

High Precision Astrometry of Occulting Asteroids

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The work at Table Mountain Observatory, on High Precision Astrometry of Occulting Asteroids is done using the 0.61m telescope with either a 4K-FLI charged couple device (CCD) camera or a 2K CCD camera, depending upon which is able to provide the best results at the time. Both of these cameras have the ability, given favorable weather conditions, to provide excellent pictures and data of the targeted asteroids. Due to the refractive nature of the Earth's atmosphere, we track and document the local temperature, barometer reading or atmospheric pressure, and humidity for each target. This data enables us to model the refractions into each picture, aiding in the overall precision. Each picture is also taken as close as possible to the meridian; which is when the object's right ascension (RA) coincides with the local sidereal time. This should ensure that the picture of the target will be taken through the least amount of atmosphere, increasing accuracy. The process of data reduction after each night of observations provides the opportunity to eliminate errors in position that could occur. Such errors can be common given the distance and visible magnitude of the targets. After our data is reduced with all errors taken out, the data is then submitted to another group to be used in precisely calculating each target's orbit and position. The recalculated data will then be used to refine ground tracks of asteroid occultations. This new data is used to document where, from the Earth's surface, each asteroid that passes in front of a star can best be viewed.

Procedure

The first process in High Precision Astrometry is the prediction process. To complete this there are two simple steps that need to be taken in a specific order. The first step in this process is to run an update script which enables the computer to predict the positions for each visible object on the specified date. The script is setup as depicted in the image below (Fig. 1).

```
update YYYY MMM DD YYYY MMM DD  
dubhe.jpl.nasa.gov% update 2012 AUG 20 2012 AUG 20  
2012 AUG 20  
2012 AUG 20  
dubhe.jpl.nasa.gov% █
```

Figure 1: update script

The first set of Year Month Day as the input date, and the second as the output date, enabling you to predict multiple days at one time if desired. For example, if I wished to predict the positions for objects over the time period of August 19, 2013 through August 21, 2013 the input script would look like this: 2013 AUG 19 2013 AUG 21. This update would prepare the observing team for the next step in the prediction process.

The custom prediction script is the next script that is used; this is the one doing the actual computerized predictions. When input, this script looks like the image below (Fig. 2).

```
pred2k
dubhe.jpl.nasa.gov% pred2k
Predicting dawn
Predicting mass
Predicting special
Predicting sp1111
Predicting occ1206b
Predicting occ1207a
Predicting occ1208a
Predicting occ1208b
Predicting occ1208c
Predicting occ1209a
Predicting occ1210a
Predicting occ1210b
Predicting occ1211a
Predicting occ1211b
Predicting occ1211c
Predicting occ1212a
Predicting occ1212b
Predicting occ1212c
Predicting occ1212d
Using satellite ephem /home/wmo/ephem/jup172.nio
Predicting jov
Using satellite ephem /home/wmo/ephem/sat105.1.nio
Predicting outer
Predicting phoebe
dubhe.jpl.nasa.gov% █
```

Figure 2: pred2k script

This script is specifically written for the 2K CCD camera that we had to use after the original 4K CCD began to experience voltage problems. The two scripts are very similar from the outside. The script for the 4K is simply “pred,” however once the original 4K camera finally gave out, it was replaced with a new 4K-FLI CCD camera. The new 4K-FLI camera received the new script pred4f, and was later adapted on several of the machines to just “pred.”

After the prediction process has been completed, the predicted plots must be chosen and prepared for observation. To choose each of these plots a program named ghostview (gv) (Fig. 3) is used. This program displays each of the target asteroids, minor planets, or outer planets with satellites. Plots are determined as either “good” or “bad” by their position among reference stars and positions using: right ascension, declination, beta angle, all of which is displayed in gv, as shown below. The red selection labeled as “Outlying Reference Stars” shows where outlying stars that are used in a targeting mosaic are located. The blue “Targeted Reference Stars” points out reference stars that are directly within the targeted area. The green “Target Object” is just that, the Targeted Object, which is not always visible as a point on the plots. The section at the bottom indicates the three numbers that either place an object in the observable or trash

categories. The Right Ascension (RA: position in space measured in hours along the celestial equator) must be within a maximum of one and a half hours from the current Local Sidereal Time (LST: time based upon Earth's rotation using reference stars), the Declination (Dec: angle from the celestial equator in either direction towards a celestial pole) must be greater than -30° , and the Beta Angle (BT: angle from the sun to the target) must be greater than 90° ; all of these conditions must be met in addition to sufficient reference stars both inside and outside the targeted area, indicated in the gv display for the plot to be considered "good".

