**High Precision Asteroid Astrometry**

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**Abstract:**
High precision asteroid astrometry is the process in which exceedingly accurate positions of individual asteroids are determined from images taken of each asteroid within a star field. To successfully acquire highly precise coordinates for each asteroid three steps are necessary. The first of these steps is planning for observable targets based on a set of criteria. Planning requires the use of the Trajectory Geometry Program within the Optical Navigation Program to make predictions of the asteroid's location, PLTPSF to make plots, and Ghostview to look at the plots and print them. The second step is observing and taking images of each object with the 0.6 meter telescope and 4K CCD camera located at Table Mountain observatory. The camera consists of 4096x4096 pixels which allow for a wide, 21.9 arc minutes, field of view and 15µm pixels that allow for a high, 0.321arc seconds/pixel, image resolution. The third step involves using Xrover for picture registration of the images taken at Table Mountain Observatory, and the Automated Astrometric Data Analysis System for data reduction. The final results are then sent to the Minor Planet Center where they will be used for the navigation of future NASA missions.

**Introduction:**
Scientists at the Solar System Dynamic Group, Minor Planet Center and The International Occultation Timing Association use high precision astrometric measurements of satellites, planets and asteroids to improve models of their orbits. Their updated models more accurately predict the occultation of solar system objects and improve the navigation of missions to space. DAWN, a mission set to orbit Ceres and Vesta, used astrometric measurements of both asteroids to determine the orbital path to embark on. Producing accurate astrometric data is a process that involves planning, observing, and reducing data collected.

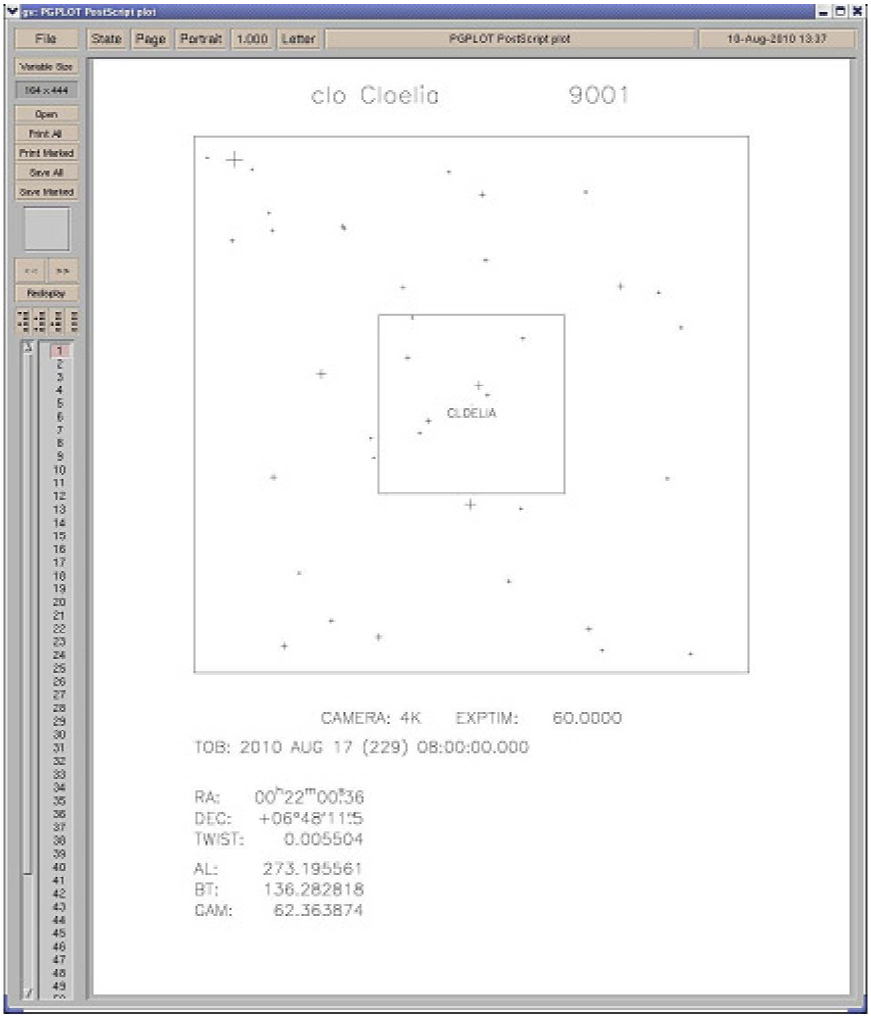
**Project method and procedures:**
*Planning*

