



Keo Arinae

Fabry-Pérot Interferometer

Deployment and Operations Manual

February 2022

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Revisions

Revision	Description
2022-02-01	Initial Revision

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1 Introduction

Thank you for purchasing a Keo *Arinae* Fabry-Pérot Interferometer (FPI). This deployment and operations guide will provide instructions for unpacking, setting up, configuring, and operating your new Keo Scientific FPI system.



Figure 1: Assembled 100mm FPI System

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2 System Setup

2.1 Unpacking the System

While unpacking the FPI system, check the system components for possible signs of shipping damage. If there are any, notify Keo Scientific immediately.

The FPI system is shipped in 3-4 custom cases depending on the configuration of the FPI. Please save the cases so that they can be used to ship the device to a new location or to return it to Keo Scientific for repairs, if necessary.

Please leave the components in their shipping cases until needed during assembly. This will prevent any accidental damage to the components.

The main components that make up the FPI are shown below. Depending on the configuration of FPI, these items maybe be packed in different cases but once unpacked they should appear similar to those pictured.



Figure 2: SkyScan Pointing Head



Figure 3: Upper Optical Column

Consists of filterwheel or filter-drawer, etalon enclosure, and connecting tubes.

**Figure 4: Lower Optical Column**

Consists of apochromatic lens system and camera sensor.

**Figure 5: Etalon****Figure 6: Mounting Frame**

Shipped disassembled.

**Figure 7: Base Plate****Figure 8: Laser Diffuser**

With attached fiber cable

**Figure 9: Laser Head**

With attached shutter and collimator



Figure 10: Cloud Sensor



Figure 11: Environmental Control Components (optional)

Varies depending on configuration, but typically will consist of four fan units (two with heaters) plus some tubing and connecting brackets.



Figure 12: Control System

All controllers are pre-installed in the 12U rack case. Monitor, keyboard, and mouse are not included.



Figure 13: Accessories

Cables and various accessories are packed in bags and/or white cardboard box(es).

2.2 Etalon Installation Preparation

70mm and 100mm FPI systems use two different styles of etalons as pictured below in Figure 14 and Figure 15. Please follow the instructions for the size of etalon in your system. Always work in a fairly clean environment.



Figure 14: 70mm Etalon



Figure 15: 100mm Etalon

2.2.1 70mm Etalon Unpacking and Installation Preparation

70mm etalons are smaller than the 100mm etalons and of a different internal design and as such do not require locking the flexures in place for shipping.

1. Carefully unpack the etalon assembly from its packaging. It will be in a sealed bag with desiccant packs inside.
2. Remove the top and bottom plastic covers. Take extreme care to not touch the exposed window surfaces.
3. The etalon is now ready for installation into the FPI.

2.2.2 100mm Etalon Unpacking and Installation Preparation

Due to the size and design of the 100mm etalons, they ship with the internal flexures locked in place with six (6) setscrews. This is done to provide support to these relatively delicate components during shipping. These setscrews must be loosened before installing the etalon in the FPI.



Caution

Once the etalon flexure setscrews are loosened, the etalon is more susceptible to damage from impact. Please exert extreme care while handling the etalon after the setscrews have been loosened to prevent impact on the etalon.

1. Carefully unpack the etalon assembly from its packaging. It will be in a sealed bag with desiccant packs inside.



Figure 16: Packed 100mm Etalon

2. Note that there are six (6) locations for screws around the outside of the etalon, five (5) of which are installed during shipping. One is not installed for shipping to prevent pressure changes during shipping as well as to allow the desiccant to keep the inside of the etalon dry. Remove these five (5) installed Phillips-head screws and place them somewhere safe. Note how these screws have integrated O-rings to seal the etalon when installed. The sixth screw (plus several spare screws) are provided in a small bag, and it will be needed shortly.



Figure 17: 100mm Etalon Screw Locations



Figure 18: 100mm Etalon Screws

3. Use a metric 1.5mm hex key to rotate all six (6) setscrews (now accessible through the screw holes) 1-2 full turns counter-clockwise. This will unlock each of the flexure arms in the etalon.



Figure 19: 100mm Etalon Setscrew Adjustment

4. Replace the six (6) screws into the enclosure and tighten. The etalon is now unlocked and sealed from the environment.



Figure 20: 100mm Etalon with Screws Installed

5. Remove the top and bottom plastic covers. Take extreme care to not touch the exposed window surfaces.



Figure 21: 100mm Etalon Ready for Installation

6. The etalon is now ready for installation into the FPI.

2.3 Assembling and Mounting the System

Please follow the separately provided instructions on how to assemble the system into its operational form. After completing assembly, your FPI system should look similar to the one shown in Figure 22.

To minimize the weight of the device during mounting, we suggest the following assembly order. Note that if using an apparatus that allows for raising the entire completed FPI assembly up and down, then all assembly could take place prior to mounting it under the dome. In practice it is more common to rigidly mount the system and this is what our instructions assume.

1. Assemble the frame and baseplate.
2. Mount SkyScan onto baseplate.
3. Raise this assembly up under the dome and mount securely in its final location (see Section 2.3.1 for mounting considerations).
4. Continue assembly to the mounted frame by adding the upper and lower optics, laser diffuser, environmental control system, and any other components.
5. Insert the etalon into the fully assembled FPI system (see Section 2.3.2).
6. Position the control system rack case in its desired location.
7. Install all cables between mounted FPI system and control system. Organize cables into neat and tidy bundles.



Figure 22: Fully Assembled FPI System

2.3.1 Mounting Considerations

The FPI system is supported inside a frame constructed of aluminum T-slot extrusions. The system should be mounted securely to this frame so that the large flat base plate is as high up in the dome as possible.

Please consider the following important points when planning your FPI installation. Do not hesitate to contact Keo Scientific should you have any questions.

