**I. Process overview – asteroid and short-period variable star lightcurves with MPO Canopus and PhotoRed**

**A. Overview**

**1. Processing workflow is overviewed in Chapter 5 of Warner's *Lightcurves* book. This workflow outline parallels Warner's section numbers in Chapter 5.**

**2. In MPO Canopus, astrometry and instrumental magnitude data are captured from only target field images. In PhotoRed, instrumental magnitude data is captured from reference fields.**

**a) Then PhotoRed is launched to perform photometry reduction and to create a datafile of the target in standard magnitudes. This data is looped back into Mpo Canopus and which is used to plot the final lightcurve for the asteroid.**

**b) Alternatively, once raw instrumental magnitudes are extracted in Mpo Canopus, a "quickpeek" plotting of the lightcurve from raw instrumental magnitudes can be done.**

**3. Photometry reduction as an abstract process involves finding rough and color index transformation coefficients, finding nightly extinction coefficients, finding specific color index coefficients for comparison stars and the target in the target field, and applying all of the above to find the standard magnitudes of the comparison stars and target in the target field. Specific abstract steps include:**

**a) *Measure images to extract observation data:* The basic "high-low" imaging sequence consists of one high-color index reference field within 2 degrees of the target field; a low extinction reference field; that field as it transits is reimaged and then is called the "high extinction reference field"; and, a continuous series of target field images.**

**(1) In MPO Canopus/PhotoRed, the MPO Canopus lightcurve wizard is used to extract data from the target fields. The photometry wizard in PhotoRed is used to extract data from reference fields.**

**b) *Find rough coefficients to transform instrumental to standard magnitude* using reference fields. *Lightcurves* at Sec. 5.7; User Guide v9.2 Lessons 18 (first half at pp. 60-62 – "Transforms" option).**

**c) *Find the (hidden) color index coefficients to transform instrumental to standard magnitudes* using a reference field. *Lightcurves* at Sec. 5.8; User Guide v9.2 Lesson 18 (first half at pp. 60-62 – "Transforms" option).**

**d)** ***Find an initial rough estimate for first order extinction coefficients and nightly set point*** **– a predicate for finding refined first order extinction using the Modified Hardie Method from the reference fields.** ***Lightcurves*** **at Secs. 5.9-10 and User Guide v9.2 Lesson 18 (last half at pp. 62-63 – "Comps - All Sky" option).**

**e)** ***Check the transform errors in the reference fields. Lightcurves*** **at Sec. 5.8; User Guide v9.2 Lesson 19 ("Errors" option).**

**f)** ***For the target field refine the first order coefficients, readjust the nightly extinction and set the transformation equation nightly zero-point.*** **Now that you have an initial rough estimate of the transform and extinction coefficients from the reference field, a more refined estimate for the target field can be obtained. Use the target field and** ***Lightcurves*** **Sec. 5.12 (continuous target field images – "First-Order Comps") and User Guide v9.2 Lesson 20, and either:**

**(1) continuous V, R and C measurements of the target field.**

(a) Reduce one filter only serially to set the V, R or C extinction coefficient on the Reductions – Ext./Simp tab

**(2) Less accurate continuous C or continuous V measurements of the target field.**

(a) Reduce one filter only on the Reductions – Ext./Simp tab

**g)** ***Find the color index coefficients for comparison stars in the target field. Lightcurves*** **at Secs. 5.13 and 5.14 and User Guide v9.2 Lesson 21 (option "Color Index (Comps/Target)").**

**h) For PhotoRed, make special single group *.obs file of target observations.**

**i)** ***Find the standard magnitudes of target field comparison stars and target.*** **Use one of three alternative methods – the older "basic" method, the newer "Binzel" method or the "Quick Mags" method. The Binzel method can be used where the color indices of the comparison stars in the target and reference fields are similar. The "Quick Mags" method is used for AAVSO variables stars fields that have predetermined with AAVSO standard star magnitudes and color indices –:**

**(1) "Basic" instrumental to standard magnitudes:**

(a) In the target field, convert the instrumental magnitudes for the comparison stars to standard magnitudes, using a special single group *.obs file observations for the target field. *Lightcurves* at Secs. 5.15 and 5.16 and User Guide v9.2 Lesson 22 (option "Comp Standard Mags").

