‘Opihi Observing Manual

Revision #	Author(s)	Date	Comment
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1. Introduction

‘Opihi is a 0.43 meter wide-angle finder scope mounted to the IRTF. Four SDSS filters (g’, r’, i’, z’) and a clear position are available. A summary of ‘Opihi’s parameters are given in Table 1 and the filter wheel positions are given in Table 2.

‘Opihi can be used concurrently with other instruments on the IRTF. The primary use case of ‘Opihi is to recover the locations of newly discovered near-Earth objects (NEOs) with large uncertainties in ephemeris in order to perform follow up observations with the IRTF’s infrared spectrograph (SpeX). ‘Opihi can also be used for absolute spectral flux calibration as the i’ and z’ filters overlap with the 0.7-2.5 μm spectral modes of SpeX.

‘Opihi runs independently of facility instruments and is also capable of monitoring atmospheric extinction. A cover keeps ‘Opihi closed during the day as it is not intended for daytime observing.

The purpose of this document is to serve as an observing manual for ‘Opihi. We assume that the user is already familiar with the XUI and DV. For more information, please refer to the observing manuals for SpeX[1] and MORIS.[2]

[1] http://irtfweb.ifa.hawaii.edu/~spex/observer/
[2] http://irtfweb.ifa.hawaii.edu/~moris/user/

Table 1: Summary of instrument characteristics.

‘Opihi	
Diameter	0.43 m
Field of View	32’
Pixel Scale	0.94”/pixel
Filters	g’, r’, i’, z’, clear
Detector (CCD)	
Bandpass (FWHM)	360 - 970 nm
Number of Pixels	2048 x 2048
Operating Temperature	-50°C
Dark Current	1 e-/s
Read Noise	41.2 e- rms at 5 MHz (default) 10.3 e- rms at 1 MHz
Gain	6.9 e-/DN at 5 MHz (default) 4.0 e-/DN at 1 MHz
Well Depth	128,245 e-

Table 2: Filter wheel positions. The software position number is currently offset from the actual filter wheel position.

Position #	**FIlter**	**Description**
0	block	An opaque plate that can be used for darks
1	open	Do not use
2	open	Do not use
3	z'	
4	i'	
5	r'	
6	g'	
7	clear	Clear over the bandpass

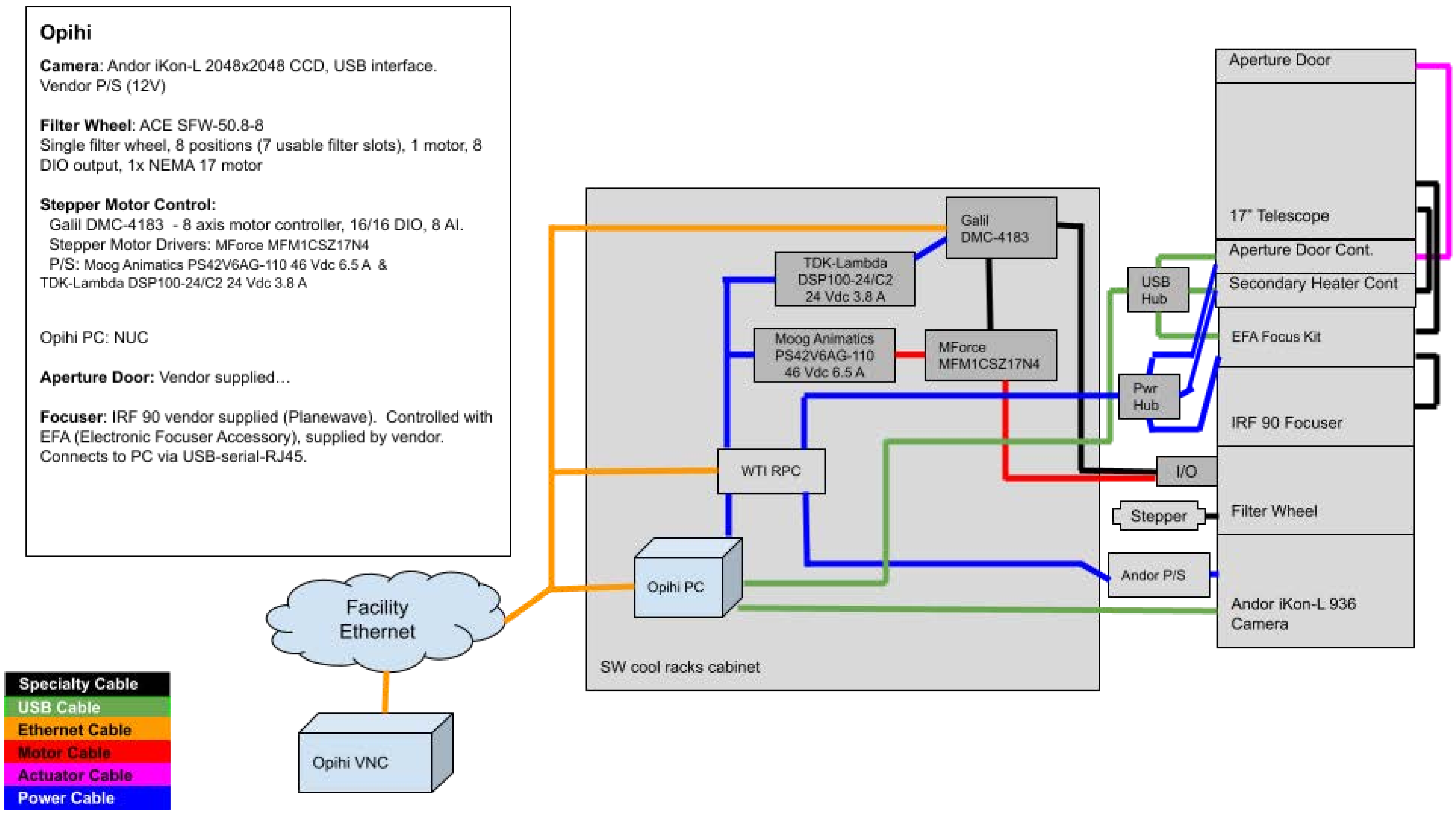


Figure 1: A block diagram of 'Opihi's major electronic components.

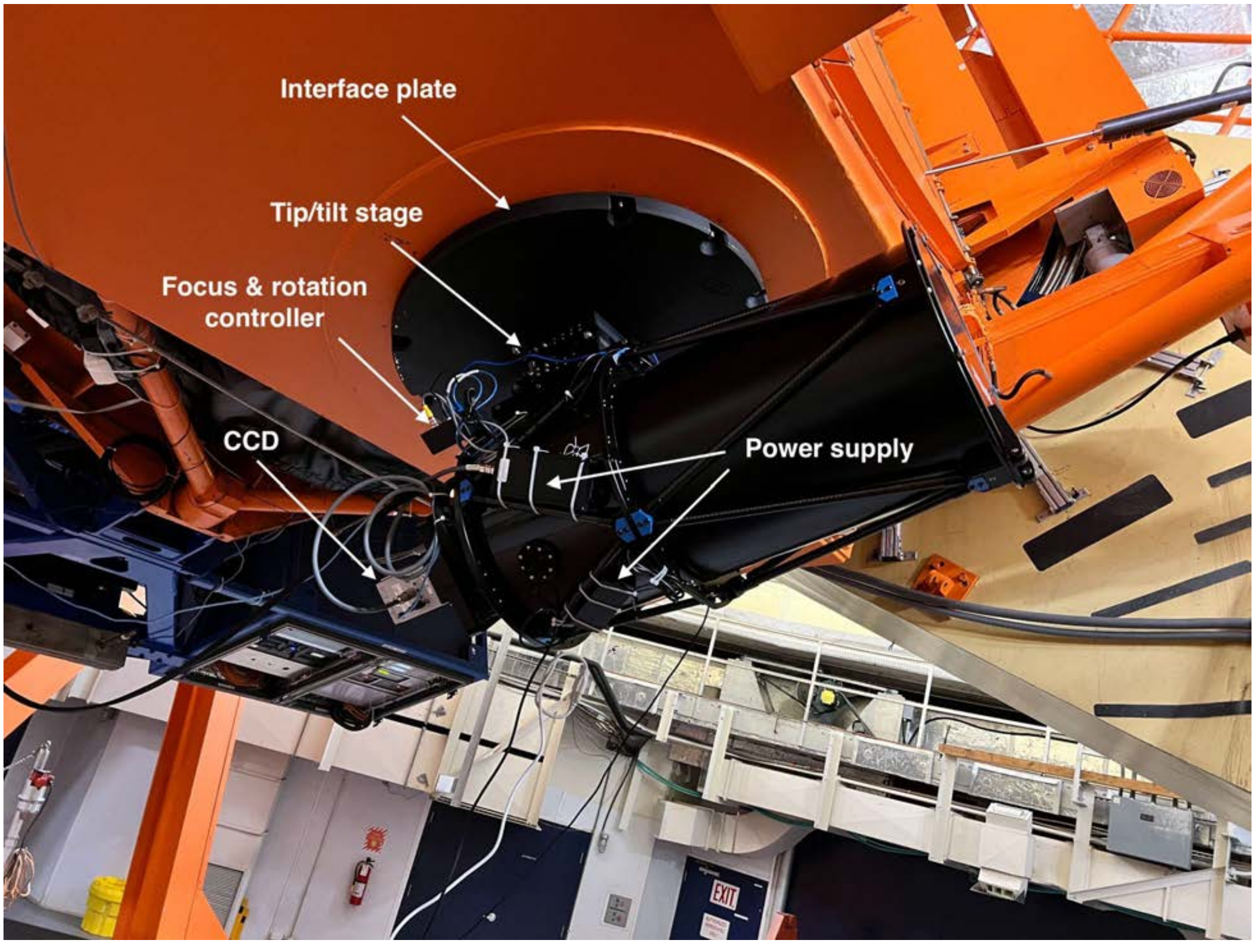


Figure 2: An image of ‘Opihi mounted to IRTF. The protective outer shell is not pictured.

