# Appendix

## Measuring Transformation Coefficients

There are two ways of measuring transformation coefficients; these are the Two-Star Method and the Multiple-Star Method. The Two-Star Method is easy to use, but the Multiple-Star Method is more accurate. One should make transformation measurements under excellent sky conditions and at a temperature near that of what measurements are made. Transformation measurements should be made near 10°C (50°F).

### Multiple-Star Method

In this method, one must measure the brightness of several stars with different B–V values. The stars should be as close to one another as possible, and be as close to the observer's zenith as possible. This will insure that extinction corrections will be small. The selected stars should not change in brightness by more than ~0.02 magnitudes. (It is the writer's opinion that most of the stars visible to us, including the Sun, undergo at least small changes in brightness from time to time.) Once measurements are made, one must compute values of $\Delta V$, $\Delta v$ and $k' \times \Delta AM$ for each of the target stars in the same way as described in Chapter 5. The heart of this method is Equation A.1:

$$\varepsilon_V \times \Delta(B - V) = \Delta V - \Delta v + k' \times \Delta AM + k'' \times AM_{avg} \times \Delta(B - V) \qquad (A.1)$$

where $\varepsilon_V$ is the transformation coefficient, AM is the air mass and other letters and symbols are defined in the same way as in Chapter 5. (This is the same as equation 13.10.6 in Hall and Genet, ©1988, p. 200.) The $k'' \times AM_{avg} \times \Delta(B-V)$ term is negligible except for the U and B filters. In order to transform a filter to the Johnson V system, one should plot average values of $\Delta V - \Delta v + k' \times \Delta AM$ versus the values of $\Delta(B-V)$ and compute the slope ($\varepsilon_V$) or, if the data is not linear, one should use a curve fitting routine to develop an equation which will yield a value of $\varepsilon_V$

Here is how one carries out measurements using the Multiple-Star Method with an example. As a first step, I selected the constellation Ursa Major because it was near my zenith. Afterwards, I checked to see if stars in this constellation changed in brightness by a large amount using the Millennium Star Atlas and I avoided any stars listed in the Atlas as variables. After this, I selected several bright stars in Ursa Major. On May 9, 2007, under clear skies, I carried out V filter measurements of

**Table A.1** Stars used in my multiple-star analysis made on May 9, 2007

| Star | V Magnitude [a] | B–V [a] |
|---|---|---|
| Eta-Ursae Majoris (η-UMa) | 1.86 | –0.18 |
| Delta-Ursae Majoris (δ-UMa) | 3.33 | 0.08 |
| Gamma-Ursae Majoris (γ-UMa) | 2.44 | 0.00 |
| Beta-Ursae Majoris (β-UMa) | 2.38 | –0.01 |
| Alpha-Ursae Majoris (α-UMa) | 1.80 | 1.07 |
| Theta-Ursae Majoris (θ-UMa) | 3.20 | 0.46 |
| Iota-Ursae Majoris (ι-UMa) | 3.15 | 0.19 |

[a] Magnitude and B–V values are from Iriarte et al (1965).

them with the goal of measuring the transformation coefficient of my system. Eta (η) Ursae Majoris, one of the seven stars, was the comparison star in this study. The magnitudes and B−V color indexes of the selected stars are listed in Table A.1. I used the method described in Chapter 5 to measure values of ΔV, Δv and k′ × ΔAM for the other six stars (k′ = 0.2419 magnitudes/air mass). The results determined on May 9, 2007, are shown in Table A.2.

After computing the ΔV, Δv and k′ × ΔAM values, I computed average values of these quantities and used them to compute average values of ΔV − Δv + k′ × ΔAM for each of the six stars. Average values of Δv, k′ × ΔAM and ΔV − Δv + k′ × ΔAM are listed in Table A.2. Afterwards I constructed a graph of ΔV − Δv + k′ × ΔAM versus Δ(B−V) and determined the best fit curve. As it turned out, I was able to fit the data to a linear equation using a least squares approach. The resulting equation was:

$$\Delta V - \Delta v + k' \times \Delta AM = 0.0145 - 0.061 \times \Delta(B - V) \quad (A.2)$$

and the slope, $\varepsilon_V$, was equal to −0.061.

## Two-Star Method

In order to measure transformation coefficients with the Two-Star Method, one should pick out two stars near each other with different B−V values. These stars

