Commissioning and Integration of the Asteroid Large aperture PHotometry exoplAnet transit (ALPHA) Observatory

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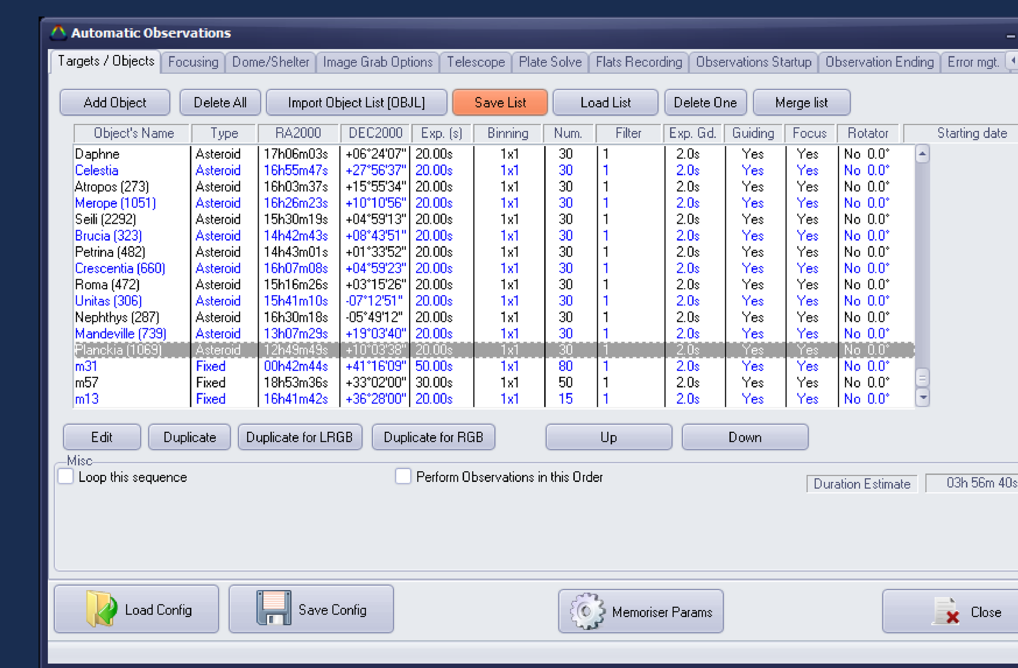
Introduction

The purpose of this project was to commission an observatory at Capitol Technology University (CTU) to track, identify, and perform orbit determinations on near-Earth objects (NEOs) such as asteroids and comets. (Figure 1) Over the commissioning process, the observatory dome, cameras, and telescope were assembled and configured to move synchronously. The associated software was configured with them to automatically make observations according to designed plans (Figure 2), making the process of collecting data simpler and more accurate than if done manually. Additionally, observations could be monitored and control administered remotely via AnyDesk. Each component was calibrated to ensure proper tracking, alignment, guiding, and focus.

Upon completion of commissioning activities, various observations were made, including 17 unique NEOs. The sensitivity of the system allows objects as faint as 17th magnitude to be detected. Each set of data was processed to account for noise and to identify and track the object(s) captured, then submitted in a report to the Minor Planet Center (MPC). (Figure 4) After making several successful reports, the MPC awarded the ALPHA Observatory its own code, W58.