2. Initialization

2.1 Opening the Software

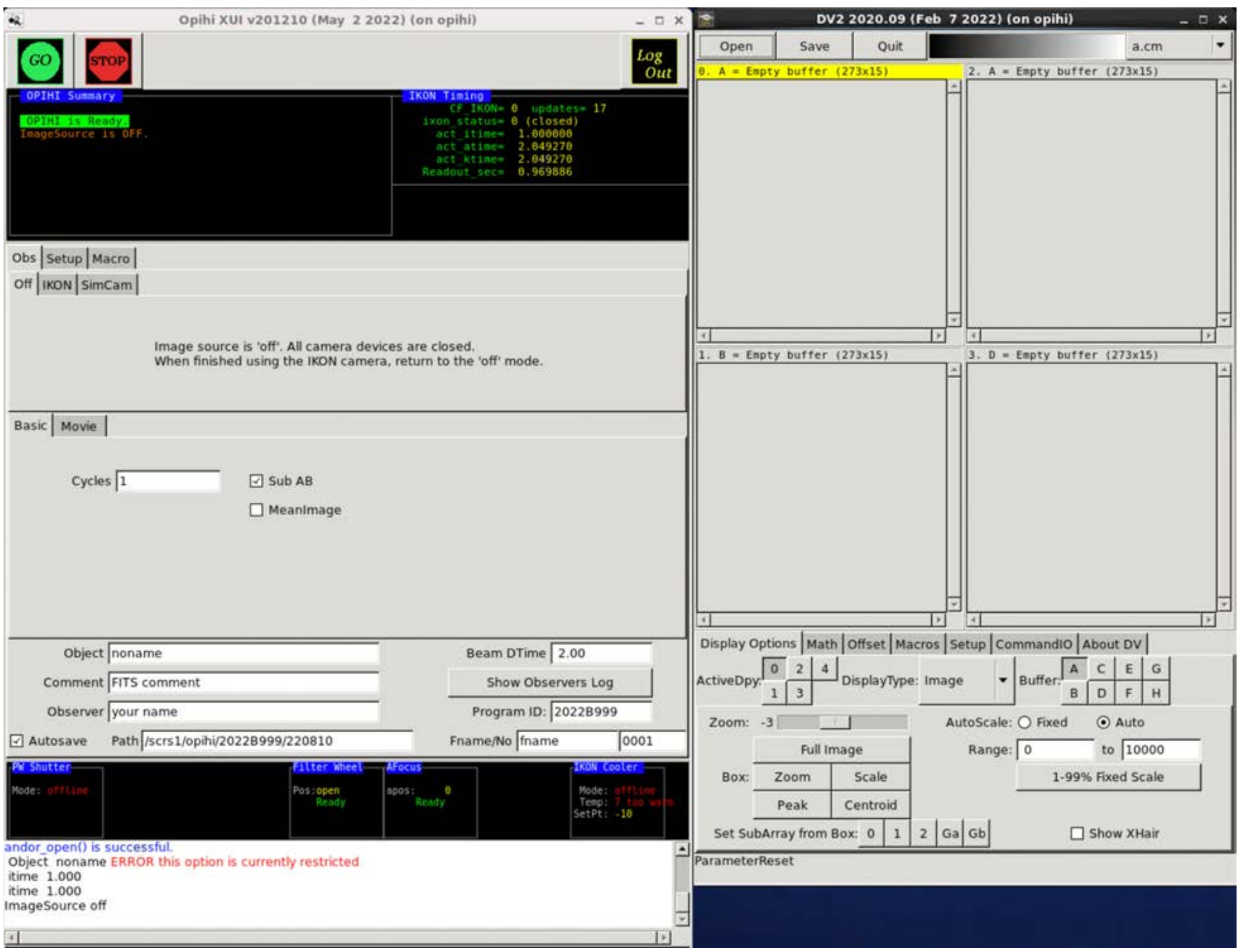
The OPIHI software consists of three components: the instrument control server, the GUI, and the data viewer (DV). It should currently be accessed through stefan:7.

1. After connecting to the VNC session, open three xterm sessions using the Desktop launcher buttons named “SSH OPIHI.” This launcher starts an xterm and automatically logs into the OPIHI pc. Enter the password for each instance.
    a. Run the command “`startic`” in the first xterm. This executes the IC server software in that xterm, launching the multiple processes used for controlling various subsystems.
    b. Run the command “`startxui`” in the second xterm. This executes the XUI software in that xterm, and presents the OPIHI GUI.
    c. Run the command “`startdv`” in the third xterm. This executes the DV software in that xterm, showing the DV user interface.

2. The GUI will connect to the IC server at startup. At this time, the OPIHI XUI login window will be showing. Login with the project account or enter a different username and password for the observing program. Click “Login with the above username.”
    a. By default, the DV will show previous observations. If desired, check “Reset DV on login” to clear the DV.

You may want to use OpihiExarata depending on the situation. Refer to the OpihiExarata User Manual[3] for more information. We recommend that the user open OpihiExarata in another desktop to reduce clutter. To start OpihiExarata, open another xterm and navigate to the home directory of the user (“`cd /home/opihi/`”).Then, use the following commands.

1. Run “`exarata manual`” to start the manual mode of OphiExarata. This mode can be used for asteroid detection and photometry.
2. Run “`exarata automatic`” to start the automatic mode of OphiExarata. This mode can be used for automatic zero point monitoring.



The XUI (left) and DV (right) after login.

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3 https://psmd-iberutaru.github.io/OpihiExarata/build/html/user/index.html

2.2 Starting ‘Opihi

After the software has successfully been started, check that ‘Opihi is prepared for observing.

1. The TO should enable the ‘Opihi dome offset in the TCS to center the dome slit between the beams of ‘Opihi and IRTF. This is to prevent vignetting in the ‘Opihi images. This should not clip into IRTF’s beam. The dome offset should be disabled when ‘Opihi is not in use.
    a. ‘Opihi cannot be used when IRTF is pointed near zenith. Refer to the dome offset algorithm documentation for details.[4]
    b. Though the dome offset algorithm is good for most cases, it is not perfect. If the dome begins to vignette IRTF at any time, disable the Opihi dome offset. This may happen at specific pointings.
2. If the Filter Wheel or AFocus are not initialized, initialize them using the Filter.Init and Focus.Init buttons found on the **Setup** tab.
3. Open the telescope cover from the **PW Shutter** tab. Make sure that the cover is closed when you have finished! ‘Opihi will become a fire hazard if the cover is off and the dome is open during the day.
    a. A “`cover close`” command will run automatically upon logging out of the XUI, but we strongly recommend users to manually click the “Close Cover” button when they are finished. Depending on the orientation of IRTF, you can verify that the cover is physically closed by checking the cameras on stefan:9.
    b. The cover is programmed to close automatically at sunrise. However, the instrument control software is not designed to work in real time; this is an emergency measure that should not be relied upon.
    c. It is also possible to open and close the cover from the command line. In a fourth xterm, run the command “`cover open`” or “`cover close`” to open or close the cover, respectively.
4. Turn on the camera by clicking on the **IKON** tab. Check that the camera temperature is set to -50°C; this can be changed using the **IKON Cooler** panel. Wait until all components are initialized and the temperature is cool. It takes the CCD about 7 minutes to get to the correct temperature from ambient.
5. The telescope will usually not need to be focused before observing. However, if you notice that the image quality is poor, the telescope may be focused by changing “apos” in the **AFocus** panel.
    a. Good ballpark values for the step size are in the positive or negative hundreds (e.g., -300 or +500 steps).
6. Enable “Autosave” when you are ready to observe.