(b) In the target field, convert the instrumental magnitudes for the target to standard magnitudes, using the raw multi-group observation data for the target field. *Lightcurves* at Secs. 5.17 and 5.18 and User Guide v9.2 Lesson 23 (option "Target Standard Mags").

**(2) Binzel method for instrumental to standard magnitudes, typically used where single filter (usually V) reference images and continuous C target images are taken *and* where the color indices of the comparison stars in the target and reference fields are similar:**

(a) In a nearby reference field, reset the average offset between the instrumental and comparison stars in the V filter only. User Guide v9.2 Lesson 24 (option "Binzel Ref. Field" sets the Ref. Offset field).

(b) In the target field, reset the initial estimate for comparison star instrumental transforms using User Guide v9.2 Lesson 25 (option "Binzel Target Work" sets the "Target-comp" value).

(c) In the target field, reset the coefficient to transform target field C values to standard magnitude V filter values using User Guide v9.2 Lesson 26 (option "Binzel Target Std" sets the "<Target-instrumental", "Target Anchor" and "Standard shift" values per Guide at 105).

(d) In the target field, convert the instrumental target magnitudes to standard magnitudes using User Guide v9.2 Lesson 27 (option "Binzel Std Magnitudes").

**(3) "Quick Mags" – the AAVSO method – is meant to be used with long-period variables and for reporting to the AAVSO.**

(a) Obtain the Henden sequence files for the variable and make a user catalogue. MPO Canopus v9.2 Reference Manual at 196-197.

(b) Measure the field using the Quick mag method using User Guide v9.2 Lesson 28 (option "QuickMags Method").

(c) Optionally, prepare an AAVSO report using User Guide v9.2 Lesson 29 (option "QuickMags Report").

**j)** ***Plot the lightcurve of the target*** **in standard magnitudes.** *Lightcurves* at Chapter 11; User Guide v9.2 at Lessons 16-17.

**II. Miscellaneous tips**

**A. Alternative imaging workflows: When reducing images with MPO Canopus, there are two alternative but exclusive methods for estimating extinction. Selection between the choices dictates what images you will make before reducing in MPO Canopus. The choices are:**

**1. Image a high color index Henden or Landolt standard reference field in V, R and C filters. Image a low Landolt extinction field. Then continuously image your target field in only V or in only C. When the low extinction field transits, image it in V, R and C filters.**

**2. Image a high color index Henden or Landolt standard reference field. Then continuously image the target field in V, R and C filters, ending the evening by imaging one standard reference field near the meridian. Warner prefers this method citing efficiency of movement.**

**a) Outline author's comment: Unless you have an automated filter wheel, continuously imaging the target field with a V, R and C filter is more labor intensive than using the "high-low" method described first.**

**B. Reusing instrumental transforms**

**1. Warner's** ***Lightcurve*** **book recommends with respect to cooled cameras that users only set their transform coefficients every few months. For cooled cameras, their operating parameters do not change significantly over time. Transform coefficients are used to make an initial estimate of standard magnitudes that are used by the Modified Hardie Extinction method. The Modified Hardie Extinction method requires standard magnitude estimates within a certain error range in order to return accurate results. The instrumental transform coefficients are set on one night from images of standard Landolt or Henden fields. The transform coefficients are exported and stored to a *.ppr file. The coefficients can be reloaded on subsequent nights. Author's note: Whether the assumption that parameters are stable for air-cooled cameras is unknown.**

**C. Plan you imaging session**

**1. Select a target**

**a) Select an asteroid target using the MPO Bulletin at http://www.minorplanetobserver.com/mpb/**

> **(1) Selection criteria might include V, Period < 8.0 hours; Amplitude: > 0.2-0.3; Altitude at desired local time: preferably >40 degrees.**
>
> **(2) Where the light curve period is not listed in the MPO Bulletin, use the Harvard lightcurve list to find the period: http://cfa-www.harvard.edu/iau/lists/LightcurveDat.html**

**b) Using Asteroid browser feature in MPO Canopus ( Utilities | Asteroid browser ), to generate ephemeris data for the planned night of observation. Determine if the target is higher than 40 degrees in altitude when imaging will start.**