1. The FPI system is heavy, upwards of 150lb (70kg). Two people are required to lift the system and it is very important to ensure it is properly mounted before powering it on.
2. The SkyScan pointing head on the top of the system rotates and when it does so it imparts some force onto the supporting structure. Please ensure the mounting system is rigid so that the system does not 'wobble' during motion. It is suggested to support the FPI system at both the top and bottom of its frame so as to provide adequate support and rigidity.
3. There may be a need to occasionally access the SkyScan pointing device on the top of the device. Ideally the FPI should be mounted in such a way as to allow for easy access to the SkyScan or to allow for the entire device to be lowered from the operating position to gain access to the system.

4. The optical column of the FPI needs to be centered underneath the dome. This will provide equal clearance around the dome for the SkyScan to operate. Failure to center the optical column could result in damage to the dome should the SkyScan impact it during operation.
5. Ideally the ‘chimney’ (the hole through the building’s roof underneath the dome) dimensions should be as large as possible so as to maximize the available space under the dome. For a cylindrical chimney, its diameter should be as close to the diameter of the dome as possible or if it is a rectangular chimney, its side dimensions should be similar to the diameter of the dome. Refer to Appendix B for examples of how this could be done.
6. The control station where the operator will control the device will need to be located within 20ft (7m) of the FPI system. This is a limitation in the length of cables available for some devices. We suggest positioning the control station immediately beside or below the FPI system installation.
7. It is of utmost importance that you purchase a dome of the correct size for your FPI system. If your dome is too small in diameter it will restrict the observable part of the sky and you will not be able to use the FPI system to its fullest capabilities. See Appendix B for details on acceptable dome sizes.

2.3.2 Etalon Insertion

After the FPI system is securely mounted and assembled, it is time to insert the etalon into the FPI. Note that it is possible to do this as part of assembling the system, but we recommend that the etalon be installed as the final step to minimize the risk of damaging it.

Please refer to the separately provided assembly instructions which include instructions for inserting the etalon into the system.

2.4 Software Configuration

After assembling and mounting the FPI system, there are a few items that must be configured in the software scripts for it to operate properly. This can be done now or after initial testing of the devices (see Section 3.3).

Note

It is assumed that you are familiar with the software and scripts for the following configuration discussion. If that is not the case, please skip ahead and familiarize yourself with Section 4, and in particular Sections 4.3.3.1 and 4.9.

2.4.1 Configure SkyScan North Offset

It is very likely that after installation the SkyScan is not aligned exactly with the geographic North direction. To compensate for this discrepancy, we can adjust for this in the scripts so that when we command it to point North, it points to actual geographic North.

1. Determine the offset from FPI North to geographic North. The laser diffuser is mounted on the north side of the instrument and the SkyScan is aligned to this so that FPI North is in the direction of the laser diffuser.

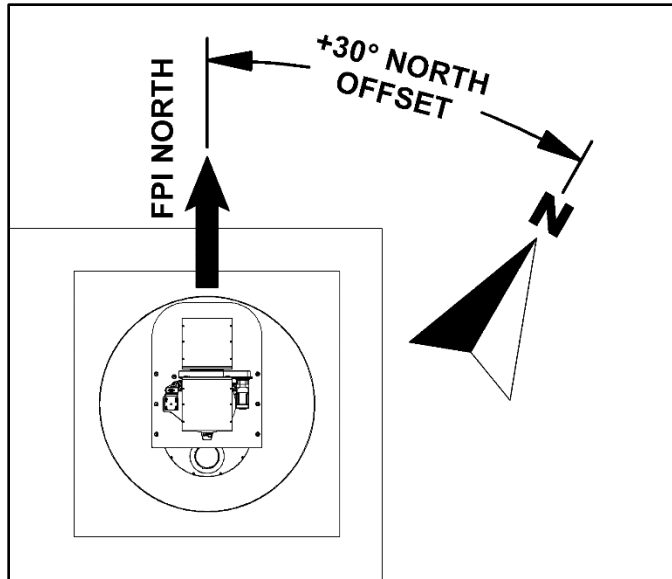


Figure 23: SkyScan North Offset as Viewed from Above

2. Open *ObservatoryControlFile* in the program root directory (see Section 4.3.3.1) and find the **AzCorr** setting. Enter the offset in degrees from the FPI North (SkyScan home) position to geographic North. A positive value is clockwise rotation as viewed from the top looking down. Figure 23 depicts a +30° north offset value.
3. Since the laser is always located at the SkyScan home position (90,180 in SkyScan coordinates) and we are adding an offset to all azimuth values sent from the scripts (for example +30°), we also need to compensate for this in our laser positions by cancelling out this offset. This can be done by opening the *Keo_SetupHardware* configuration script (see Section 4.9.2) and locating the **az_laser** value. Change this value to be $90.0 - \text{AzCorr}$ (AzCorr being the value used in step 2 above). You can either just leave this as the calculation (i.e., literally leave it as “90.0-30.0”) or simply enter the result, “60.0”. Note that the value used must include one decimal place (e.g. 60.0) otherwise there will be a script parsing error.

```
az_laser = 90.0-30.0    // or 60.0
ze_laser = 180.0
```

2.4.2 Configure Location for Ephemeris

The Observatory application calculates the Sun and Moon ephemerides and it needs to be told where the site is located so that it can make this calculation accurately. Open *ObservatoryControlFile* in the program root directory (see Section 4.3.3.1), find the location settings section, and set the **stationLatitude**, **stationLongitude**, and **stationHeight** parameters to the correct values for your site.

2.4.3 Configure Device IP Settings [Optional]

For the environmental temperature controller (if ordered), Power Distribution Unit (if network accessible PDU provided), and computer to be independently remotely accessible (accessible without using the computer), they should be connected directly to the network, configured with local static Ips, and appropriate port forwarding put in place to allow access from outside the network. Of course, it is ultimately up to the IT Department at the installation site to determine the best way to allow remote access to these devices, but in general they will require an IP address be assigned to them that doesn't

change. If remote access software like AnyDesk or TeamViewer is to be used on the computer, then the computer may not need a static/reserved IP. But if IPs are being reserved for the other components, then the computer might as well get one as well.

It is our recommendation that at the very least, an IP be assigned to the computer and a second one to the PDU. Should the computer lock up, the PDU can then be accessed independently of the computer and used to power cycle the computer.