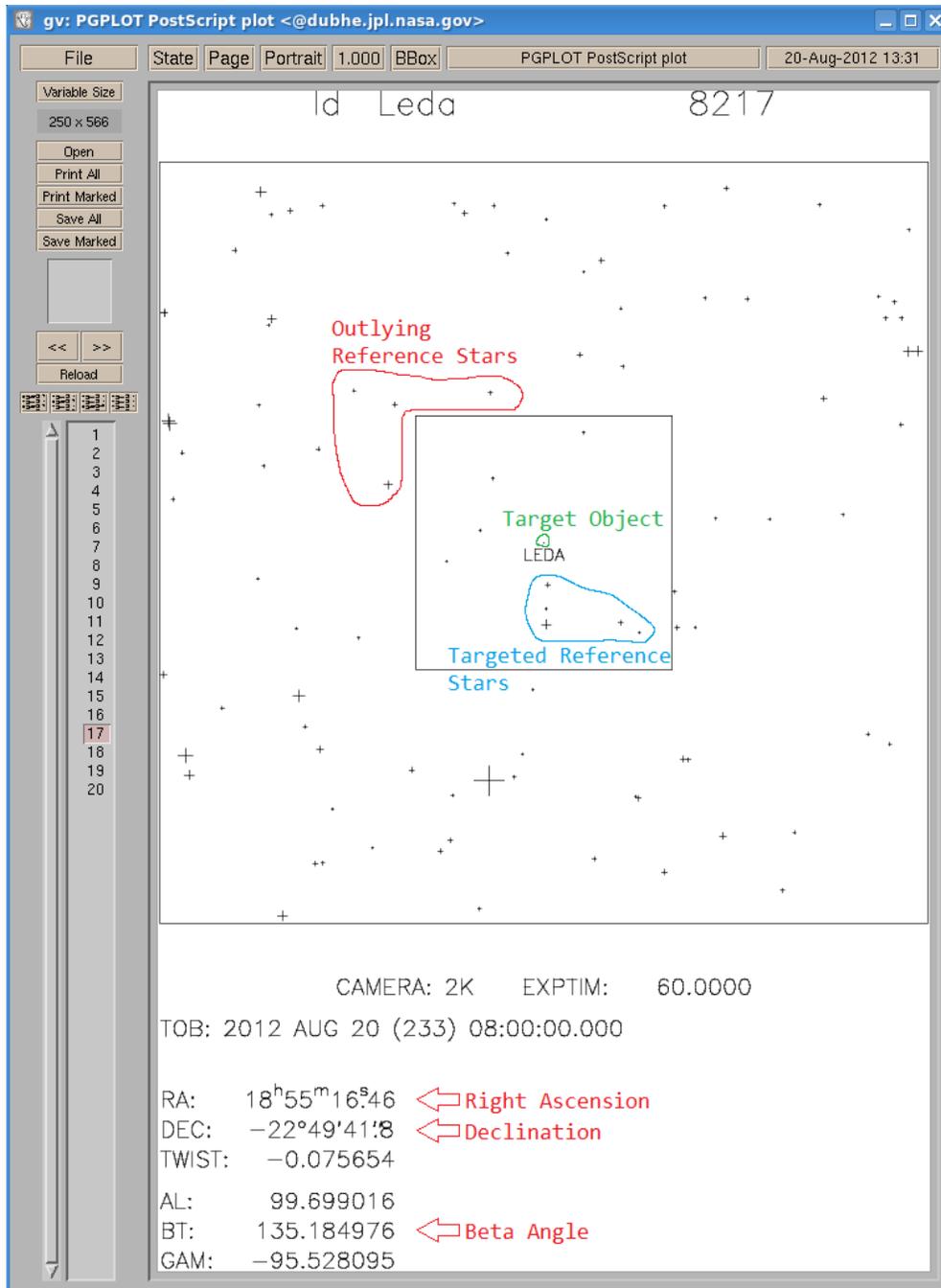


Figure 3: ghostview (gv) program

Once the “good” plots have been chosen, marked, and printed the observations for that night can begin.