Prediction files on the Trajectory Geometry program are available for both the outer planet satellites and for asteroids of $9^{th}$ to $15^{th}$ magnitude. Accessing these files gives an observer, based on a Right Ascension and Declination coordinate system, the expected location of an object for a specific night. Updating the files for a desired date of observing allows the observer to retrieve the predicted location of a target on that date. The PLTPSF program creates a finding plot for each target and the Ghostview program displays the finding chart in which the asteroid is located inside and at the center of a square which represents the field of view. The object is surrounded by reference stars that are useful for offsets.

A target is observable if it meets a set of criteria. The Right Ascension of a target should be close to local sidereal time when observing. Hour Angle is usually less than 2 hours for each target. If the target's Right ascension is too far from the local sidereal time, the airmass of the object is too high. High airmass reduces the visibility of the a target because too much air is being looked through in observing the target. In addition, the beta angle of an object must be more than 90°, the declination of each object must be north of -30° and it must be surrounded by reference stars that can be captured by offsets. Targets are filtered out if they do not satisfy all three requirements.

The finding charts for the selected targets are printed out. Offsets, usually 2, of 10-20 seconds on right ascension and 2-5 arc minutes on declination are calculated for each target.

Offsets capture additional reference stars that help locate the target in the field of stars it is in for a given night.




Cloelia, using the plot displayed by ghostview, was chosen as a target. It has Right Ascension that will be close to LST, Declination north of -30°, beta angle more than 90°, and has reference stars that are captured when offsets are calculated.

*Observing*

The 0.6 meter telescope, located at Table Mountain Observatory, and 4K CCD camera installed on the 0.6 meter telescope are used to observe and take images of the selected asteroid. The camera has 4096x4096 pixels which allow for a wide, 21.9 arc minutes, square field of view and 15µm pixels that allow for a high, 0.321arc seconds/pixel, image resolution.

During an observing run, data is collected for three consecutive nights. Each night the pointing of the telescope must be adjusted. A 1 second exposure of a standard star is taken to determine the amount and direction by which the telescope needs to be moved. If the pointing of the telescope is accurate the star will be displayed at the center of the image. The pointing is usually slightly off. The telescope is therefore slewed to and calibrated at the correct position. Furthermore, the sharpness and clarity of an image is dependent on the focus. To find the best focus for the 4K CCD camera a standard star is mosaicked. A series of 11 images of a standard star, each exposed for 10 seconds, are displayed within a larger image. The middle point between the two matching top and bottom points is the best focus because it is the sharpest and clearest point. In addition, cooling the camera is an important and necessary part of successful observing. At the beginning and end of each observing night, the dewar of the telescope is filled with liquid nitrogen. Liquid Nitrogen keeps the pixels on the CCD chip from getting excessively hot and increasing the noise in the images. Increased noise will decrease the certainty of our measurements because faint objects will become lost in the noise finding their (x,y) coordinates on the CCD camera will not be possible. The end results will therefore be less accurate.

Two images are taken of each asteroid, one for each offset, using the R filter. The coordinates are entered on the telescope interface and then loaded on to the telescope. Once activated the telescope slews in the direction of the asteroid and takes an exposure of it for 180 seconds. Once the exposure is complete the image is downloaded, saved as a file with the object's prefix and onto a directory corresponding to the observing date, and displayed on the camera computer screen through the program Monet. The coordinates for each offset and target prefix are saved onto a file. The barometric pressure, temperature, and humidity are recorded for the first exposure of the target and saved onto a file as well.