‘Opihi is now ready for use. By default, the CCD is used with the following settings:

Array: 0 0 2048 2048
XY Binning: 1
ReadOut: CV_16bit_05MHz

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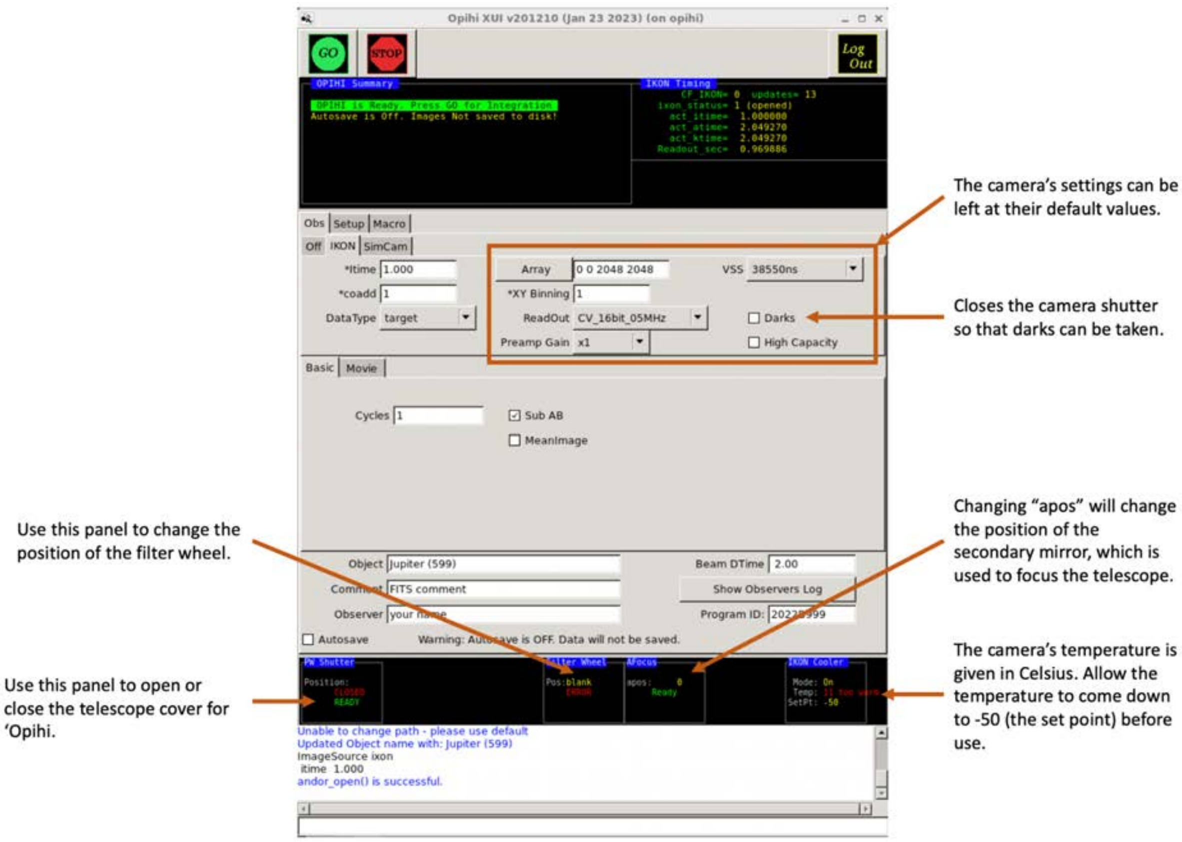
[4] http://irtfweb.ifa.hawaii.edu/~tcs3/tcs3/history/23/05-opihi-code/Opihi_Dome/report.pdf

Preamp Gain: x1
VSS: 38550ns
High Capacity: Disabled

In general, these settings can be left untouched because ‘Opihi has been thoroughly tested for these parameters. However, you may choose another configuration by changing the appropriate dropdowns.



The XUI after the IKON camera has been turned on.

3. Target Acquisition and Guiding

Guiding is done with either Guidedog (Sec. 3.2 of the SpeX manual) or MORIS. Objects should be sent to the TO with the T3 Remote TCS. You may open a t3remote panel in the ‘Opihi VNC by clicking on the “t3remote” icon on the desktop if needed. Depending on the use case, you may want to select a nearby guide star with Starcat. Searching for asteroids typically involves pointing the telescope to the star field and guiding at known non-sidereal rates (Refer to Sec. 5).

The center of IRTF’s FOV is close to the center of ‘Opihi’s FOV but drifts around somewhat due to flexure. We have measured that the flexure does not exceed 1’ in any direction. Searching for the target’s entry on the SIMBAD astronomical database can be useful for identifying the target in the ‘Opihi image.

4. Imaging

As shown in Fig. 3, the CCD is linear within 0.2% of the full well depth up to saturation (65,535 counts in the DV). However, the counts in any pixel should not exceed 60,000 for safety. Refer to Table 3 for the measured sensitivity.

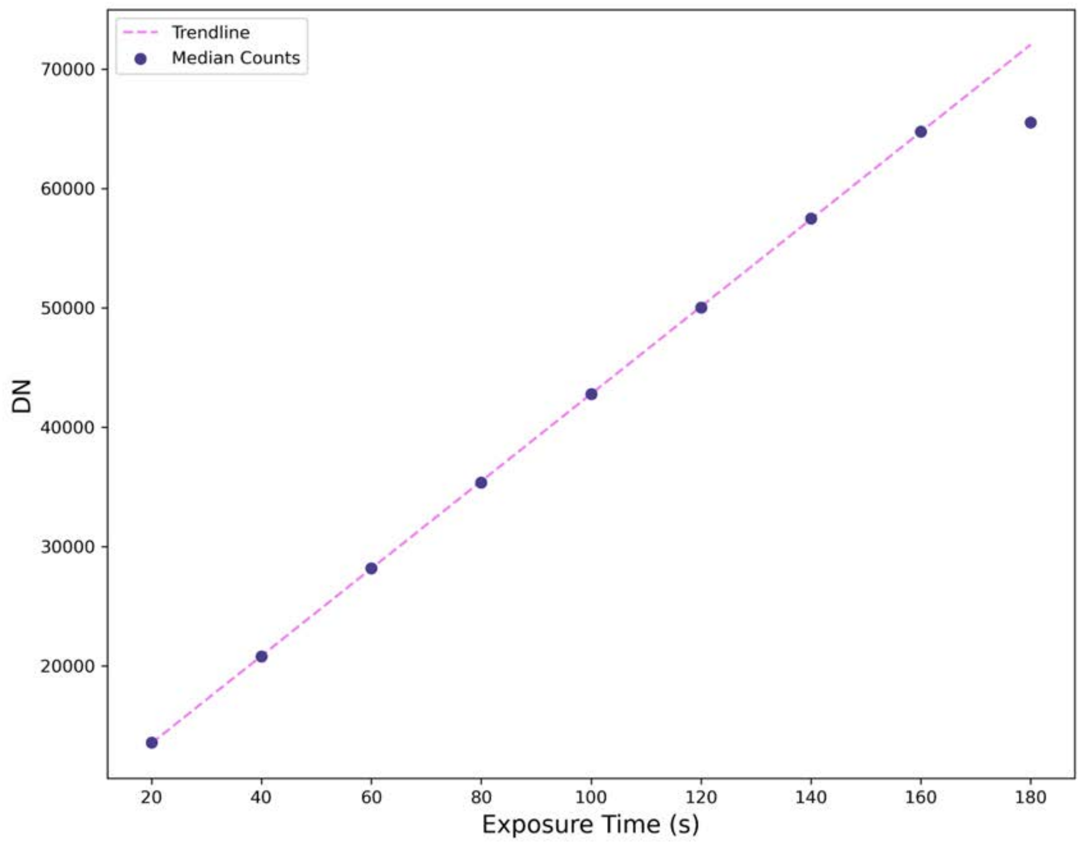


Figure 3: The linearity of the CCD's response. Saturation occurred at 180 s exposure time, which is why the median counts for that time do not lie on the fitted line.

Table 3: The measured zero point and estimated limiting magnitude for each filter (quarter moon). The expected flux of the clear position is approximated by averaging the fluxes of the four filters. Note that it becomes difficult to make a visual detection of an A-B subtracted asteroid below S/N~60. Refer to Sec. 5.

Filter	**Zero point**	**m (S/N=60, t=60 s)**
g’	21.6	18.5
r’	21.2	18.3
i’	21.1	18.0
z’	20.5	17.2
clear	22.5	20.1

To manually take data with ‘Opihi:

1. Check that “Autosave” is enabled. Set the name of the object and file name.
2. Set the desired exposure time. We recommend taking a test exposure to check the signal level before setting the number of cycles and coadds.
3. Set the filter wheel position in the “Filter Wheel” panel. Wait until the panel says “Ready” before taking the exposure.
    a. It is <u>faster</u> to rotate the filter wheel from z’ → i’ → r’ → g’ → c’ because the motor only moves in one direction.
4. Click **GO**.

4.1 Data Reduction, Flats, and Darks

Data reduction is done by OpihiExarata. Upon opening a file (see Sec. 5), OpihiExarata will automatically save a reduced version of the image as indicated by the “.pp” extension. OpihiExarata will reduce the data by using archived calibration images. <u>Generally, you do not need to take your own flats and darks.</u>

Flat fields were captured by placing an illuminated translucent screen in front of ‘Opihi. Flats can also be taken by turning on the floor lights in the dome and pointing ‘Opihi to the white dome spot. We have also created a bad pixel map providing the locations (row, column array indices) of the 1,023 hot pixels and the one dead pixel. These pixels should be excluded when trying to make an asteroid detection.

There are two ways to take darks: you may either check the “Darks” option to close the camera’s shutter or set the filter wheel to the block position. Set the number of cycles to take multiple darks of the same exposure time.