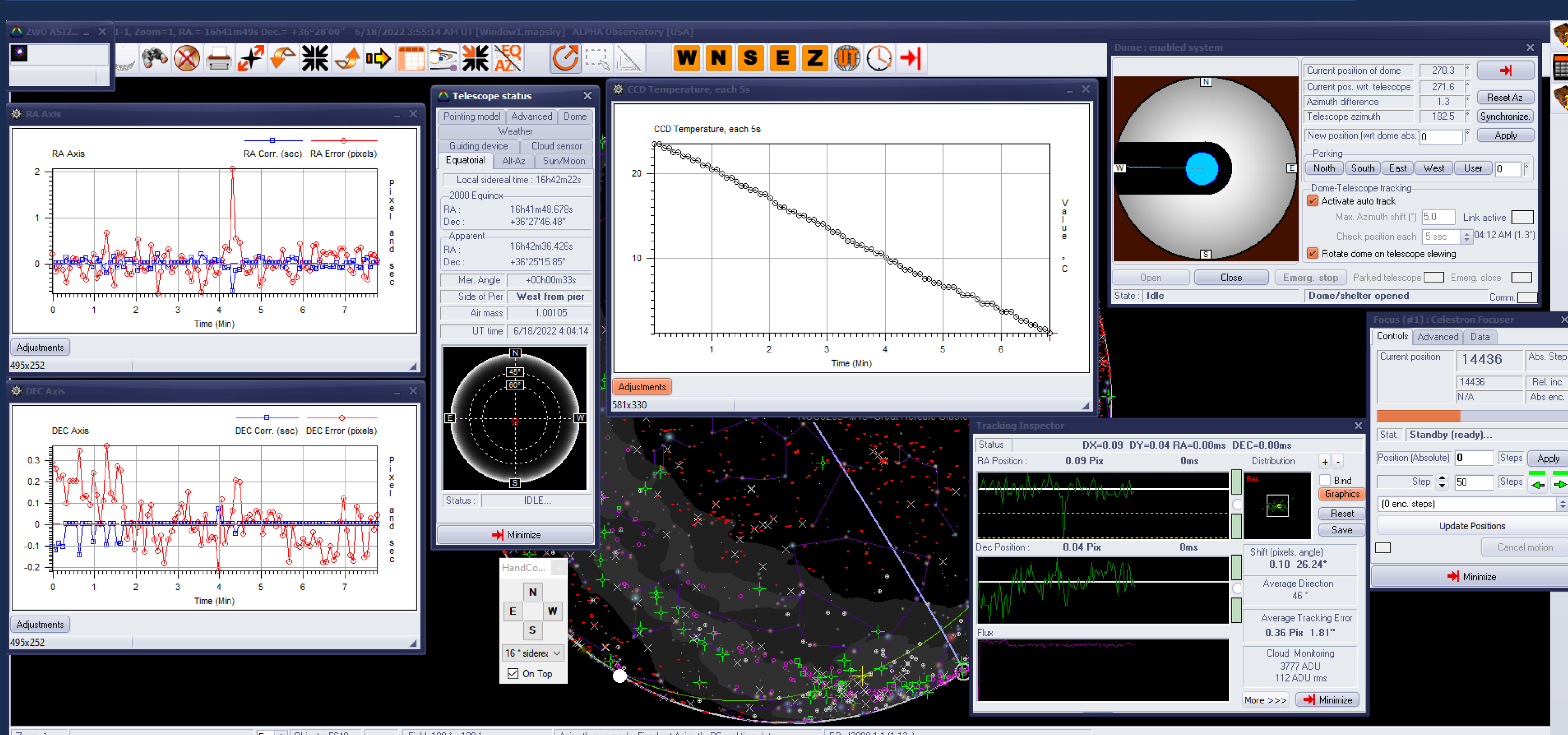


Figure 1: (above) The ALPHA Observatory.

Figure 2: (top right) A list of objects to automatically be observed. Note that not all objects were captured on this run, as enough were added such that the program could determine which could be captured over the course of the night.

Figure 3: (left) The PRISM dashboard, showing the dome status, telescope status, telescope hand control, CCD temperature of the main camera, and error tracking post observation.

Figure 4: (below) An example of the data sent in an MPC report. The number on the left (148) is the object's designation, which corresponds to the asteroid Gallia. The date, location, magnitude, and observatory code are also given.

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00148         KC2022 07 20.22389 17 49 04.98 +04 03 13.3          12.1 V      W58
00148         KC2022 07 20.23773 17 49 04.44 +04 03 05.9          12.3 V      W58
00148         KC2022 07 20.25074 17 49 03.94 +04 02 58.9          12.5 V      W58
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System Overview

Equipment:
- NexDome Observatory
- 11" Schmidt-Cassegrain Celestron telescope on a CGX-L Mount
- ZWO ASI1600mm Pro Monochrome (Main Camera)
- ZWO ASI1290mm Mini Monochrome (Guiding Camera)
- Pegasus Astro USB Control Hub (UCH)
- PrimaLuceLab 60mm Compact Guide Scope
- Dew heaters
- Dew Shield
- Focuser
- Weather Station

Software:
- ASCOM Platform
- PRISM (see Figure 3)
- NexDome Beaver Dome Controller
- Tycho
- SharpCap
- Celestron PEC tool
- ASI Studio
- FreeFlyer
- Anydesk

Functionality:

The ASCOM platform interfaces between the hardware and software, allowing them to communicate. Beaver controls and reads the status of the dome's motor and weather station. The weather station can send a signal to Beaver to close the dome's shutter, so the equipment is not ruined by surprise rain. PRISM interfaces with the telescope and its components, as coordinates them with the dome. The Pegasus device hub allows for control of each of the smaller components. (Figure 13)

Calibration:

The calibration process involves taking dark, bias, and flat frames and using them to remove noises from images. Bias and dark frames are images of the camera's readout noise, with biases being for any exposure and darks being for noise produced at various exposures. Flat frames are taken the night of an observation to account for vignetting and dust on the lens.