The PDU and environmental temperature controller are shipped with their default IP settings which will need to be changed before they can be used on a network. These can be changed by following the instructions that follow.

2.4.3.1 Configure Computer IP Address

The computer is currently configured to use DHCP to acquire an IP address. As mentioned above, this is acceptable if a service like AnyDesk or TeamViewer will be used to access the computer remotely. If Windows Remote Desktop (RDP) or VNC will be used, then it is very likely that a static IP will be needed.

Note that the computer has 2 LAN ports. One of these will be used to connect to the site's local network (which in turn connects to the WAN/internet) and the second will be used temporarily to configure the other devices. First identify which port is which (this can be done quickly by only connecting the primary network cable and seeing which ethernet connection is listed as connected. For the purposes of these instructions, we will assume that "Ethernet 1" is connected to the site's local network and "Ethernet 2" is to be used for configuring the other devices.

2.4.3.2 PDU IP Settings Procedure

Here is the procedure for setting the IP settings of the PDU:

1. Connect the "Ethernet 2" LAN port on the computer directly to the PDU with a cabled connection.
2. Configure the "Ethernet 2" IP settings to have a static IP of 192.168.0.50. This ensures it is on the same subnet as the PDU.
3. Open a web browser and navigate to <http://192.168.0.100>. This should take you to a login screen. Use username "Admin" and password "1234".
4. Navigate to Setup (link on left side), then scroll down to the Network section. Update the IP address, Subnet mask, and Gateway as instructed by your IT department (subnet mask and gateway will likely be the same as the computer's).
5. Click on the "Submit" button at the bottom of the Network section (note there is a submit button for each section). You should see a message that network settings have changed and it will redirect you to the new IP address after a few seconds. This will fail since the PDU is still connected directly to the computer.
6. Disconnect the PDU from the computer LAN and connect it back to the switch. Refresh the webpage and you should see the login page again. Login and you should be done.

2.4.3.3 Environmental Temperature Controller IP Settings Procedure

The environmental control system uses an X-410 web-enabled programmable controller as its temperature controller. We can configure its IP settings as follows.

Note

The X-410 could also be left connected to the computer's Ethernet 2 port if giving it a static IP is not an option. In this case, the device would only be accessible by first remotely accessing the computer and then navigating to the X-410's web server from the browser on the computer.

1. Connect the "Ethernet 2" LAN port on the computer directly to the X-410 with a cabled connection.
2. Configure the "Ethernet 2" IP settings to have a static IP of 192.168.1.50. This ensures it is on the same subnet as the X-410.
3. Open a web browser and navigate to <http://192.168.1.2/setup.html> (note that if you skip the setup.html part of the address you will just go to the status page). You should get a login prompt where you can use "Admin" and "webrelay" again to login.
4. Navigate to the General Settings > Network section on the left and at the top enter the IP Address, Subnet Mask, and Gateway. DNS is not needed unless the mail server options are enabled so that the X-410 can send emails and notifications.
5. Click on the "Submit" button on the bottom to save the settings.
6. Disconnect the X-410 from the computer LAN and connect it back to the switch. Navigate to the new IP address and you should see the status page.

2.4.4 Configure Scripts with PDU IP Address [Optional]

The scripts can communicate with the PDU to automatically turn devices on and off. By default, the scripts are configured to turn the laser off during the day to extend its operational lifetime. For them to be able to do this, they must be configured with the IP address of the PDU.

1. Open the *Keo_SetupPDU.txt* configuration script (see Section 4.9.3).
2. Change the **pduAddress** value to the correct one. This should be the only value that needs to be changed.
3. Save and close the script.

3 System Operation

The FPI system is controlled by software running on the provided computer.

Note

It is assumed at this point that you are familiar with the software and scripts. If that is not the case, please refer to Section 4 for an overview of the software and the scripts.

3.1 Powering Up the System

Follow the instructions below to power on the FPI system.



Caution

To minimize the risk to users or to the system equipment, ensure all cables are properly connected and the FPI system is securely mounted and clear of all obstructions before turning the power **ON**.

1. If your system is provided with a network addressable PDU (power distribution unit), ensure that its power switch is turned **ON**. By default, power to each of the ports on the PDU should turn on. If that does not happen, then use the buttons on the front of the PDU to select each port and turn them **ON**. For PDUs that are not network addressable, power will be turned on to each port as soon as the PDU is connected to wall power.
2. Turn **ON** the computer and log into the Operator account (no password, by default).
3. Turn **ON** the FPI Controller. This provides power and control to the filterwheel, SkyScan, and etalon thermal stabilization. The temperature controller display will illuminate and the SkyScan pointing head will start a homing cycle to find the HOME position.
4. Turn **ON** the laser with the provided key. Ensure the laser Mode selector is set to **Frequency**. The Status LED will pulsate while the laser is warming up. Only once the LED is solid (about 30 minutes after power on) should you start using the system for routine operations.
5. Turn **ON** the camera if it has a switch (sometimes this can be on the camera itself, on its power supply, or it might not have a separate switch). You should hear the fans turn on.
6. Your FPI system is now fully powered on and ready for operation.

3.2 Wait for Temperature Stabilization

It is important that you only use the FPI system for routine operation when everything has stabilized thermally. As the temperature of the etalon, filter, and camera sensor changes so does the response of the system. Please allow at least 1 hour after powering up the system to allow the etalon and filters to stabilize at their target temperatures (35°C for the etalon enclosure – the etalon will settle in around 29-

30°C – and 25°C for the filters). The camera will start to cool to operating temperature once we start using the software to control it.

Note

For testing purposes, you can proceed to use the system while everything is still thermally stabilizing. Just be aware that the response of the system may change as the temperature of the components are changing.

3.3 Initial Testing of Devices

Prior to attempting routine observations, it is suggested that each component of the system be tested to ensure it is installed and configured properly. To facilitate this, a series of test scripts have been provided that isolate and test one device at a time.

After assembling the FPI system as outlined in Section 2.3 and powering on the system as in Section 3.1, run each of the following tests to ensure each system component is operating correctly.