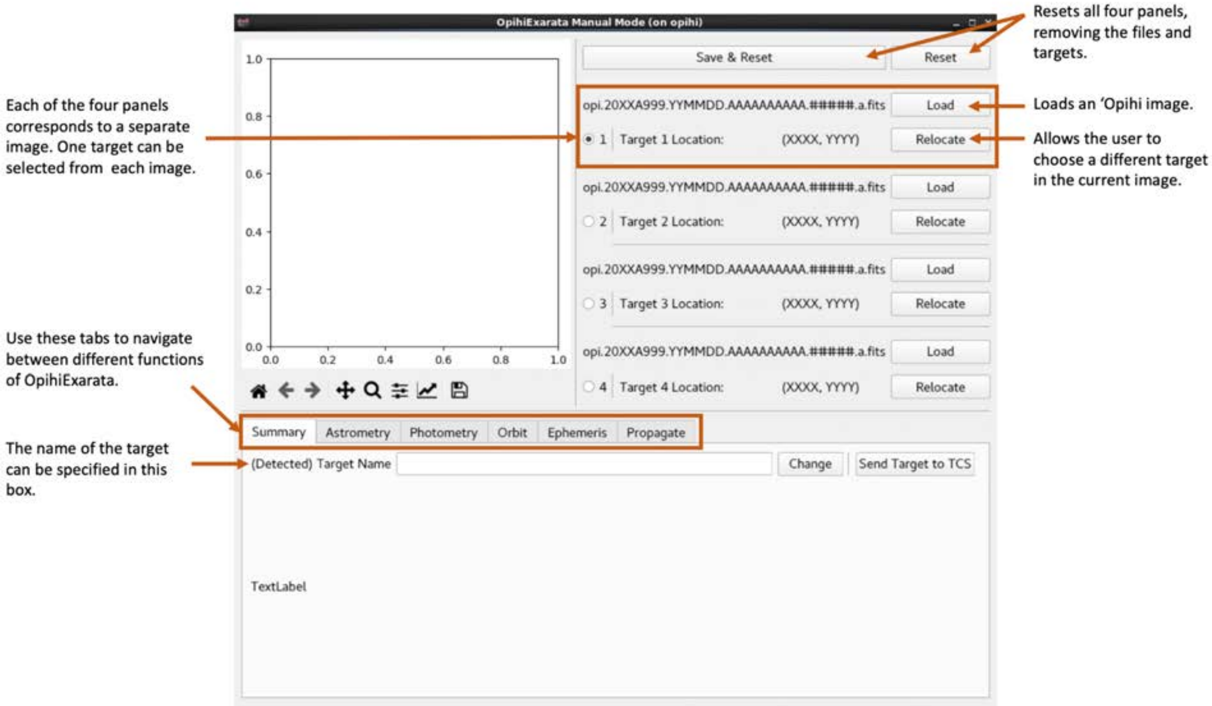
5. Asteroid Detection

Asteroid detection is done by loading images into the manual mode of OpihiExarata. The general workflow is as follows:

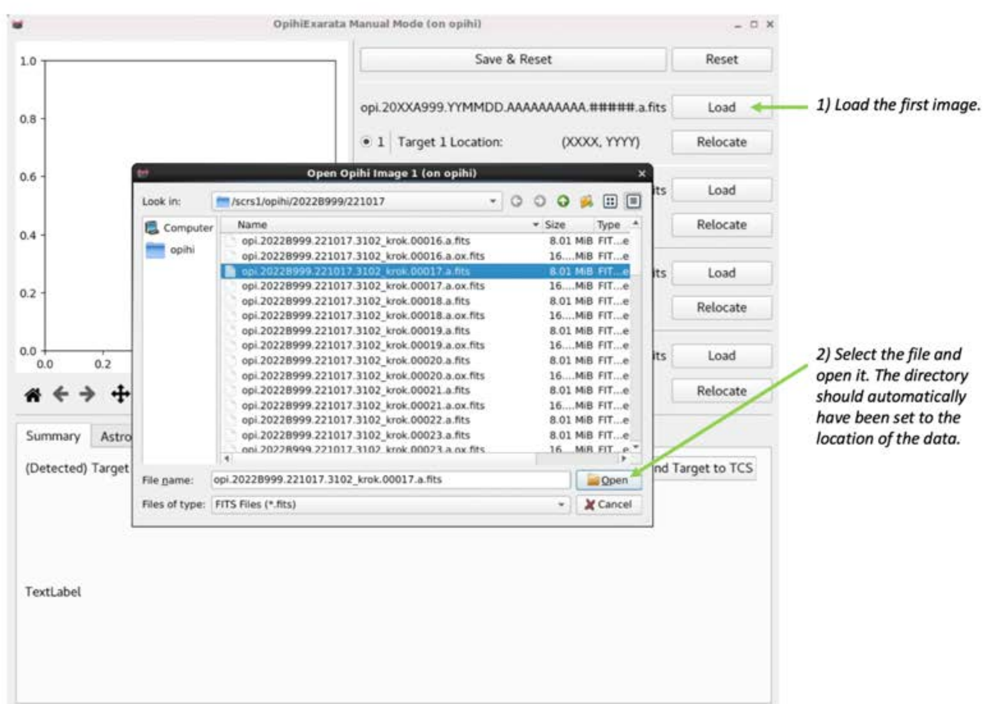
1. Point IRTF to the expected location of the asteroid and guide at a known non-sidereal rate.
2. Take at least two images with ‘Opihi.
3. Load the ‘Opihi images into OpihiExarata to perform the asteroid detection, propagate its ephemeris, and send the updated position to the TCS.

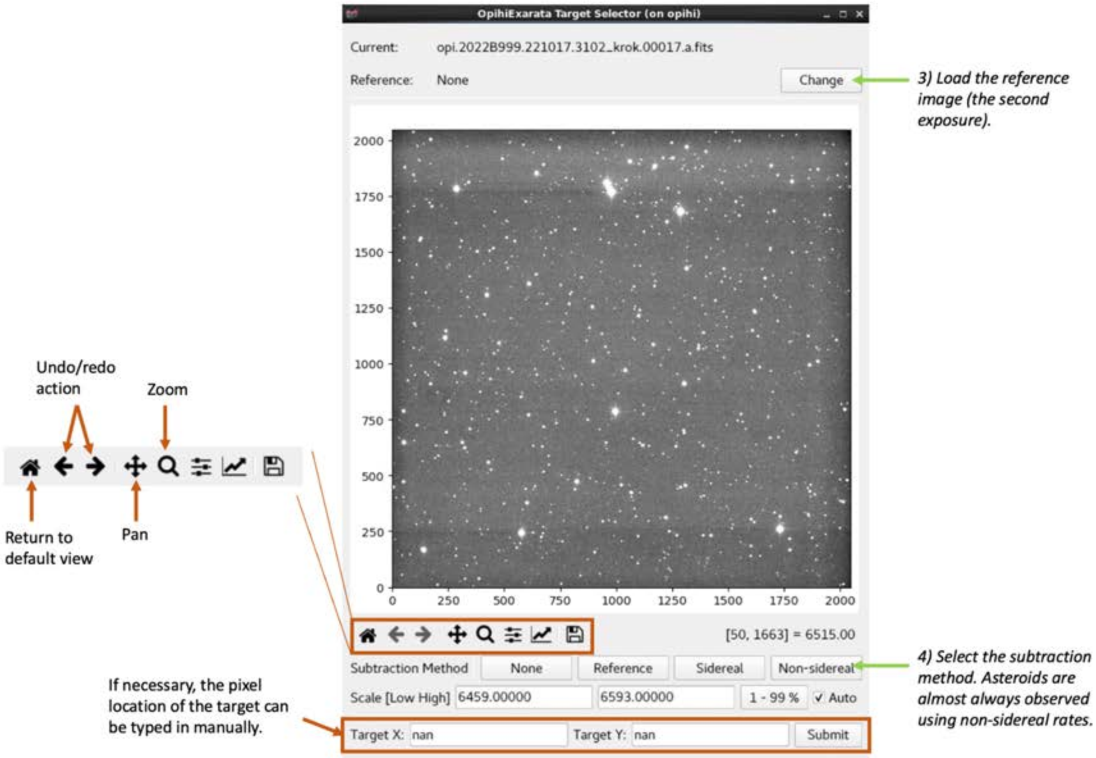
The asteroid detection is performed visually. For illustrative purposes, we will walk through a sample detection and propagation of asteroid 3102 Krok. <u>At least two images are required. All images must have the same exposure time and filter for asteroid detection with OpihiExarata to work properly.</u>

- Verify that the ‘Opihi dome offset is enabled in the TCS.
- Point IRTF to the expected location of the asteroid. Guiding at non-sidereal rates is almost always preferred for asteroid detection, but you may guide on a background star as well.
- Set ‘Opihi’s filter wheel to the clear position and take an exposure.
- Take another exposure. Depending on how quickly the asteroid is moving, it may be necessary to wait for some time until the asteroid has moved several arcseconds away from its previous position on the sky.
    - Two exposures is enough to propagate the asteroid’s ephemeris with OpihiExarata assuming a linear fit. Up to four exposures can be used at once.
- Start the manual mode of OpihiExarata (Sec. 2.1). The following window should appear:

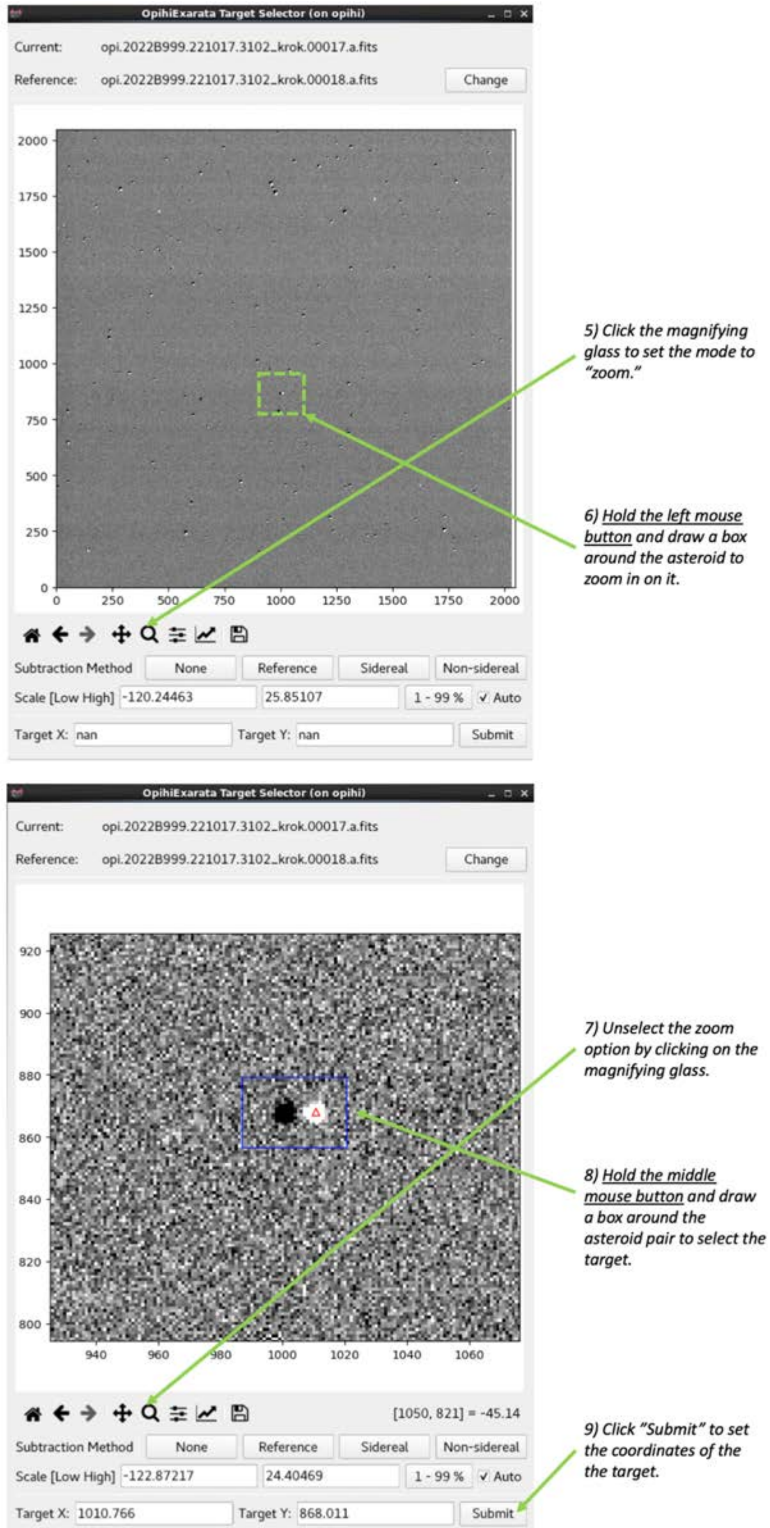


- Load the first image. The target selector should appear as soon as the file is opened. In the target selector, load a different exposure and set the subtraction method ("non-sidereal" in our example).

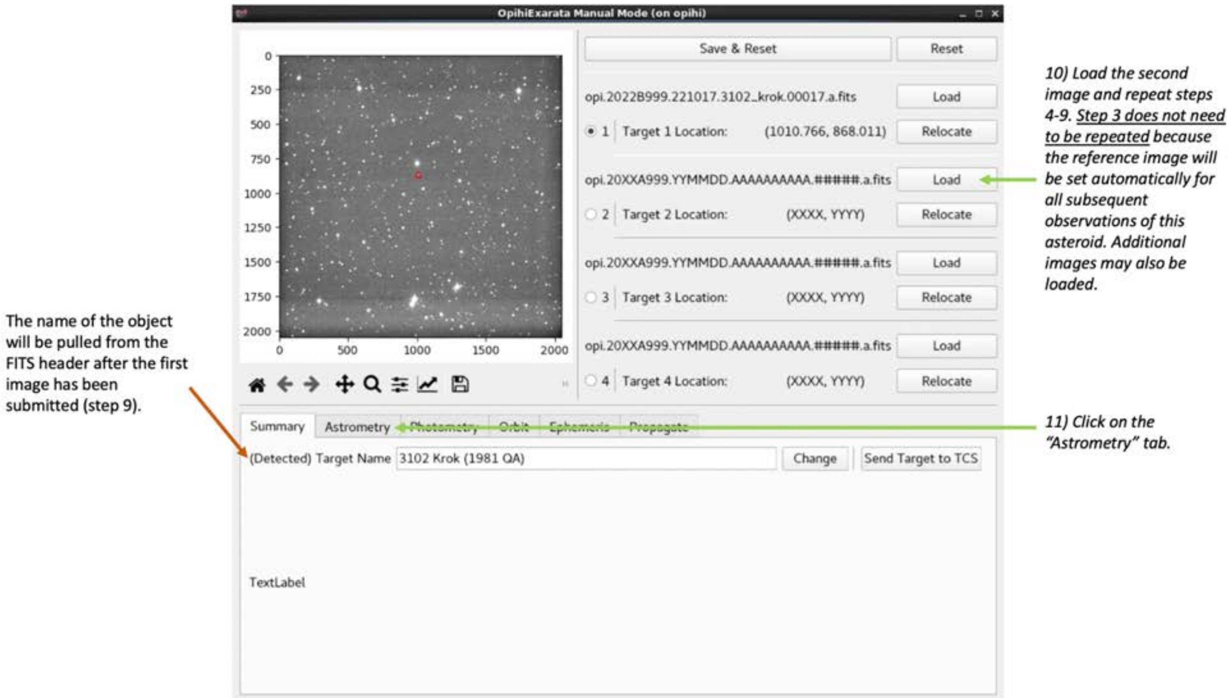




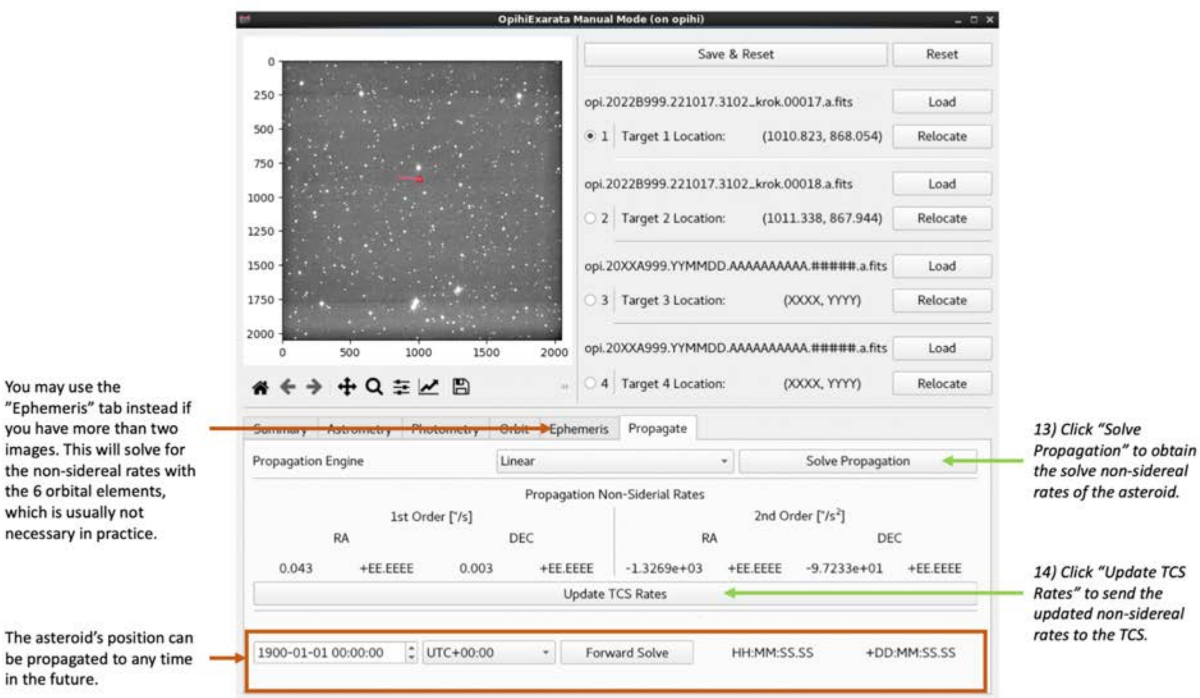
- The AB subtracted image should appear after setting the subtraction method. Locate the asteroid in the image and select it. Then, submit the target's coordinates.
  - The stars should be almost entirely subtracted out of the image. The asteroid can be identified by the fact that its AB pair has a different direction and spacing relative to the other pairs.
  - Zooming in is done by clicking on the magnifying glass and <u>holding the middle mouse button</u> to draw a box.
  - At any time, you may select the target by <u>holding the middle mouse button</u> and drawing a box around it. Unselect the magnifying glass before drawing a box to enable target selection.