Data Generated:

A typical night generated about 25 GB of data, though not all of it was of usable quality, due to clouds or an insufficient numbers of images captured in a night. The total amount of data used was 82.18 GB.

Near-Earth Objects

It is important to track and find NEOs, both because of the potential danger they pose to space missions and the Earth, and because they offer a vast potential for research. After calibrating an image taken of a NEO, PRISM can plate solve it and locate known NEOs within frame, even if they are too faint in the image to see. Figure 5 show just how many known NEOs can be seen in a single wide-frame shot. PRISM scripts were created to accomplish time-consuming preprocessing, such as calibration, alignment, subtraction, and plate solving. Pre-processed files can be sent to Tycho for object tracking (Figure 6). This program plate solves the images and identifies moving objects, then compares them to known object locations. This process allows for new objects to be found as well. Fast-moving objects, such as the comet C/2017 K2 (PanSTARRS) can be made into a composite image using PRISM's stacking feature (Figure 7). The blur in the background shows that it was moving quickly. All successfully imaged NEOs were mapped by right-ascension (RA) in hours and declination (Dec) in degrees (Figure 8). One target, the asteroid Daphne, was observed for enough nights to estimate its orbit. Its orbit was modeled in FreeFlyer (Figure 9) using the data collected. Due to the relatively small number of nights that it was observed and the sub-optimal sky conditions, this model does not exactly match Daphne's real orbit. While the calculated orbital period only matches 80% of the real period, additional observations will enable ALPHA to refine the orbit.

Figure 7: (left) A composite picture of the comet C/2017 K2 (PanSTARRS).

Figure 5: A starfield captured by ALPHA of asteroid Reid (in the center, obscured by another label), overlayed by PRISM with labels for known NEOs in frame.

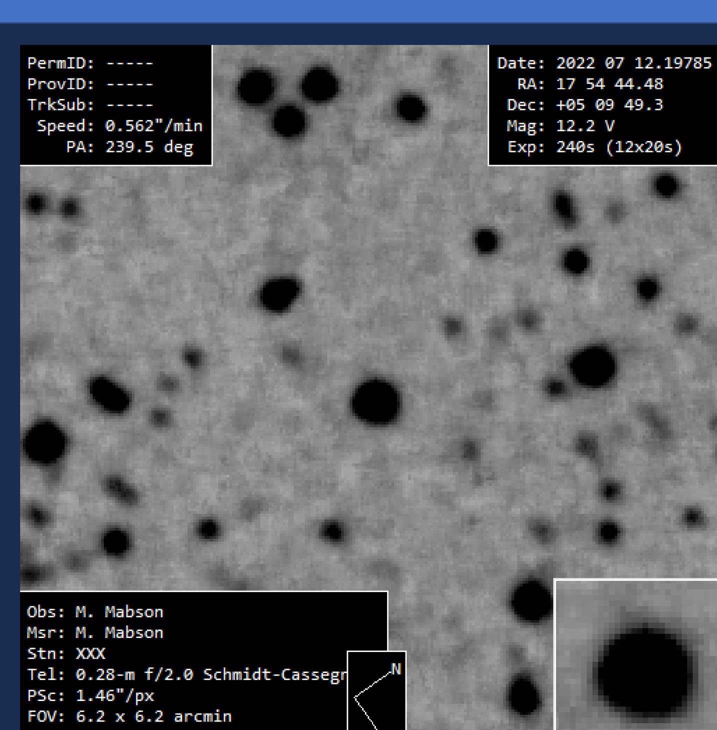


Figure 6: A calibrated photo of the asteroid Gallia, in Tycho's object tracker.