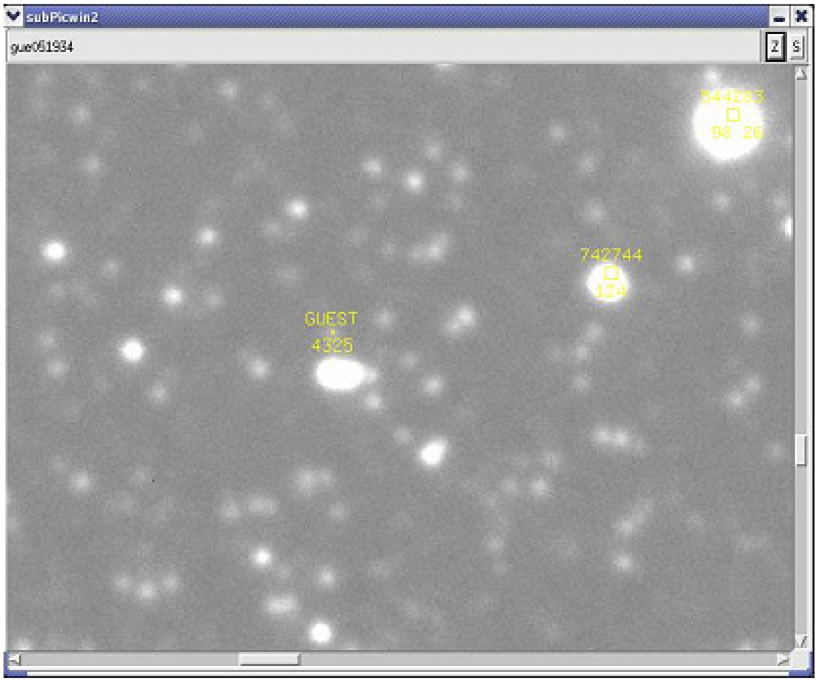
Five images of a calibration field are taken once during each observing night to solve for the difference between the ideal projection and the observed location of the image. By taking 5 images of the calibration field, a dense region of stars, using five different offsets, it is possible to see how that difference changes. This is necessary for targets that are not located in dense field of stars. The results taken from the calibration field, once the data is reduced, are incorporated with the solutions of the targets. Globular cluster M13 and IC4756 were used as calibration fields.

The image files are transferred from the 4K camera computer onto Nekkar, the computer located at TMO that we can access from our JPL computers in order to reduce the data collected. On Nekkar, the *doit* script is run once each observing night is complete. *Doit* reformats the images, creates input files for amp using the temp file created during observing, centroids the objects in the images using the point file created while observing, puts the telescope pointing into the schedule PSFs, and reduces the data.

