High Precision Astrometry of Occultation Asteroids

Sarah Estabrook, Victor Valley College
Mentor: Dr. William M. Owen, Jr., JPL
Advisor: Michael Butros, Victor Valley College

ABSTRACT

Using the 0.6-m telescope located at Table Mountain Observatory, our team collects data on occultation asteroids—bodies which pass in front of stars and block their light for a brief moment. Observations of occultations are useful for calculating an asteroid’s mass and size, but the events are rare and require highly precise knowledge of the object’s location in order to derive the time of occultation. The observations made by our team determine precisely where the asteroid is and can be used to predict the locations and times of occultations. This data can further be used in spacecraft navigation by allowing a craft to image objects in its vicinity and compare them to our own images. This provides an accurate and efficient method of locating a spacecraft. Our team is also interested in collecting data on other various objects in our solar system including Uranus, Neptune, Pluto and their satellites. We then execute a series of LINUX-based commands to reduce our collected data into right ascension and declination coordinates that can then be used by astronomers to update orbital information.

INTRODUCTION

Astrometry is the science of precisely locating celestial bodies in order to derive useful information regarding these bodies. Calculations made on an asteroid’s location are subject to a cumulating error of possibly just a few milliarcseconds per year. This seemingly small error, however, is enough to cause significant differences in object location over time. An asteroid occultation is an event during which an asteroid passes in front of a star and blocks its light for a brief period of time. In order to observe this rare phenomenon, an astronomer must know exactly when it will occur which requires highly precise data on the asteroid’s position.

Information regarding the position of celestial bodies is also used to a large extent in spacecraft navigation. The NEAR Shoemaker (Near Earth Asteroid Rendezvous) mission to the asteroid Eros was one of the first missions that inspired our project as it involved collecting data on background stars and asteroids for use in navigating and calculating corrections in the craft’s trajectory.

Our team is specifically interested in collecting data that will aide in refining the predictions of cataloged occultations. We record highly precise coordinates that can be applied to updating orbital information and used in optical navigation. Additionally, we collect data on the outer planets and bodies (Jupiter, Saturn, Uranus, Neptune and Pluto) and their satellites. Our task consists of three main components: prediction, collection, reduction. From there our data, along with data collected from professional and amateur astronomers, is collected and reported to the International Occultation Timing Association (IOTA), the Minor Planet Center (MPC), the Jet Propulsion Laboratory (JPL) and other similar organizations. The asteroid’s position and velocity can then be updated.
Our team conducts its observations using the 0.6 m Ritchey Chrétien telescope located at JPL’s Table Mountain Observatory (TMO) in Wrightwood, California. There are two types of charge-coupled device (CCD) cameras at our disposal: a two-thousand by two-thousand pixel or a four-thousand by four-thousand pixel camera (2K and 4K respectively). The 2K camera has one-fourth the viewing area of the 4K and is primarily utilized only when the 4K is malfunctioning. Both cameras require cooling to keep the images from appearing lighter due to unwanted, energetic electrons raised into the conduction band of the camera because of excess heat. The 2K camera has a self-regulating apparatus which provides it with ethylene glycol and requires little maintenance on our behalf. The 4K camera requires a much colder environment and must be filled with liquid nitrogen (LN₂ ≈ -200°C). Each member of our team must be certified to handle LN₂ and the camera must be refilled approximately half way through the night to ensure constant image quality.

Method

The predictions of the locations of our targets for the night are made through a computer which can calculate the three-dimensional vector distance from our observing location to the target. We use Linux-based commands to request the predictions and must then determine which targets are suitable and possible. Depending on the time of the year and the camera we are using, we can have fifteen to sixty targets in one night. Every target has a predicted right ascension and declination. These locating coordinates are measured in hours, arcminutes and arcseconds for right ascension, and degrees, minutes and seconds for declination. Both are used as though the stars are projected on the inside of a sphere around the earth. Right ascension is analogous to longitude on the earth and declination is analogous to latitude. The targets are arranged in order of the time they will appear in the sky—their right ascension. There are three main criteria on which we determine which targets are suitable.

Along with the predicted right ascension and declination values, the computer is also able to predict numerous other data about our target. One value of interest is known as the beta angle, which is the angle between the sun and our target. If this value is below 90° the object will be obscured by the sun’s brightness and we cannot image it. If an object is too far south the telescope will also not be able to see it. This is represented when the object’s declination is less than -30°. Finally, we must determine that there are adequate background stars within range of the target. The stars in the background serve as a reference for determining an object’s relative position. The figures shown below are typical prediction charts used to calculate offsets and determine the location of a target.
Figure 1.1 a: Although the beta angle and declination meet the minimum requirements, there are few background stars on which to reference the image.

Figure 1.1 b: The beta angle and declination are appropriate, however in this image there are many more background stars.

The inner square on the figures shown above is a prediction of what can be seen through the telescope’s camera, however, we want a picture that includes as many reference stars as possible and ensures that the target is not obscured by the boundaries between quadrants of the 4K camera. To do this, we add or subtract a few seconds to the right ascension and add or subtract a few arcminutes to the declination. Depending on which camera we are using and how many reference stars are present, we will calculate differing numbers of offsets. For a target like Henrietta (Figure 1.1 a) we would calculate more offsets than for a target like Gertrude (Figure 1.1 b). Further, with the 2K’s smaller field of view, we must calculate four to five offsets whereas we would only calculate two to three using the 4K.