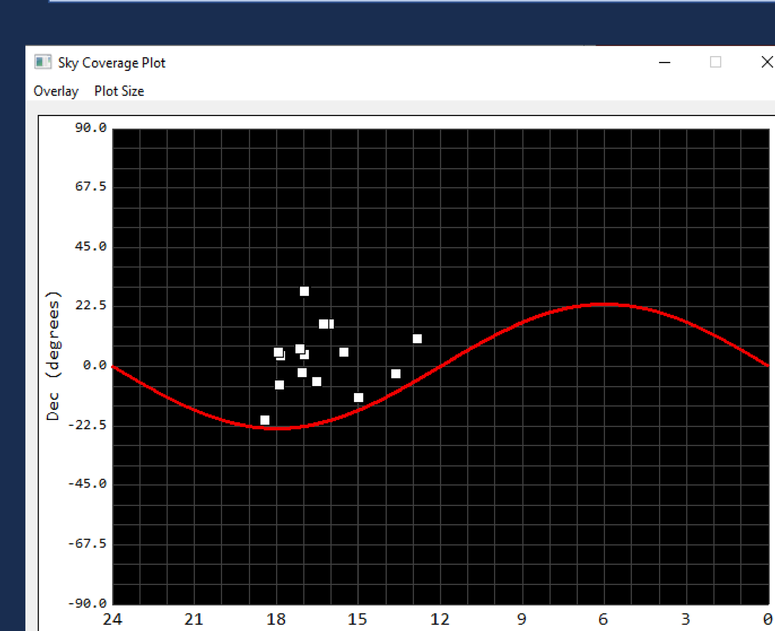


Figure 8: (above) The locations of each of the NEOs successfully imaged. The red line is the ecliptic of the solar system.

Figure 13: (right) Flowchart of how the system is organized. ASCOM allows the components to work together, PRISM and Beaver are the software running them, and the mount and Pegasus allow for control of other equipment.

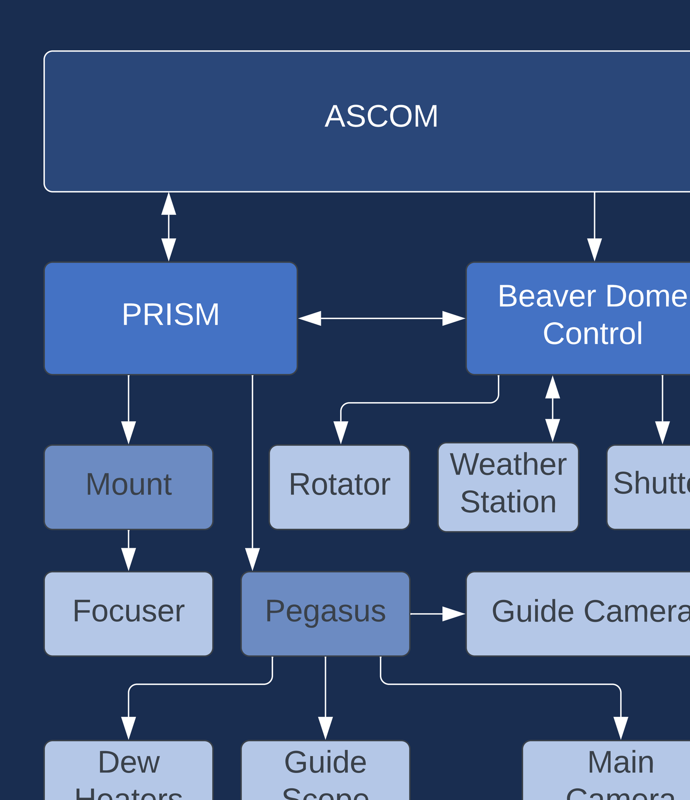
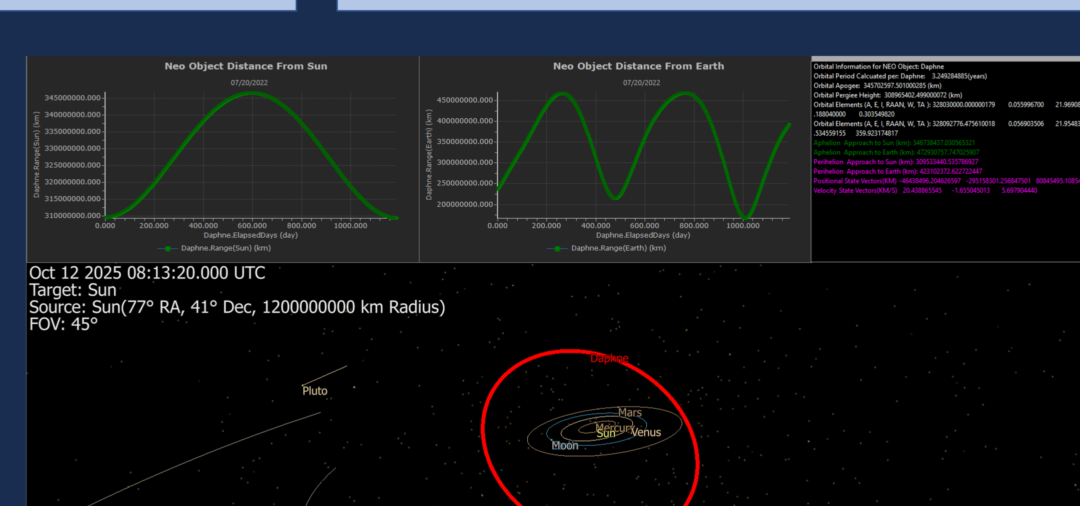