If these tests all complete without issues, the FPI system is considered to be functioning correctly and it is ready for routine observations.

3.3.1 Testing the SkyScan Pointing Head

This test will confirm that the SkyScan pointing head is connected properly and communicating with Observatory and will then cycle through the positions defined in the *Keo_SetupCycleAcquisition* script.



Caution

Ensure the SkyScan pointing head is securely mounted and all personnel are clear of its mechanical operating range before starting this test.

1. Configure Master to run the *testSkyScan* script.
2. Start Master and Observatory A3O applications.
3. Scroll up in the Observatory log window and find the following (some text removed for brevity):

```
Tell "I?"
Tell wrote 3  result=1
Successful SetCommTimeouts [...]
Listen 80 chars  timeout=50 ms
ReadFile result=1 [...]
Identification string = "KEO SCIENTIFIC LTD,SKYSCAN4,1.2,10318"
Successful SetCommTimeouts [...]
```

This confirms that the SkyScan is detected and communicating with Observatory.

4. Run the Master script and observe the following behavior:
 - a. The Master User 3 log in the Master GUI shows current testing operation.
 - b. The SkyScan moves smoothly between the positions defined in *Keo_SetupCycleAcquisition*.

- c. “Finished testing SkyScan operation” is displayed when complete.

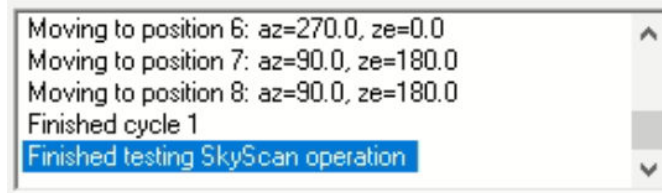


Figure 24: SkyScan Testing Output

5. Close both the Master and Observatory applications. The test is complete.

3.3.1.1 SkyScan Troubleshooting

If the SkyScan pointing head is not detected or moving, check the following items.

1. **SkyScan Pointing Head Turned On:** Ensure the pointing head is turned on. Refer to Section 3.1 for details.
2. **Observatory Configuration:** Ensure the Observatory application is configured to communicate with the correct COM port for the pointing head. This configuration is done in *ObservatoryControlFile* located in the program root directory.
3. **Power Cycle:** If all else fails, turn the power off and on again for the system and then try again.

3.3.2 Testing the Filterwheel

This test will confirm that the filterwheel is connected properly and communicating with Observatory and will then cycle through all filter positions.

1. Configure Master to run the *testFilterwheel* script.
2. Start both the Master and Observatory A3O applications.
3. Scroll up in the Observatory log window and find the following (some text removed for brevity):

```
Home color wheel (GOSUB5) ret=0
Successful SetCommTimeouts [...]
Listen 199 chars timeout=3000 ms
ReadFile result=1 err=10069 nRead=69 "Initializing...Finding
HOME...HOME FoundHOME Offset = 3508HOME:1"
```

This confirms that the filterwheel is detected and communicating with Observatory.

4. (optional) To visually confirm that the filterwheel is operating, remove the filter access port on the filterwheel so that the wheel can be directly observed during the following tests.



Figure 25: Filterwheel Filter Access Port

5. Run the Master script and observe the following behavior:
 - a. The Master User 3 log in the Master GUI shows current testing operation
 - b. The filterwheel moves smoothly between all filter positions
 - c. “Finished testing filterwheel operation”



Figure 26: Filterwheel Testing Output

6. Close Master and Observatory applications. The test is complete.
7. If the filterwheel access port was opened, remember to close it.

3.3.2.1 Filterwheel Troubleshooting

If the filterwheel is not detected or moving, check the following items.

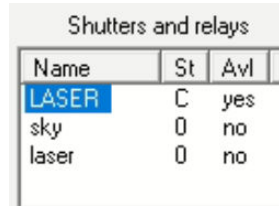
1. **Filterwheel Turned On:** Ensure the filterwheel is turned on. Refer to Section 3.1 for details.
2. **Observatory Configuration:** Ensure the Observatory application is configured to communicate with the correct COM port for the filterwheel. This configuration is done in *ObservatoryControlFile* file located in the program root directory.
3. **Power Cycle:** If all else fails, turn the power off and on again for the system and then try again.

3.3.3 Testing the Laser Shutter

This test will confirm that the laser shutter is operating correctly by cycling the shutter open and then closed with a 5 second delay between each state. The laser diffuser will light up when the laser shutter opens and will go dark when the laser shutter closes.

1. Configure Master to run the *testLaserShutter* script.

2. Start both the Master and Observatory A3O applications.
3. In Observatory, find the “Shutters and relays” section of the GUI and confirm that there is an entry called `LASER` with `Avl=yes` as shown below in Figure 27.



Name	St	Avl
LASER	C	yes
sky	0	no
laser	0	no

Figure 27: Laser Shutter Availability

4. (optional) If testing is performed in a brightly lit room, it can be hard to see if the laser diffuser is illuminating or not. In this case, either dim the room lights (or turn off entirely, if possible) or temporarily remove the laser fiber cable from the laser shutter housing and observe the laser output directly.
5. Run the Master script and observe the following behavior:
 - a. The Master User 3 log in the Master GUI shows current testing operation.
 - b. Laser shutter opens (laser diffuser illuminates or light shines out of laser) and closes (laser diffuser goes dark or laser output turns off).
 - c. “Finished Testing laser shutter operation” is displayed when complete.



Figure 28: Laser Shutter Testing Output

6. Close both the Master and Observatory applications.
7. If the fiber cable was removed in step 4, remember to replace the fiber cable into the laser shutter housing.

3.3.3.1 Laser Shutter Troubleshooting

If the laser and/or diffuser is not illuminating, check the following items.

1. **Laser Turned On:** Ensure the laser is turned on and fully stabilized. Refer to Section 3.1 for details.
2. **Laser Shutter On:** Ensure the laser shutter is connected to the host PC with the provided USB cable. There are several LEDs around the connector on the laser shutter – these should illuminate when plugged into the host computer.
3. **Laser Fiber Cable Connected:** Ensure the fiber optic cable between the laser shutter and laser diffuser is connected.