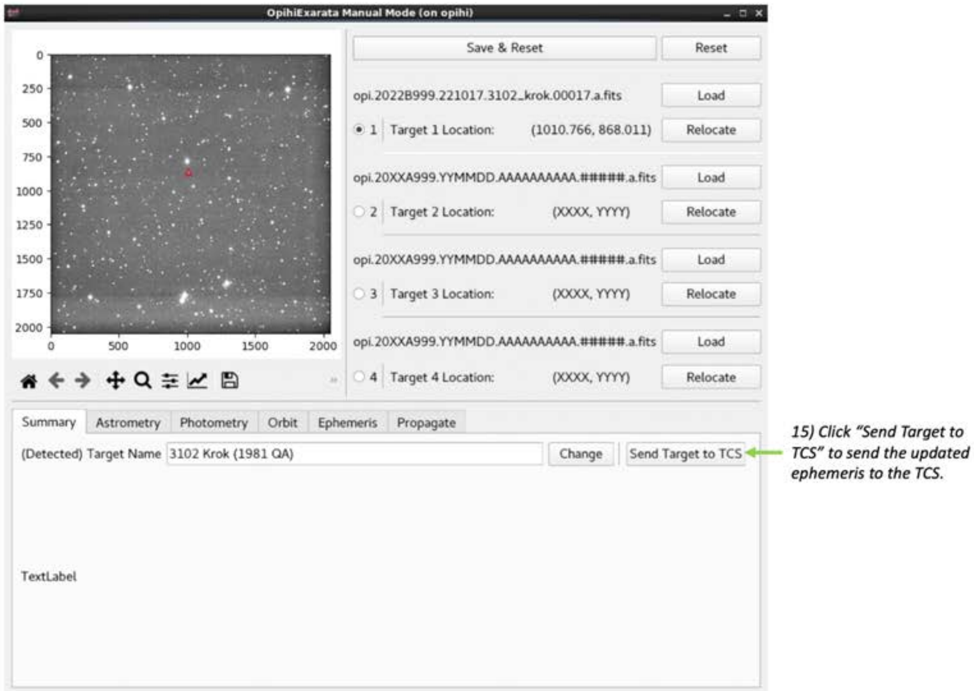


- Repeat the previous steps for subsequent exposures. The reference image will be set automatically after the first image has been submitted so it does not need to be changed. When you are finished, click on the **Astrometry** tab.



- Use the **Astrometry** tab to compute the astrometric solution for the images. Then, obtain the non-sidereal rates and send the ephemeris to the TCS.



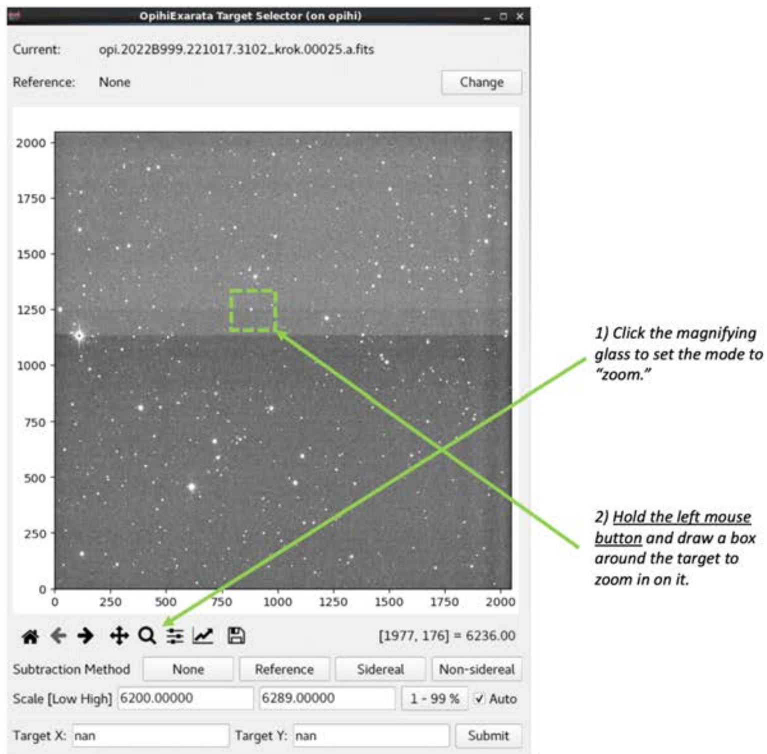


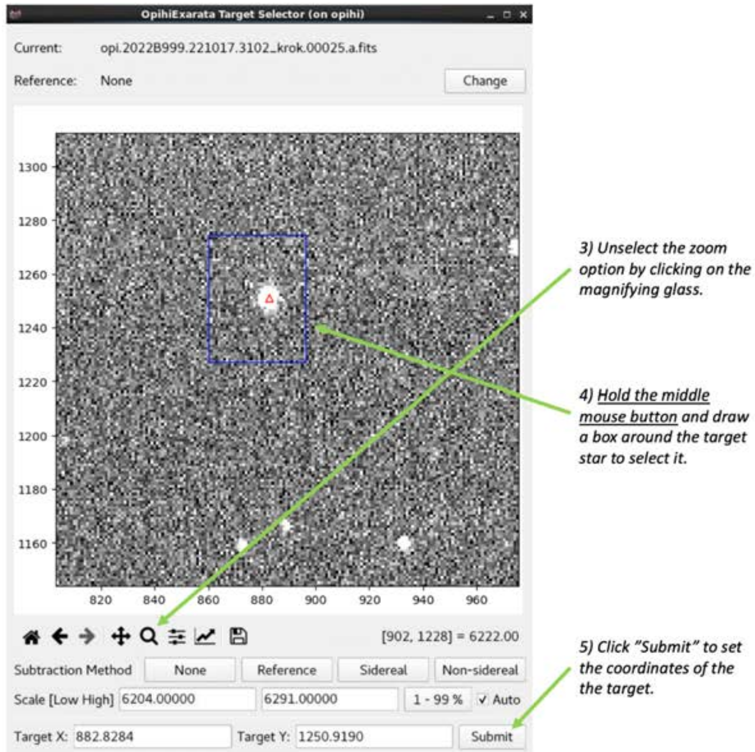
- Finally, follow Sec. 7 to shut down 'Opihi when you are done using it and/or at the end of each night.

6. Photometry

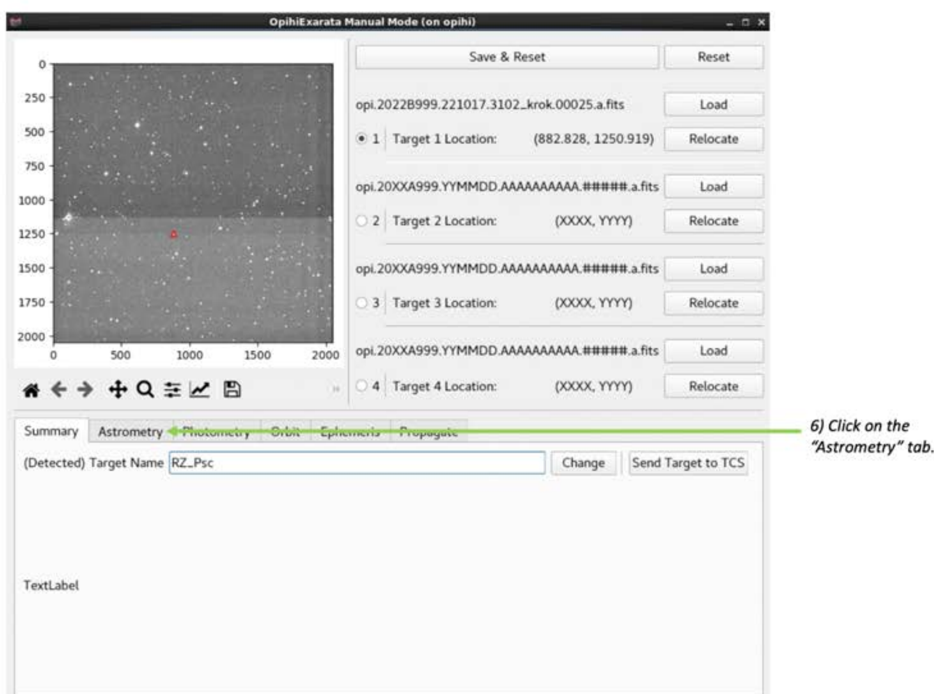
OpihiExarata can also perform aperture photometry on selected targets. It should not be used for photometry of extended sources. Photometry can only be done for images taken with the four SDSS filters.

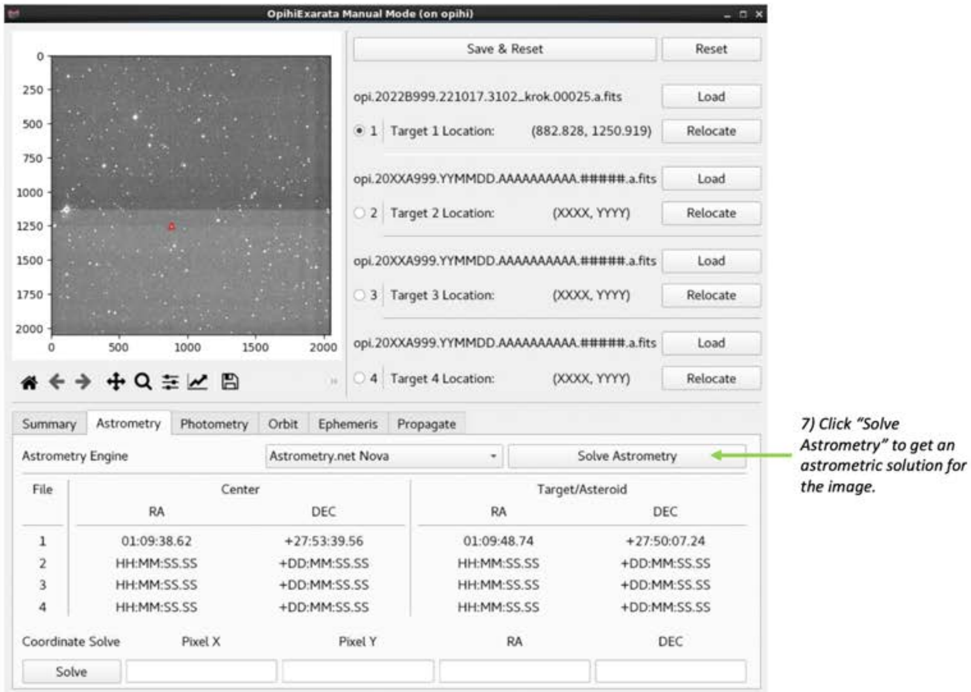
- Following the guide in the previous section, load the image. Then, select the target without setting a reference image.