Observing

The act of observing at JPL’s Table Mountain Facility known as TMO, begins with the 0.61m telescope. The telescope is referred to as such because of the primary mirror being 0.6m diameter. The steps required to begin a night of observing start with entering the observatory and turning off the air conditioner, which keeps the air inside the dome cooled to the same, or close to the same temperature as the ambient overnight temperature. Once the air unit is off, the telescope control programs are initiated, and depending upon the camera additional steps are taken.

The 4K-FLI CCD requires no outside cooling processes, the camera was designed for commercial use and therefore is equipped with a heat sink and cooling fans. The 2k CCD requires an ethylene glycol cooling system. Both the 2K and 4K-FLI cameras require a simple click of the mouse to turn their coolers on from the camera control program on the computer. The remainder of these procedures will follow the protocol for the 4K-FLI camera, as that was the unit used the majority of the nights.

The telescope control program (TCP) requires more than one software program, they are as follows: Dome client, Camera Focus Client, Position Client (Fig.4), Paddle Client, and TCP (Fig. 5) are all required to be initialized; before moving on the position client must be set to J2000 otherwise the telescope will track incorrectly. Once all of these control programs are running then the camera control software is initialized. The camera control software consists of a filter client program, shutter control program, and the main image processing program.

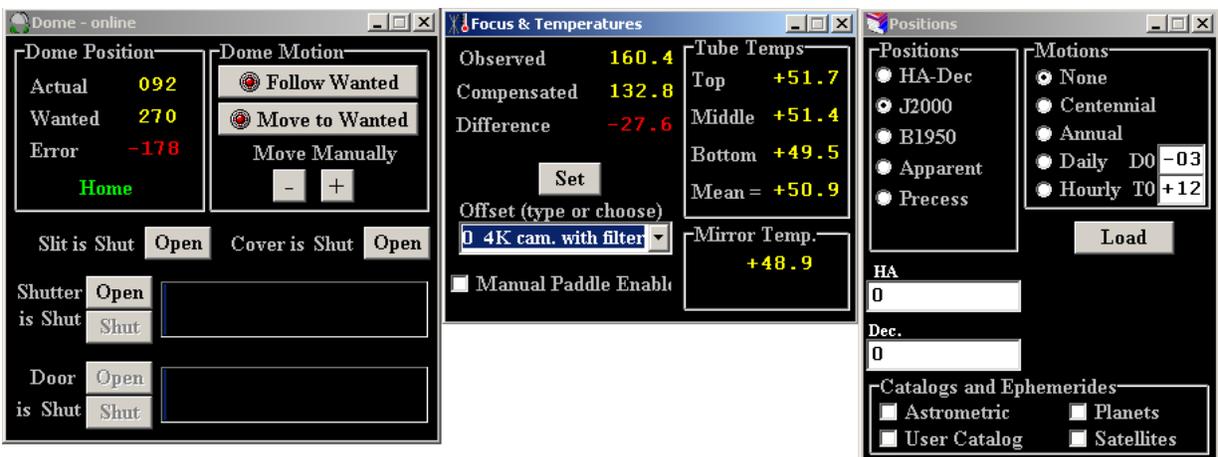


Figure 4: Dome, Focus, and Position clients

After all of the software and client programs are running, the telescope and camera need to be calibrated. To calibrate, there are just three simple steps, select a target star from the catalogue that is very near to the zenith, take a picture of the star with a short ten second exposure, and then calculate how far from center the star is in the picture and paddle the

telescope accordingly. The picture displays the position of the cursor in pixels and the paddle client moves the telescope in arc-seconds, so a conversion is necessary.