3.3.4 Testing the Camera

This script will connect to the camera and cool it to operating temperature. Capture of images will be tested in Section 3.3.6.

1. Configure Master to run *testCamera* script.
2. Start both the Master and Camera A3O applications.
3. Run the Master script and observe the following behavior:
 - a. The Master User 3 log in the Master GUI will show current testing operation.
 - b. The camera temperature slowly decreases to the desired setpoint.
 - c. "Done testing camera operation" is displayed when complete.

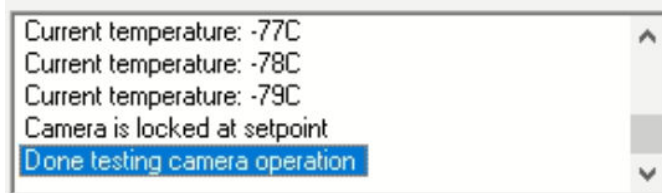


Figure 29: Camera Testing Output

4. Close both the Master and Camera applications.

3.3.4.1 Camera Troubleshooting

If the camera is not cooling, check the following items.

1. **Camera Connected and Turned On:** Ensure the camera is connected to the computer and that it is turned on.

3.3.5 Testing the PDU

On FPI systems with a network-connected PDU, this test will turn the FPI Controller off and then on again.

1. Configure Master to run the *testPDU* script.
2. Start the Master A3O application.
3. Run the Master script and observe the following behavior:
 - a. The Master User 3 Log in the Master GUI shows current testing operation.
 - b. FPI controller device turns off and on again.
 - c. In the PDU system log (login to PDU webpage and navigate to the system log), there should be entries like those shown below that show the requests from the scripts to turn the FPI controller off and on again.

```
user.notice auth[1550]: login allowed for 10918@192.168.0.50 (plaintext)
user.notice www[1638]: login 10918 succeeded from 192.168.0.50
user.info auth[1550]: 10918@192.168.0.50 session closed
user.notice www[1638]: "10918" from 192.168.0.50 has requested to switch
outlet 2 [FPI Controller] OFF
```

```

user.notice relay.state[1338]: Outlet 2: Configured state set to Off by
10918 from 192.168.0.50 via web ui
user.notice relay.state[1338]: Outlet 2: Physical state set to Off by
relay hardware via relay
user.notice auth[1550]: login allowed for 10918@192.168.0.50 (plaintext)
user.notice www[1638]: login 10918 succeeded from 192.168.0.50
user.info auth[1550]: 10918@192.168.0.50 session closed
user.notice www[1638]: "10918" from 192.168.0.50 has requested to switch
outlet 2 [FPI Controller] ON
user.notice relay.state[1338]: Outlet 2: Configured state set to On by
10918 from 192.168.0.50 via web ui
user.notice relay.state[1338]: Outlet 2: Physical state set to On by
relay hardware via relay

```

4. Close Master application.

3.3.5.1 PDU Troubleshooting

If the FPI Controller did not power off and on again, check the following items.

1. Check PDU system log for authentication errors. If present, check that username and password configured in the *Keo_SetupPDU* configuration script is correct (see Section 2.4.4).
2. If the PDU system log has no messages at all, then check that the IP address in *Keo_SetupPDU* configuration script is correct (see Section 2.4.4).

3.3.6 Testing Ring Centering and Focus

This test script will test all the devices together and aid in performing ring centering and focussing.

The following will happen in this procedure:

1. SkyScan will be commanded to point to the laser diffuser.
2. Filterwheel will be set to position 6 (typically an empty filter slot, this can be modified if desired by editing the *testRingCenteringAndFocus* script).
3. Laser shutter will be opened.
4. Camera will be cooled to setpoint and will start acquiring images with a 0.5 second exposure time.

Images that are acquired are sent to the Analyze application for display where they can be viewed while you adjust centering and focus of the rings until they are suitably centered and in-focus.

1. Configure Master to run *testRingCenteringAndFocus* script.
2. Configure *AnalyzeControlFile* (in program root directory) to re-define `Process L` as an empty process (see Section 4.3.4.1). This reduces the processing time of the images which allows them to display faster.

```

//Process L darkSubtract annularIntegrate peakLocate [...] // laser
Process L

```

3. Start the Master, Observatory, Camera, and Analyze A3O applications. There will be a warning from Analyze about “tag L” (see Figure 30 below) – this can be safely dismissed.

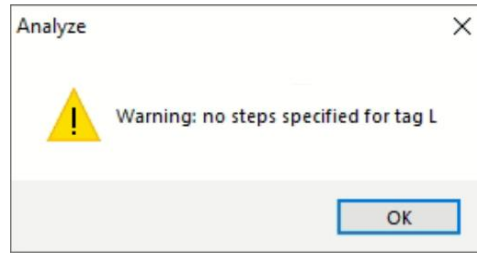


Figure 30: Analyze Process Warning

4. Run the Master script and observe the following behavior:
 - a. The Master User 3 log in the Master GUI shows current testing operation.
 - b. The log displays “Acquiring images ... (close Master to stop)”.
 - c. Analyze starts displaying a new image every approximately 2 seconds.
5. Perform ring centering and focusing as detailed in Section 3.4.
6. Once ring centering and focussing is complete, close all A3O applications.
7. Configure *AnalyzeControlFile* back to original configuration.

```
Process L darkSubtract annularIntegrate peakLocate [...] // laser
//Process L
```

3.4 Ring Centering and Focus

When the FPI system is initially setup it is highly unlikely that the etalon ring patterns will be in focus or centered on the camera sensor. The below procedure can be used any time you wish to adjust the focus or centration of the etalon, although normally it should only be necessary to do this once after moving or setting up the FPI system in a new location.

1. Get the *testRingCenteringAndFocus* script running as detailed in Section 3.3.6. Once this is done, you should start seeing a stream of images (about one every 2-3 seconds) displaying in the Analyze application. These images will most likely be out of focus and not centered in the image, like the one shown in Figure 31 below.