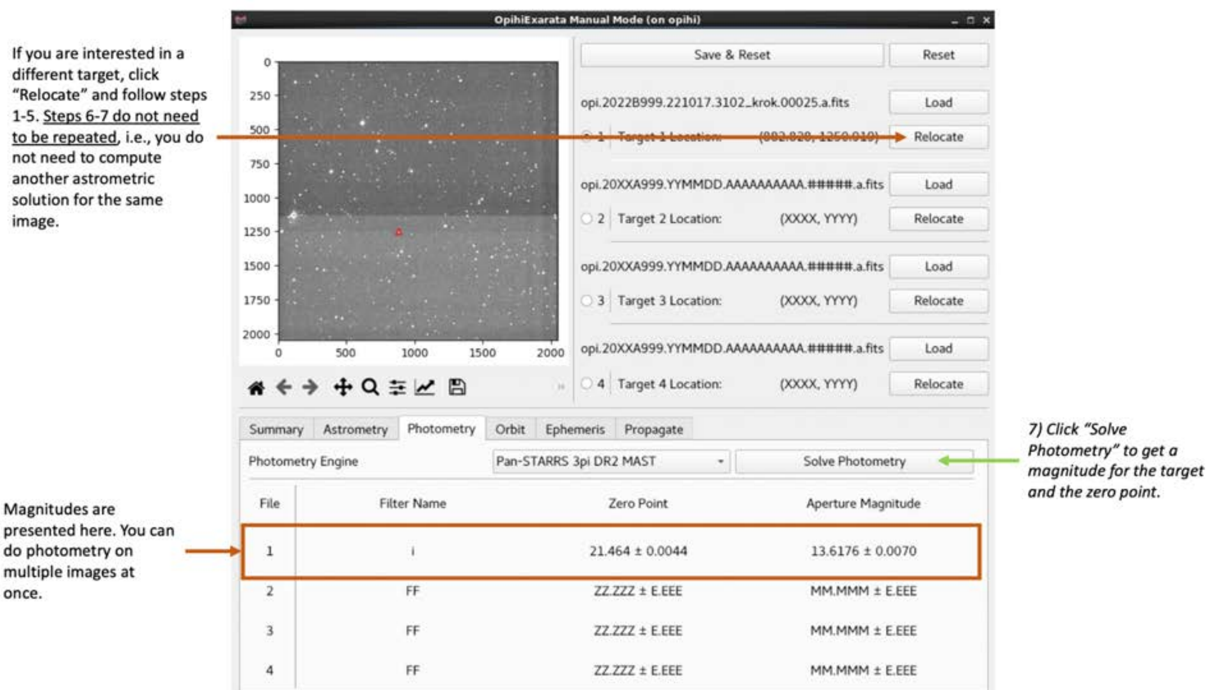


- Use the **Astrometry** tab to compute an astrometric solution.





- Use the **Photometry** tab to obtain a magnitude for the target.



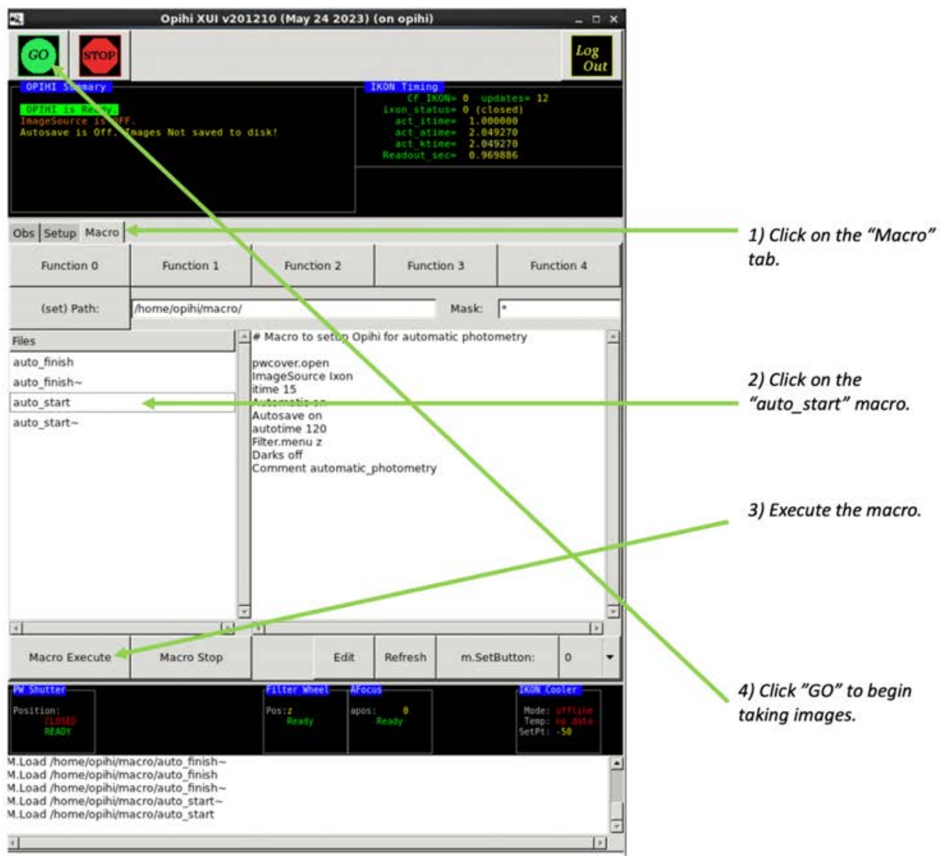
- Finally, follow Sec. 7 to shut down 'Opihi when you are done using it and/or at the end of each night.

6.1 Automatic Observing and Zero Point Monitoring

Automatic observing with ‘Opihi is not fully implemented yet. This mode allows for atmospheric monitoring throughout the night by taking images continuously with ‘Opihi through different filters. Updates are posted to the zero point monitoring web page.[5]

Currently, the user must take exposures manually with ‘Opihi to obtain new measurements of the zero point. Computing the zero point based on a new image and updating the webpage are done easily with OpihiExarata. <u>Only operate Opihi’s automatic mode between ~30 minutes after sunset and before sunrise!</u>

- Verify that the ‘Opihi dome offset is enabled in the TCS.
- Under the **Macro** tab of the ‘Opihi XUI camera controller, run the “`auto_start`” macro. Then, click **GO** in the XUI. The camera will take images according to the specified intervals.



- Start the automatic mode of OpihiExarata-(Sec. 2.1). Verify that the directory is correct and click **Start**. The software will now automatically solve new images taken with ‘Opihi.
- Optional: You may change several parameters in OpihiExarata. The defaults are likely good enough.