Figure 9: (left) Visualization of the orbit of Daphne, determined by FreeFlyer using data analyzed in Tycho's find orbit function.



First Light Observations

To validate the observatory's systems, such as automatic observations, automated focus routines, tracking, and dome synchronization, ALPHA captured the following images. The moon image (Figure 10) was taken using SharpCap to ensure it was in focus, showing a great amount of detail. Images were also made of the Hercules Globular Cluster, M13 (Figure 11), and the open star cluster, NGC457 (Figure 12), which were imaged through PRISM similar to NEOs, but with more images taken over longer exposure times. These images were then calibrated and stacked into the results shown here.

Figure 10: The moon, imaged early the morning of June 15, 2022, the first night of ALPHA's operation.

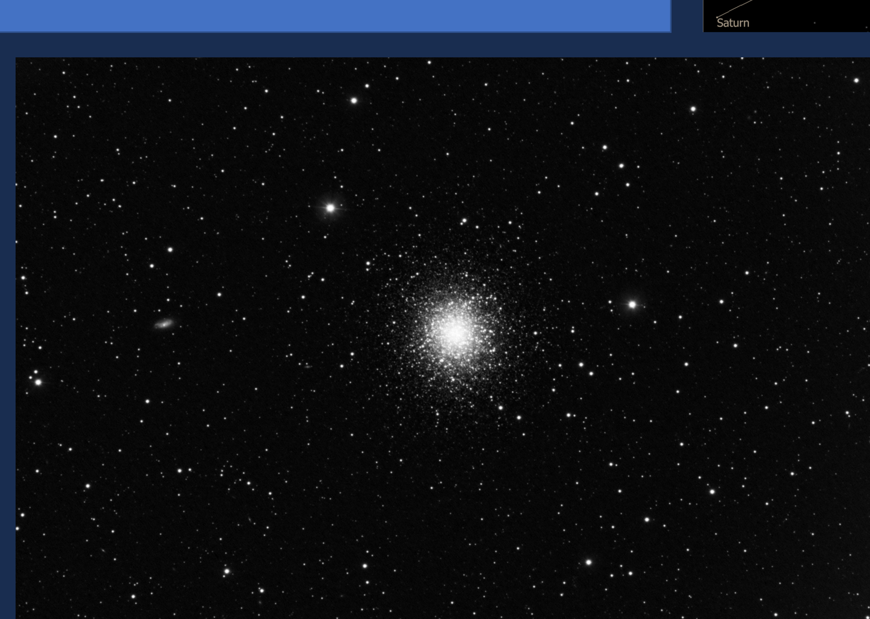


Figure 11: M13, the Hercules Globular Cluster. Imaged July 23, 2022.

Figure 12: NGC457, an open cluster in Cassiopeia. Imaged July 19, 2022.

Challenges and Lessons Learned

Over the duration of this project, many challenges arose: shipping times were delayed, some equipment needed replacement or mending, and there were software and hardware issues throughout. These issues have taught me to have patience and to plan for things to go wrong every step of the way. Luckily, each problem that came up could be solved, and sufficient data could be collected, though not as much as originally intended. I learned much about astronomy and how it is used to determine orbits, and gained a greater awareness of the scope of our solar system and deep space.

Overall, the project was a success: there is a now a functioning observatory at CTU, and it has been used to collect meaningful data on a variety of near-Earth and deep sky objects.

Acknowledgements

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