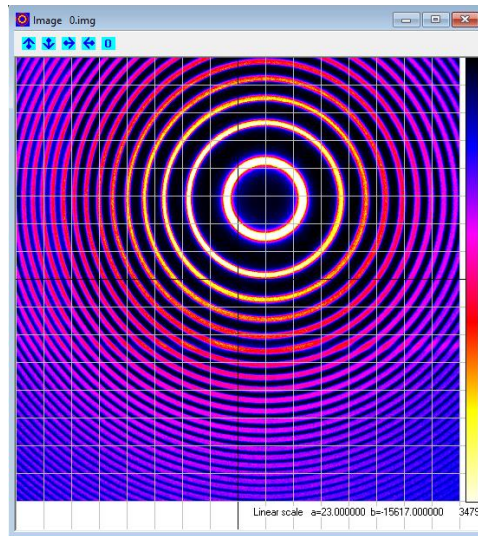


Figure 31: Rings before Centering and Focusing

2. Now adjust the focus using the lens focus mechanism until the rings become fairly in-focus. We will fine-tune the focus later, but for now we just want them to be 'roughly' in-focus.



Figure 32: Lens Focus Mechanism

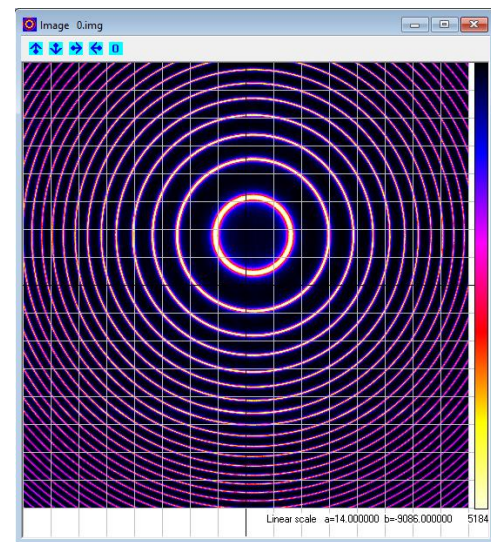


Figure 33: Lens Roughly Focused

3. Now use the three precision adjusters on the bottom of the etalon enclosure to tilt the etalon. As you do this you will observe that the ring pattern moves around on the camera sensor. You now want to roughly center the rings so that the black cross-hair in the image is within the inner ring. Note that there are white grid lines on the image and that the center grid lines are black – this is the center of the image. Once this is done, the auto center calculation will start functioning properly. This feature automatically calculates the current ring center offset and displays it.

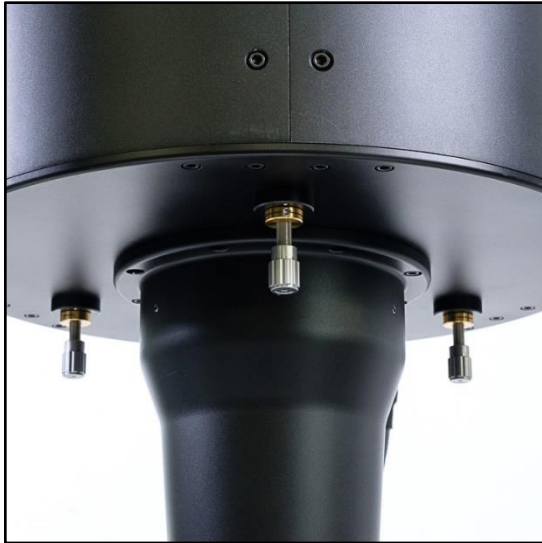


Figure 34: Etalon Tilt Adjusters

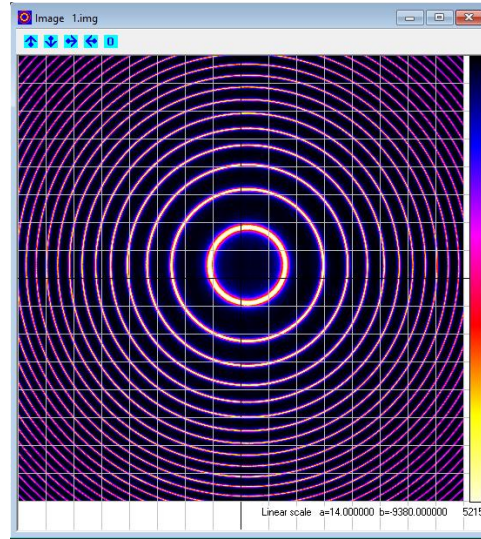


Figure 35: Etalon Roughly Centered

4. Now that the black gridlines are within the inner ring, the auto center calculation will start working (see the auto center calculated coordinates below the red highlight in Figure 36 below) and we can use that as a convenient reference as we continue to fine-tune the centration of the rings. In the example below, the rings are currently centered at (7.0,15.0). These coordinates are in pixels in (x,y).

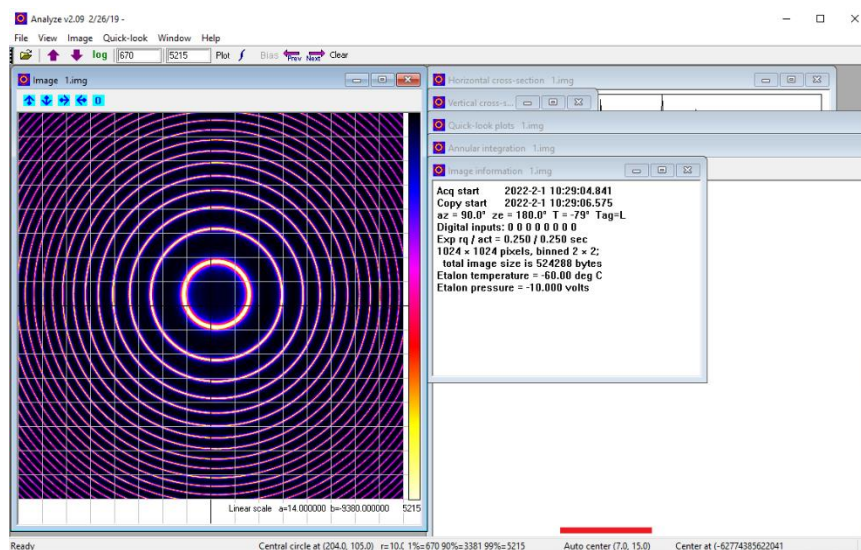


Figure 36: Analyze Auto Center Calculation

5. Continue to adjust the etalon tilt until you reach an auto-calculated center of (0.0,0.0). Congratulations, the rings are now perfectly centered on the sensor.
6. Finally, continue to fine-tune the focus until the rings are evenly focused within the image. You may find as you adjust focus that one side might be more in focus than the other. Continue to adjust until the focus “evens out” and it is symmetrical around the image. Due to the logarithmic color scaling, sharp in-focus rings tend to have yellow/white peaks while soft out-of-focus rings are pink. Adjust focus until the rings have nice white peaks all around the image as shown in