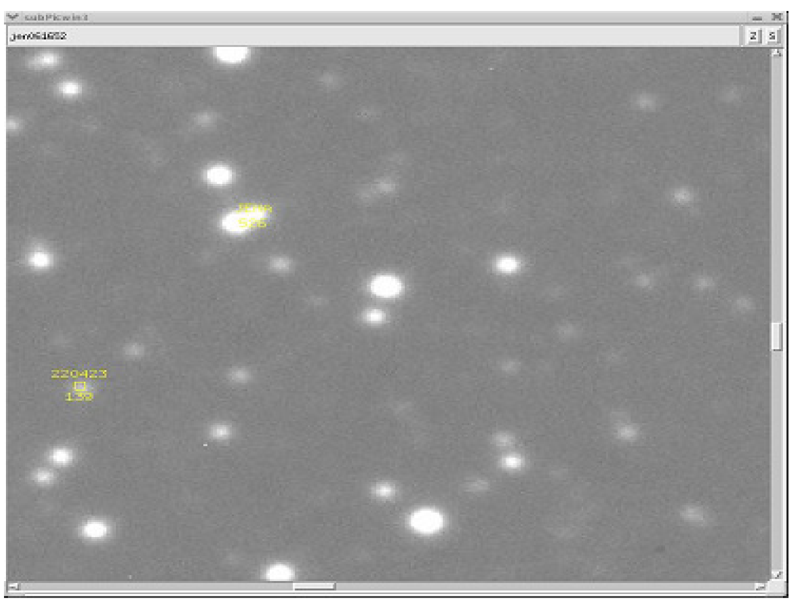
*Data Reduction*

The Automated Astrometric Data Analysis System is used for reducing data. Faint targets and targets with bad residuals require special attention. Bad Residuals arise from several possibilities. Double stars are sometimes misidentified as the same star, weak stars often times have bad measurements, and another asteroids could be present aside from the intended target. To correct or delete bad residuals, the report file is accessed on Nekkar and using Emacs the necessary changes are made. The initial attempt at centroiding very faint objects usually fails. Running the script *check*, matches the number of targets expected and the number of images taken with the number of targets captured in the images. Faint object are mismatched because centroiding is unable to located the faint object in either one or both of the images. To fix this problem, using Xrover, overlays of catalogued stars and of the asteroid are drawn over the images of the stars and over the faint object. The image is stretched and the target zoomed into. The overlays of the stars are shifted to the accurate position and the overlay of the asteroid is placed as close as possible to the center of the asteroid. The script *ctrpsf* locates the center of the faint asteroid once its image is registered on Xrover. Using Emacs, the file that contains the final pointing for all catalogued objects in the image is updated; the coordinates of the asteroid is kept and the excess data removed. The data is then reduced.

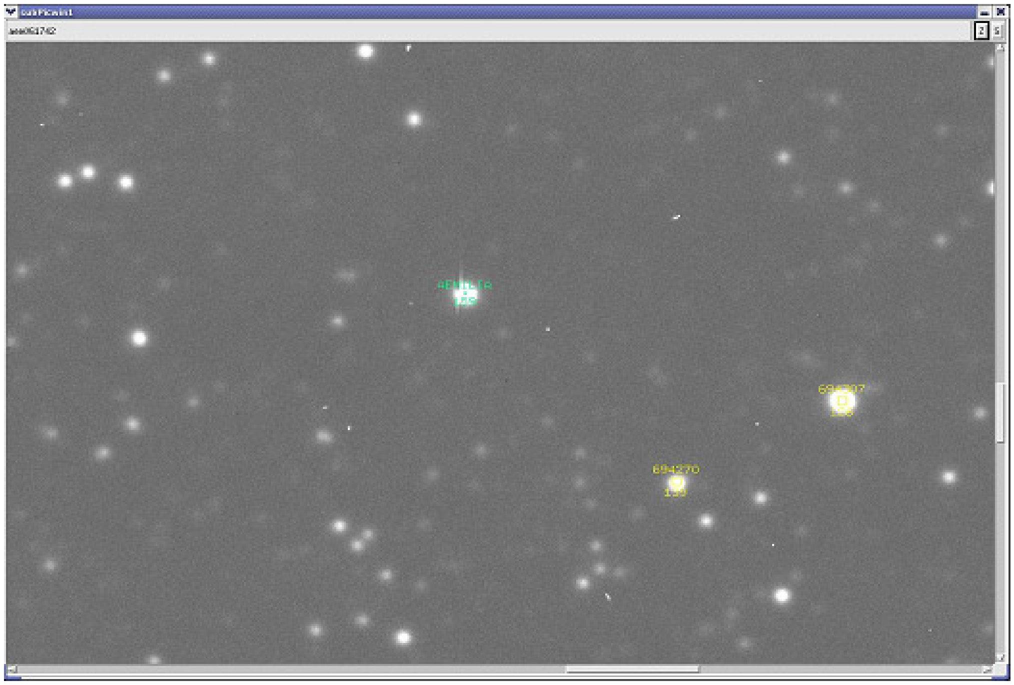
**Results:**
On average, 2-4 targets for each night are unable to be registered using Xrover for one or both of the images taken of the asteroid. The targets are either too faint, too close to another object, or are located in problem areas of the 4K CCD camera. The images of targets that are uncentroidable are deleted and the final coordinate for the target is based on the image where centroiding was possible.




The asteroid Guest is located in a dense field of stars. It is located near a brighter object. For objects this faint centroiding is not possible.




The asteroid Jena is located too close to another object. Centroiding will fail for objects that are too close to each other.



The Asteroid Aemilia lay over a defective part of the 4K CCD camera. There is a pixel shift in the fourth quadrant of the camera. For any object that lays on or near this shift centroiding will fail.

Each night of data collecting has its own final results. Running the script *deliver* concatenates the output summary files, sticks header information and writes the file that will be delivered to the Minor Planet Center and the International Occultation Timing Association. The final results are also put into a large database where they can be accessed by scientists of the Solar System Dynamic Group. The final file is a list of the final coordinates for each of the targets observed on a given night.

After 14 nights of observing, 123 different targets were observed, including Neptune, Triton and Nereid, 3 outer satellites of Jupiter, Pluto, 7 satellites of Saturn and 109 different asteroids. In total, 867 observations were reported.

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