The right ascension value corresponds to the local sidereal time (LST)—a method of keeping time relative to the motion of the earth’s rotation with respect to the stars. Gertrude (Figure 1.1 b) has a right ascension of 19^h 44^m 03.07s. At this time LST the object will be at the highest point in the earth’s atmosphere. When the atmosphere is thinnest it is an optimal time to take the image as there will be fewest residuals. However, this process is not exact and the image can be taken anytime plus or minus one and a half hours LST of the right ascension.

The viewing dome and telescope shutter are controlled through a computer located in a room adjacent to the dome. Regardless of the camera we use, it must be centered and focused. The focusing and center finding for the 2K camera is done through visual estimation. The
estimations are confirmed with a test shot. The 4K requires a more complex process. We begin with a test shot for center finding. If the target star is offset from the center of the image the telescope is manually adjusted based on a calculation of how far off center the star is. Another test shot is taken to ensure accuracy. We must then perform a series of images known as a mosaic to focus the camera. One star is imaged multiple times with a low exposure time, usually about ten seconds. Each time the telescope is manually moved a constant amount. The collection of images is then viewed as one which allows us to pick the most focused setting—whichever one gives the sharpest-looking star. These results vary each night. The 4K camera controls and telescope controls are located on separate computers while the 2K camera controls are on the same computer as the telescope controls.

The right ascension and declination coordinates are entered into the telescope when we are ready to begin observations. Once the telescope locates an object, the dome and the telescope follow it as it travels the sky. We use an exposure time of 180 seconds for the 4K camera and 90 seconds for the 2K. Every offset calculated for each target must be recorded as a text file as well as in the observer’s log. The text file which contains the target coordinates is known as a point file and the year and day of the year on which the images were taken is recorded in the file name. For observations made on the 219th day of the year of 2012, the point file would be named “point12219.txt.” This file must be without error as it is required for the data reduction. During the course of the multiple images per target, at least one must include the temperature, pressure and humidity of the environment at the time the target was exposed. This data is also recorded in the log and in a text file, which is named “tempYYDDD.txt,” similar to the point file. Both files will later be used in the reduction. If necessary, we may need to make adjustments based on any of these environmental factors. When we are finished we enter the right ascension and declination coordinates of the next target, provided the right ascension is within plus or minus one and a half hours LST, and we continue this process until we have imaged every target or the sun rises.

At the end of the night all the data is transferred to the network computers, including Nekkar—a computer located in the main building of TMO. We must then run a custom series of Linux-based commands written by Dr. William Owen, Jr. of JPL. The main command is called “doit.” This script, under perfect circumstances, will reformat the images, find the center of each object and reduce the data into pure right ascension and declination coordinates. However, the software cannot distinguish very well a single star from a double star. Nor can it always separate a planet from its satellite. Also, if there is an error in the temperature or point text files mentioned earlier the software will not be able to run the doit script and the adjustments must be made manually by our team or our mentor. Another important script is the deliver command. This process puts all the data into a standard and simple form that is sent to the International Occultation Timing Association and the Minor Planet Center.

APPLICATION

Once the data is reduced, IOTA and MPC can use it to update the orbital information for the targets we provided. These are meant to aide in future observation of occultations. The images and coordinates we provide are also useful in navigation. JPL engineers have been able to utilize similar data collected from astronomers around the world for use on missions such as NEAR Shoemaker, Cassini and, more specific to our project, New Horizons.
A spacecraft has several options for navigation. When the craft is primarily located within the asteroid belt it is more feasible to use a method of navigation such as differenced Doppler shift. This technique requires the craft to measure differences in radio frequency sent from two distant positions on earth. The craft’s three-dimensional position in space can then be extrapolated. Although radio frequencies travel at light speed, when the craft is traveling outside the asteroid belt even this amount of time becomes too great and many errors can be made in the time it takes a radio wave to travel from earth to the craft and back. Optical navigation, sometimes known as OpNav, utilizes a camera on the craft to take pictures of its destination or another nearby body against reference stars. These reference stars are well known through the contributions of our team, the interns before us, and numerous professional and amateur astronomers. The craft can then determine its position and calculate any necessary adjustments to its trajectory. Our team is primarily concerned with imaging Pluto and its satellite Charon to collect data to be used with New Horizons, the craft scheduled to reach Pluto in 2015. Similar projects, such as Cassini, image background stars with Saturn’s satellites to make orbital corrections.

Figure 1.2: Saturn’s rings as seen by Cassini. Behind them is Enceladus, one of Saturn’s many satellites
ACKNOWLEDGEMENTS

This project was possible through a grant from the National Science Foundation, grant number 0852088. Special thanks to my mentor Dr. Bill Owen and my physics instructor Michael Butros. Thanks to Paul McCudden, LACC; Richard F. Alvidrez, JPL; Heath Rhoades, JPL TMO; Milan Mijic, CSULA; and the entire staff at Table Mountain Observatory.