**Table A.2** A summary of measurements made on May 9, 2007, for the purpose of determining a transformation coefficient using the Multiple-Star Method

| Star | ΔV | Average (Δv) | Average (k′ × ΔAM) | ΔV – Δv + k′ × ΔAM | Δ(B–V) |
|---|---|---|---|---|---|
| (η-UMa) | 0.00 | 0.0 | 0.0 | 0.00 | 0.00 |
| (δ-UMa) | 1.47 | 1.467 | 0.005 | 0.008 | 0.26 |
| (γ-UMa) | 0.58 | 0.579 | 0.007 | 0.008 | 0.18 |
| (β-UMa) | 0.52 | 0.525 | 0.017 | 0.012 | 0.17 |
| (α-UMa) | –0.06 | 0.026 | 0.023 | –0.063 | 1.25 |
| (θ-UMa) | 1.34 | 1.413 | 0.046 | –0.027 | 0.64 |
| (ι-UMa) | 1.29 | 1.378 | 0.077 | –0.011 | 0.37 |

should be as close to the zenith as possible and should have a nearly constant brightness. One can rearrange equation A.1 as:

$$\varepsilon_V = (\Delta V - \Delta v + k' \times \Delta AM)/\Delta(B - V) \qquad (A.3)$$

where the $k'' \times AM_{avg} \times \Delta(B - V)$ term is dropped since it is negligible for the V filter. If Eta-Ursae Majoris and Alpha-Ursae Majoris are used, $\Delta V = -0.06 - 0.00 = -0.06$; $\Delta v = 0.026 - 0.00 = 0.026$; $k' \times \Delta AM = 0.023$; $\Delta B{-}V = 1.07 - -0.18 = 1.25$; and the resulting transformation coefficient, based on the appropriate average values would be:

$$\varepsilon_V = (-0.06 - 0.026 + 0.023)/1.25 = -0.050 \qquad (A.4.)$$

One problem with the Two-Star Method is that it implies a linear relation between the values of $\Delta V - \Delta v + k' \times \Delta AM$ and $\Delta(B{-}V)$ terms. However, this may not be the case. As a rule of thumb, if the transformation coefficient exceeds 0.1, one should use the Multiple-Star Method to measure transformation coefficients. If one desires an accuracy of 0.002 magnitudes or better, he or she should use the Multiple-Star Method.

## Measuring Extinction Coefficients

The extinction coefficient shows how much light is absorbed by the atmosphere per air mass. Its units are magnitude/air mass. The extinction coefficient is different for different wavelengths of light. Between 2004 and 2007, I measured average extinction coefficient values of 0.38, 0.23, 0.16 and 0.12 magnitude/air mass for filters transformed to the Johnson B, V, R and I system. All measurements were made under clear skies in central Georgia.

Does the extinction coefficient change from one night to the next? Yes! For example, I measured extinction coefficients of 0.184, 0.242 and 0.218 magnitude/air mass for three excellent nights on May 8, 9 and 10, 2007. All measurements were made through a filter that was transformed to the Johnson V system. I believe that extinction coefficients should be measured each time that magnitude measurements are made unless the difference in air mass between the target and comparison star is less than 0.1 air masses. If the target and comparison star are very close to each other, extinction corrections would be negligible.

There are two ways of measuring the extinction coefficient which I call the Drift Method and the Two-Object Method.

### Drift Method

Let us describe this method with an example. On May 10, 2007, I measured the brightness of Venus as it was setting. The data are summarized in Table A.3. I computed the altitude (A) of Venus from the equation:

$$\text{Inverse}\sin(A) = \cos(\theta) \times \cos(\phi) \times \cos(h) + \sin(\theta) \times \sin(\phi) \qquad (A.5)$$

In this equation, $\theta$ is the observer's latitude (33.1°N in my case), $\phi$ is the declination of the target (26.0° for Venus on May 10, 2007) and h is the hour angle which is how far (in degrees) the target is from the observer's meridian. The

**Table A.3** Venus data collected with the purpose of determining the extinction coefficient using the Drift Method

| Time (U.T.) | Delta Time (minutes) | h (degrees) | Altitude (degrees) | Air Mass (AM) [a] | Diff. | Δmag |
|---|---|---|---|---|---|---|
| 1:04 | 268 | 67 | 32.25 | 1.874 | 2566.33 | 0.000 |
| 1:13 | 277 | 69.25 | 30.41 | 1.976 | 2503.33 | 0.027 |
| 1:26 | 290 | 72.5 | 27.76 | 2.147 | 2337.33 | 0.101 |
| 1:54 | 318 | 79.5 | 22.12 | 2.655 | 2134.33 | 0.200 |
| 2:06 | 330 | 82.5 | 19.74 | 2.961 | 2066.67 | 0.235 |
| 2:19 | 343 | 85.75 | 17.17 | 3.388 | 1901.33 | 0.326 |
| 2:30 | 354 | 88.5 | 15.02 | 3.859 | 1768.33 | 0.404 |
| 2:41 | 365 | 91.25 | 12.88 | 4.485 | 1492.0 | 0.589 |
| 2:48 | 372 | 93 | 11.54 | 5.000 | 1332.67 | 0.711 |

[a] One can compute the Air Mass value for Venus from: Air Mass = 1/Sin(A) where A is the altitude of Venus.