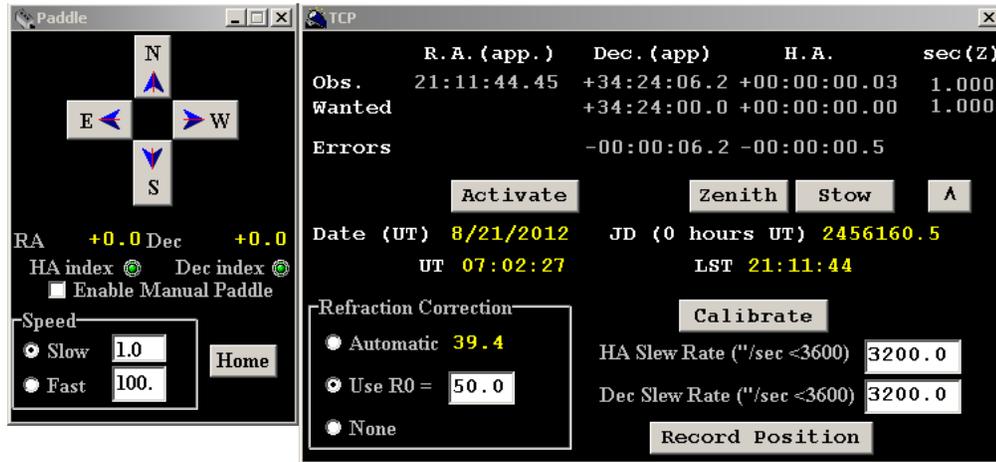


Figure 5: Paddle and TCP client

Focusing the camera comes from measurements of the calibration star, the smaller the diameter, the more in focus the picture. From experience it is found that the old 4K CCD used a focus setting of anywhere from 83 to 87, the 2K CCD uses a focus setting of 114, and the 4K-FLI CCD uses a focus setting of 73. This is the last step in preparing for a night of observations.

Once all of the preparations have been completed the observations can begin. Using the plots selected during the prediction process, and the LST, in order of increasing RA the plots are then put to use. Each picture of each target requires one log entry, where the target's name prefix and position are entered into a simple text document (pointYYDDD.txt) used later in the data reduction process. One time during the process of taking the series of pictures for each of the targets the temperature, barometer and humidity are also logged into a separate text document (tempYYDDD.txt) which is also used in the data reduction process. Moving the telescope to each target and the selected offsets (to create the photo mosaic) is done by entering the RA and Dec into the Position Client, and loading them to the TCP, where you have another chance to verify the have been entered correctly. Once the numbers are known to be correct, activating the TCP sends both the telescope and the dome to the correct corresponding positions for pictures to be taken. The exposure time for each of the targets is 120 seconds. The outer planets are far too bright for such a long exposure time, and exposures need to be adjusted accordingly. Each picture is processed as an image file which will be transferred to another computer for data reduction at the end of each night's observations. For each of the pictures the start time for every exposure is logged, in Universal Time, onto a paper observation log. Between three to five pictures are taken for each target this is done because multiple staggered pictures for each target helps ensure that the object is placed in the frame with different reference stars, which allows for more accurate measurements of the orbit and position of the object. At the end of the night the telescope and dome are reset to their home positions, and all of the pictures and point and temp files are transferred to the data reduction computer where the remainder of the work is completed.

This output from xrover, shows an example image taken with the 4K FLI CCD. The difference in the displays between the 4K-FLI the 2K and the old 4K, is that the 4K-FLI and 2K both shoot only one quadrant, whereas the old 4K used to shoot a four quadrant image. When completing the data reduction, if there is a reason to reset the center finding overlay, then the next step in the process after closing xrover is to run the “ctrpsf” script, which resolves any of the issues relating to center finding. Once the processes to correct center finding issues has completed, the files need to then be reduced one more time, using the, you guessed it, “reduce” script.

After any and all issues have been dealt with and the data is properly prepared, the “deliver” script is run which sends the data to specific parties that have requested our data. Harvard University and The Minor Planet Center are two of the major recipients. The last thing to do once the data has been delivered is to run a “cleanup” script that removes all non-essential files that are created and/or left over from the reduction process. Once completed the entire “nights” work is done, and everything is ready for the next shift of observations.

Results

Each night’s observation provides anywhere from 10 to 40 useable targets, there are often one or two images that are unusable because of either poor visibility due to a high SecZ angle, too bright of a target, or human error. Good results provide data showing the position over time across a reference background for each target asteroid. Almost every observation night our team was able to provide good data sets and images for updating ground tracks of occultations, adding to the optical navigation database and more.

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