get the images each night.

A Final Point

Why, you may ask, can't you use unfiltered measurements for the standard and comparison stars as well? You could but then you truly are on an arbitrary system. If you have a Johnson V filter using the Bessell specifications, your system should closely approximate the V system. The catalog value you'll get for the standard star is in V, or is after converted to it. Assuming you follow the general rule of using comparison stars of similar color to each other and the target and your standard star is also similar in color, the errors due to color dependencies in your system will be minimized. In this case, your semi-standard magnitudes can usually be corrected to the Johnson V standard with a simple value that one adds or subtracts from your readings.

This is why variable star observers are strongly encouraged to observe in V. Once there is good photometry available for the field stars, it's easy to do a quick study of the instrumental v magnitudes you measure vs. the accurate V-R magnitudes (or B-V or V-I). Then you can establish a simple transform that does include a color dependency term. Since all the stars are in the same field, extinction corrections drop out as you go through the math – at least in the vast majority of cases.

Stars of a Similar Color

Before going on, you may be wondering how you pick comparison stars of similar color to the target. That's a good question. If you're working a field with calibrated magnitudes, e.g., a variable star where photometry has been done on the comparison stars, then it's pretty easy to pick comparisons of the right color. Keep in mind, however, that some stars do change color as they go through their cycle.

As for asteroids, the problem is more difficult. The first choice is to shoot some quick images through two filters, e.g., B and V, or V and R; I prefer the latter since most CCDs favor the red end of the spectrum. Then you can do some quick measurements and find stars that have a similar color index, i.e., differ in one color from the other, by a similar amount. You can also use the magnitudes in a catalog covering the region as long as you take care. Most of the catalogs used by amateurs have poorly calibrated magnitudes at best.