Figure 39. Figure 37 and Figure 38 show examples where focus is *close* to being centered but is shifted slightly to the right or left of the image.

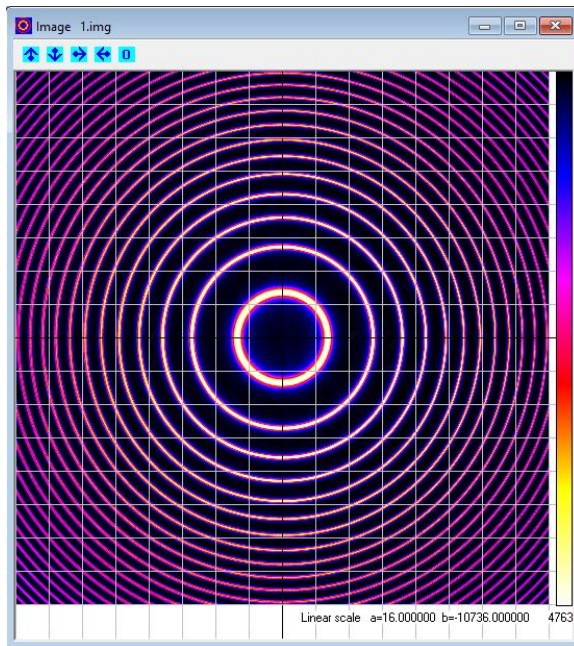


Figure 37: Lens Focus Better on Right
In this image focus is better on the right side of the image

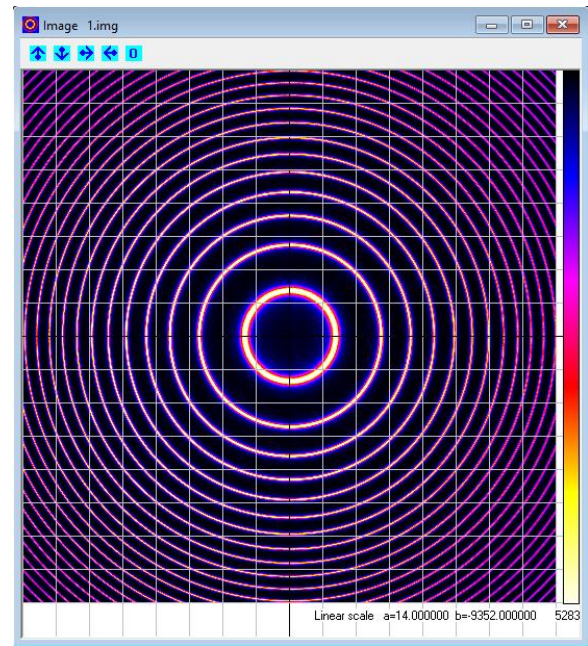


Figure 38: Lens Focus Better on Left
In this image, focus is better on the left side of the image

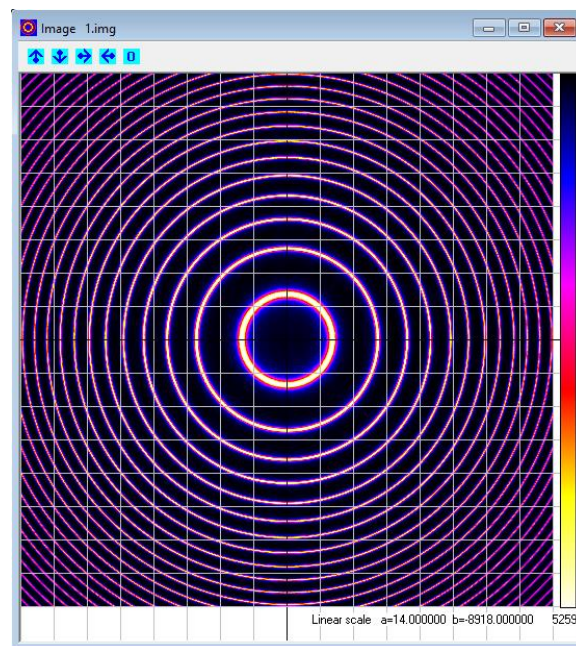


Figure 39: Lens Focus Centered
In this image focusing is nicely centered and balanced

3.5 Routine Observations

Once everything is tested and all configuration is complete, routine observations can commence.

1. Configure Master to run the *Keo_PgmDefault* script.
2. Start all of the A3O applications.
3. Run the Master script.

You will observe that it will initially run through many scripts fairly quickly. During this process, it is calculating the times at which acquisition should start (and when it should start initializing the system for acquisition). After this is complete, it will display the calculated start-times and sit idle until it is time to start acquiring data. Figure 40 shows an example of Master sitting idle waiting for system initialization.