**c) Check whether the Moon is up and would interfere with making images.**

**d) Plan enough session times to collect images across 2x the period of the asteroid. Check whether the target can be imaged on multiple nights.**

**e) Consider the portions of phase that will be captured when imaging on more than one night. This can be estimated using an Excel spreadsheet by assuming that the phase is 0 hours at the start of imaging. To align lightcurves fragments taken on different nights, MPO Canopus needs a sufficient overlap between the two curves.**

**f) Generate a target field chart using your planetarium program or the Lowell Observatory Asteroid Plotting page at: http://asteroid.lowell.edu/cgi-bin/koehn/astplot**

> **(1) Check the Lowell or other planetarium plot to determine if the asteroid will track over a nearby bright star during your imaging session (potentially reducing the number of good images.)**

**2. Select reference fields - a total of two**

**a) Prescan near the target field and select the closest Hendon or Landolt stellar reference fields. This will be the single “High color index field”.**

**b) Reference fields, particularly the "high color index reference field", should have four or five "solar colored" comp stars with a color index between 0.3 – 0.7 for best accuracy. *Lightcurves* at 5.21, p. 72. Asteriods reflect solar colored light.**

**c) Prescan near the celestial equator and select a Hendon or Landolt stellar reference field at the low 40 degree altitude that will rise to 60 degrees and is near the target field. At its low position, this is the "low extinction reference field." At its high transit position, this is the "high extinction reference field."**

**3. Plan forrising-setting imaging sessions**

**a) Decide whether the imaging session will involve: a rising target path only, a setting path only, a bifurcated rising and setting path. Plan to divide data reduction into two sub-sessions if the target path is bifurcated into rising and setting.**

**b) Both rising and setting sessions should be bounded by 40-50 degrees in target altitude.**

**D. Resourcesfor photometry data forreference fields andlightcurves:**

**1. Lightcurves**

**a) Harvard lightcurve list http://cfa-www.harvard.edu/iau/lists/LightcurveDat.html**

**b) MPO Bulletin http://www.minorplanetobserver.com/mpb/**

**c) NASA/ADS journal literature http://adsabs.harvard.edu/abstract_service.html**

**2. Plotting asteroid positions**

**a) Lowell Observatory Asteroid Plotting http://asteroid.lowell.edu/cgi-bin/koehn/astplot**

**b) Harvard CFA asteroid elements data file (for use with planetarium programs)**

**(1) http://www.cfa.harvard.edu/iau/Ephemerides/**

**(2) http://www.cfa.harvard.edu/iau/Ephemerides/Bright/2006/Soft06Bright.txt+Soft06Unusual.txt**

3. **Photometry data**

   a) **Henden VAR Photometry**

      (1) **ftp://ftp.aavso.org/public/calib/**

      (2) **http://www.aavso.org/observing/charts/phot/?C=M;O=D**

      (3) **Henden sequences are already imported into the MPO Canopus database**

      (4) **Charts of Henden sequences are on the MPO distribution disk**

   b) **AAVSO Sumner sequences**

      (1) **ftp://ftp.aavso.org/public/calib/sumner/**

      (2) **http://www.aavso.org/observing/charts/phot/?C=M;O=D**

**E. Prescreen your raw images to weed out bad data at the earliest point in the process.**

1. **Randomly check your images for errors.**

   a) **Check dark frames, white flats and target "C" images for errors like the Venetian blind effect, extraneous light spikes, drift off field, etc. Discard suspect frames to a non-destructive project "trashcan" directory.**

2. **Familiarize yourself with the magnitudes of the reference stars and your target and the travel of the target across the target field.**

   a) **You may be surprised to find that some stars you think are mag 10 or 11 are in fact mag 13 and 14. CCD cameras are more sensitive at the red end of the spectrum and reach 1 to 1 ½ more magnitudes that visual observing.**

3. **Optionally, make a gif animated movie to identify problems in the processed frames.**

   a) **(Not recommended in MPO Canopus Manual – author's preference.) If you have other image processing software like AIP4WIN, consider making a jpg or gif movie of the processed images. Running all the processed images as movie brings out changes in the background sky brightness that might other escape unnoticed.**

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