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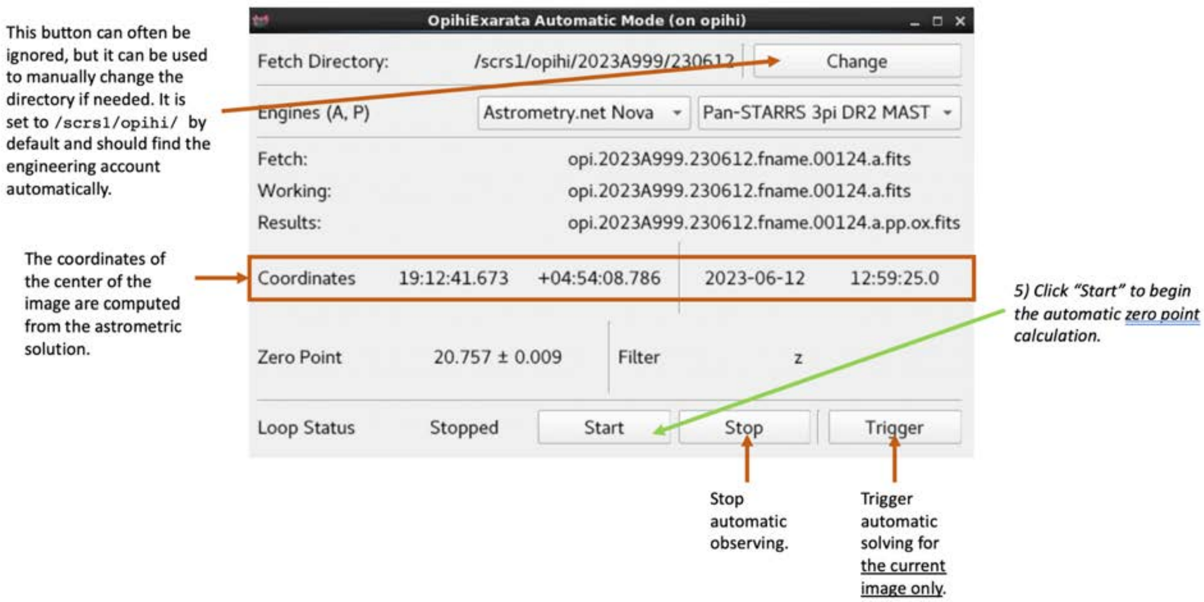
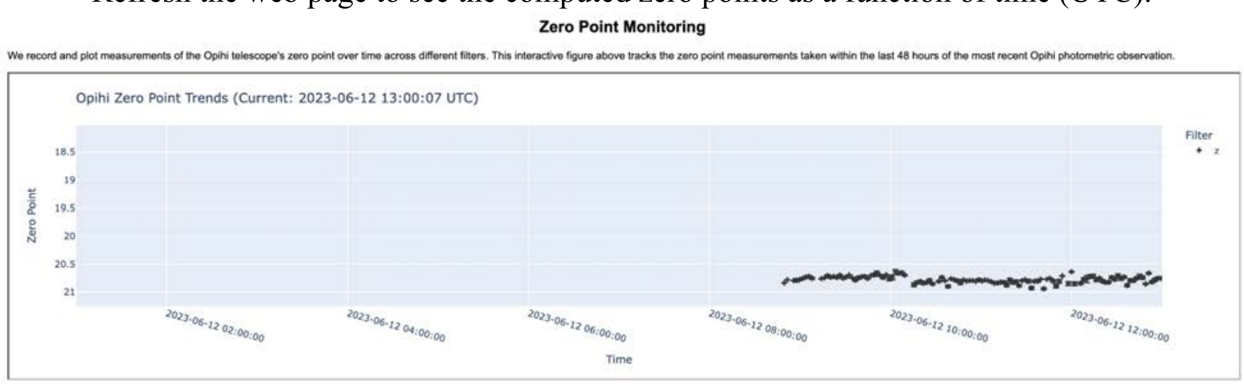
[5] http://irtfweb.ifa.hawaii.edu/~opihi/monitor/

- In OpihiExarata, click the “Change” button to change the directory to where Opihi will save its images to (i.e., the engineering account and tonight’s directory). The directory is set to `/scrs1/opihi/` by default. The software should find the engineering account within that directory, so it usually does not need to be changed.
- Set what software engines OpihiExarata will use to solve the images using the drop down menus.



- Refresh the web page to see the computed zero points as a function of time (UTC).



- When you are finished using automatic mode:
  - On the OpihiExarata GUI, click **Stop**. Then you may close the software. Please wait until the xterm is ready before closing the xterm window.
  - Under the **Macro** tab of the Opihi XUI camera controller, run the “auto_finish” macro.
- Finally, follow Sec. 7 to shut down ‘Opihi when you are done using it and/or at the end of each night.

6.2 Absolute Spectral Flux Calibration of SpeX Data

When performing the flux calibration, 'Opihi's job is to provide an accurate measurement of the target's magnitude. Although both the z' and i' filters overlap with the wavelength range of SpeX, the z' magnitude is preferred because SpeX's response drops off sharply at shorter wavelengths.

1. Follow the previously outlined instructions to obtain a z'-band magnitude for the target. Convert this magnitude to a flux density. Recall that 0 mag corresponds to 3631 Jy or 131.5e-11 erg/s/cm^2/Å. Call this flux density "Y."
2. Reduce the SpeX data using Spextool. The fully reduced spectrum will come with a pseudo flux calibration; this does not need to be very accurate. In our example, as illustrated in Fig. 5, we have changed about the B and V magnitudes in xtellcor to be about roughly magnitude fainter than the actual object.
3. Multiply SpeX spectrum by the response of the z'-band, shown in Fig. 4. The z'-band response can be retrieved from the 'Opihi webpage.
4. Integrate the resulting spectrum and divide by the FWHM of the z'-band (which is 0.13 µm). Call this flux density "X."
5. The scale factor is s = Y/X. Multiply the original reduced spectrum by s to perform the flux correction.

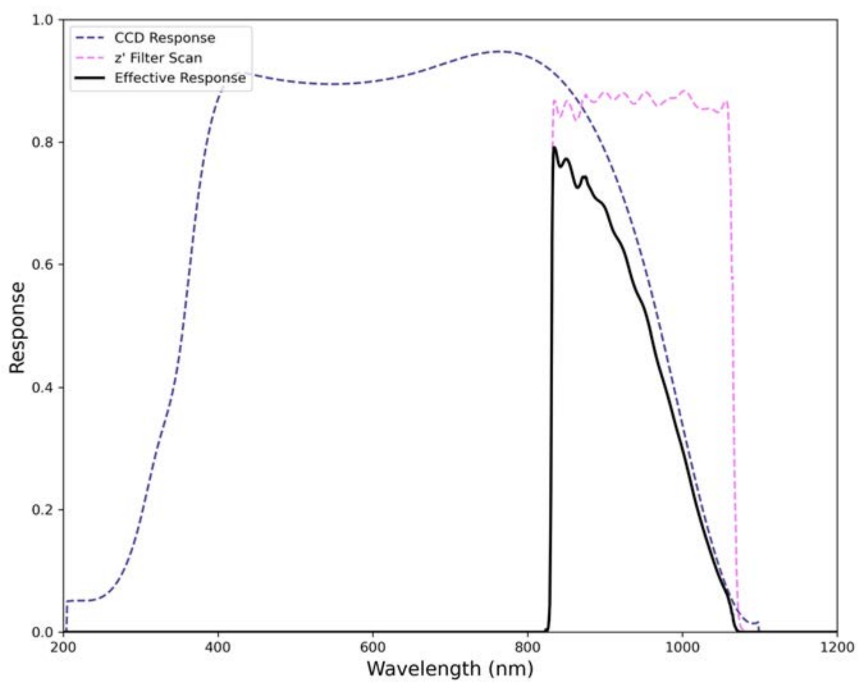


Figure 4: The effective response of 'Opihi in the z'-band (black). This response curve is obtained by multiplying the CCD's response (purple) with the z' filter's transmission curve (pink).

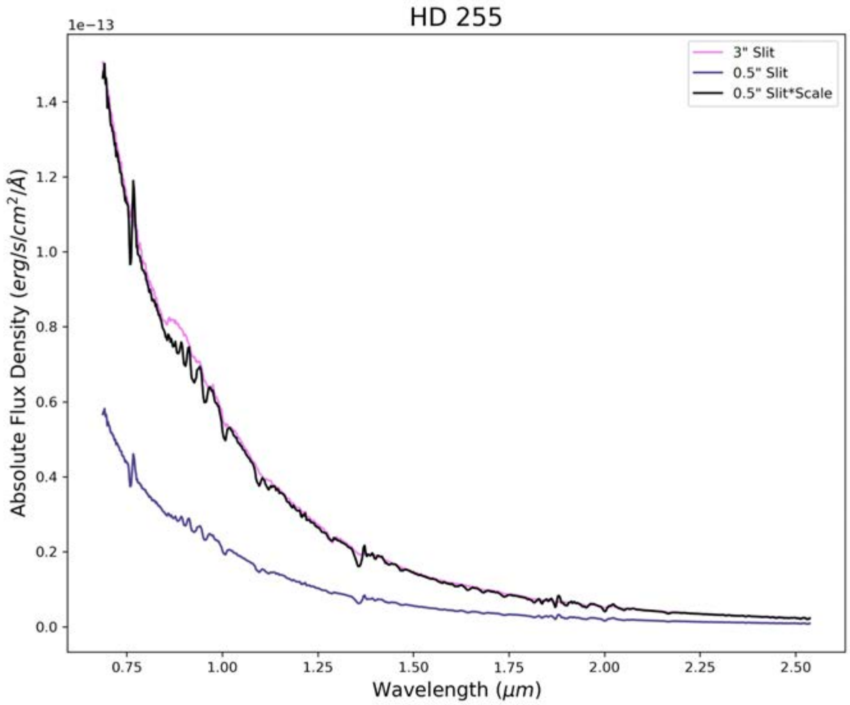


Figure 5: The scaled spectrum of HD 255 (black) compared to the slitless spectrum (pink) and the uncorrected spectrum (purple). The "slitless" spectrum was taken using the 3" slit in SpeX; due to the lack of a narrow slit, the scaling factor in Spextool has little variation and is thus a good reference point. The corrected spectrum overlaps nicely with the slitless spectrum which indicates a successful flux calibration. Note that the uncorrected spectrum is far off because we deliberately used an incorrect magnitude for the standard, which resulted in a poor pseudo flux calibration by xtellcor.

7. Shutting Down

After you have finished observing, ensure that 'Opihi is properly shut down before sunrise.

1. Close the telescope cover from the XUI by clicking **PW Shutter** and then "Close Cover." Check that the cover is closed by either using the camera in stefan:9 or by looking into the dome.
2. Shut off the camera by clicking the **Off** tab.
3. Log out of the XUI by clicking the **Log Out** button in the top right corner.
4. Disable the 'Opihi dome offset in the TCS to recenter the dome slit on IRTF's FOV.