Astronomical Almanac lists when each of the planets transit the meridian for people located at longitude of 0° on Earth. On May 10, 2007, Venus transited the meridian at 14:59 U.T. for people at 0° longitude. My longitude at the time of the measurements was 84.14°W and, since Earth rotates 15 degrees/hour, Venus transited my meridian at: 14:59 U.T. + (84.14°/15° per hour) = 14:59 U.T. + (5.609 hours) = 20:36 U.T. (Recall that 5.609 hours is approximately equal to 5 hours and 37 minutes.) I computed the hour angle, h, using:

$$h(\text{in degrees}) = (\text{delta time in minutes})/4 \qquad (A.6)$$

where delta time is the difference in time between the meridian transit, 20:36 U.T., and the time of measurement. Values for h and delta time are listed in Table A.3.

I computed the Diff. values of Venus for each set of measurements using:

$$\text{Diff} = (\text{average Venus reading}) - (\text{average sky reading}) \qquad (A.7)$$

Afterwards, I computed the Δmag values. The Δmag value is the difference in brightness between the first Venus reading at 1:04 and the other readings. For example, Δmag for the second reading at 1:13 U.T. is:

$$\Delta\text{mag} = 2.5\text{xlog}(2566.33/2503.33) = 0.027\text{magnitudes}$$

The other Δmag values are computed in the same way and are listed in Table A.3.

Finally I determined the extinction coefficient by plotting the Δmag values versus the air mass values and used a linear least squares routine to obtain:

$$\Delta\text{mag} = -0.398\text{magnitudes} + (0.218\text{magnitude}/\text{airmass}) \times \text{airmass} \qquad (A.8)$$

The slope of this line, 0.218 magnitude/air mass, is the extinction coefficient.

## Two-Object Method

A second and quicker method of measuring the extinction coefficient is to use the Two- Object Method. One simply measures the brightness of two objects of known

Name: ____________________

Address: ____________________

e-mail: ____________________

Telescope type: ____________________ Magnification: ____________________

Seeing: ____________________ Transparency: ____________________

**Drawing**

*Lable N for north sky direction and P for preceding edge of the disc.*

Drawing Intensities

Planet: ____________________

Date/Time (U.T.): ____________________

*Write comments blow*

**Color Estimate**

Planet: ____________________

Color: ____________________

Date: ____________________

Time (U.T.): ____________________

*Write comments blow.*

**Visual magnitude estimates**

Comparison star magnitudes: ____________________

Source of comparison star magnitudes: ____________________

Planet: ____________________ Estimated magnitude: ____________________

Instrument used: ____________________

Date/Time (U.T.): ____________________

**Fig. A.1** The official observation form of the Remote Planets Section of ALPO.

brightness at different altitudes and then measures the magnitude difference, which is due to extinction. These objects can be either stars or planets.

Let's describe this method with an example. Table A.4 lists the data of two objects that I measured on May 8, 2007. I used the same procedure in Chapter 5 to compute Diff. and $\Delta$v. I let Beta-Ophiuchi be the comparison star in this example.

**Table A.4** Measurements and analysis of two stars made in order to determine the extinction coefficient using the Two-Object Method

| Star | Time U.T. | B–V | Diff. | $\Delta V$ | $\Delta v$ | Air Mass [a] |
|---|---|---|---|---|---|---|
| Beta-Ophiuchi | 8:36 | 1.16 | 54.33 | – | – | 1.141 |
| Theta-Scorpii | 9:01 | 0.41 | 74.83 | –0.91 | –0.348 | 4.408 |

[a] One can use the equation Air Mass = 1/sin(A) where A is the altitude to compute the Air Mass value of the star. The only difference is that for stars, one looks for the closest planet to the star and looks up when that planet crosses the central meridian. Therefore, one adds (or subtracts) the difference in right ascension between the star and the closest planet on the date of the measurement in order to compute the time when the star transits the meridian at 0° longitude.

I rearranged Equation A.1 as:

$$k' = (\varepsilon_{V} \times \Delta(B - V) - \Delta V + \Delta v)/\Delta AM \qquad (A.9.)$$

(Keep in mind that the $k'' \times AM_{avg} \times \Delta(B - V)$ term drops out for the V filter.) I computed $\Delta(B-V)$ as: $\Delta(B-V)$ = the B−V value of Theta-Scorpii minus the B−V value of Beta-Ophiuchi or 0.41 − 1.16 = −0.75. We know that $\Delta v = 2.5 \log [54.33/74.83] = -0.348$, and the $\Delta AM$ term equals 4.408 − 1.141 = 3.267 air masses. After substitution:

$$k' = [(-0.051 \times -0.75) - -0.91 + -0.348]\text{magnitudes}/(3.267\text{air masses}) \qquad (A.10)$$

or: $k' = 0.184$ magnitude/air mass. In this calculation, I used a value of $\varepsilon_V = -0.051$.

The Two-Object Method is much quicker and is the one that I use usually. The measurements should be done at nearly the same time that magnitude measurements are made since the sky transparency can change during the night.

## ALPO Observation Form

Figure A.1 shows the official observation form of the Remote Planets Section of the Association of Lunar and Planetary Observers (ALPO). The form may be reproduced for personal use only. When making an observation, image or measurement, it is important to send as much relevant information as practicable. It is especially important for the observer to describe the location of the north direction of his/her sky and the location of the preceding limb somewhere near any drawing.

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