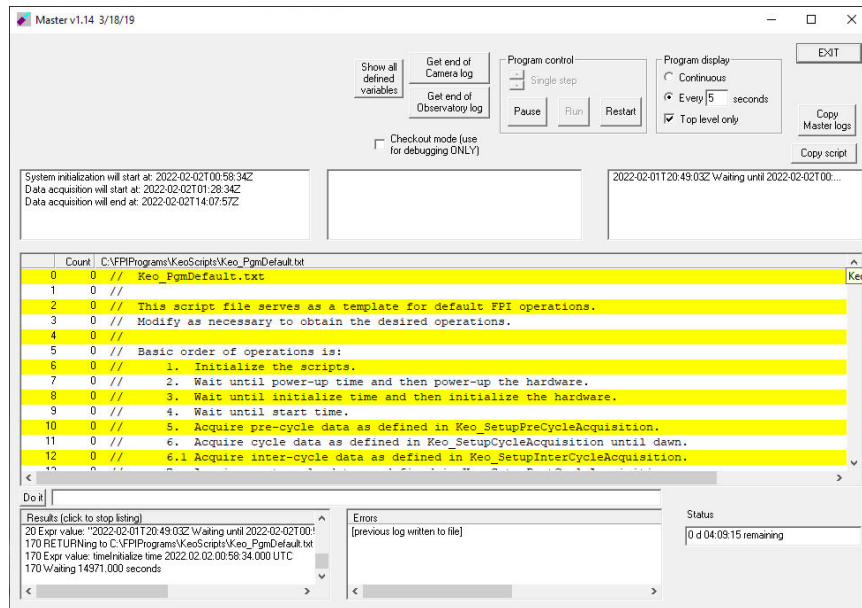


Figure 40: Master Waiting for System Initialization

3.6 Powering Down the System

When you want to turn off the FPI system, simply close the A3O applications, shutdown the computer, and turn off the laser, FPI controller, and camera.

If the system ever needs to be moved (or put in storage), please ensure that the etalon is removed from the instrument prior to moving the FPI. If the instrument will be transported, it is highly recommended that the flexure-locking setscrews be restored to their initial locked positions. This can be done by reversing the instructions in Section 2.2.



Caution

When tightening the setscrews to lock the flexures, **do not overtighten** them. They only need to be 'snug'. Tighten them until you start to feel resistance and then stop there.

4 Software Overview

The software used to control the FPI system is called “A3O” and is maintained and supported by Dr. John Meriwether and Peter Sherwood. A3O is a suite of programs which are designed to operate a Fabry-Pérot observing station. In normal operation, A3O runs four or five independent application which communicate with each other using a message-based protocol.

The A3O software is installed in `C:\FPIPrograms\` on your computer. This will be referred to as the program root directory. Inside this folder you will find the application executables (`Master.exe`, `Camera.exe`, `Observatory.exe`, `Analyze.exe`, and `Communicate.exe`) along with many other additional files used by the software.

A3O includes a comprehensive help file `A3O.chm` located in the program root directory. While it shouldn't normally be necessary to consult this file, it would be a good resource if you have a question regarding something that is not covered in this manual.

Note

If a computer is provided with your FPI system, then the software and scripts have been pre-configured for your system. The only script configuration that should be necessary is as described in Section 2.4.

4.1 Installing A3O

The A3O applications and default scripts are hosted in a git repository on Bitbucket at:

```
https://bitbucket.org/keosci/keo-a3o
```

To install the applications, simply download or clone this repository to your program root directory (we recommend `C:\FPIPrograms\`)

4.2 Installing Supporting Applications

In addition to the A3O applications and scripts, the following software is recommended to be installed:

SourceTree: This is a GUI for interacting with git repositories. It is recommended that you use git to commit changes in your configuration (to a local branch) so that any future script updates can be easily merged with your existing configuration.

RealTerm: Used for testing purposes to help determine COM port assignments.

7-Zip: Used for managing zip files on the system.

Visual Studio Code: Used for editing configuration files in a modern tab-based interface.

ClarityII: This is the software for the Boltwood cloud sensor provided with the FPI system which can be downloaded from the manufacturer here:

```
https://diffractionlimited.com/product/boltwood-cloud-sensor-ii/
```

4.3 A3O Applications

The five independent applications that constitute the A3O software are: Master, Camera, Observatory, Analyze, and Communicate. Each of these applications has a specific function as described below.

4.3.1 Master

The Master application acts as the central controller of the A3O software. It executes a user-written script which manages operations of the Camera, Observatory, Analyze, and Communicate applications. Under normal operation, this is the main program that you will directly interact with to run your observations.

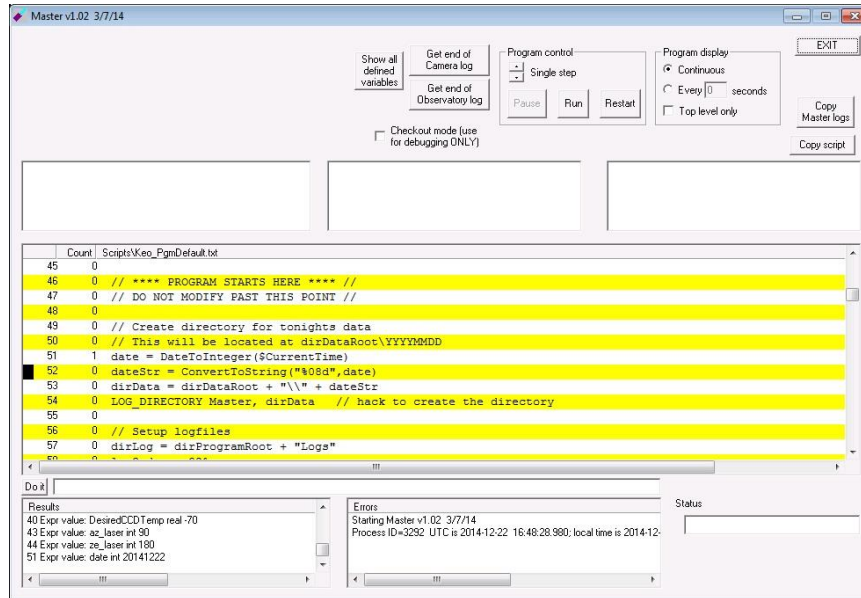


Figure 41: A3O Master Program

4.3.1.1 Master Log Files

The Master application has many logfiles that it creates under normal operations. These logfiles are by default stored in the same directory as the A3O application executables (C:\FPIPrograms\) but our custom script will redirect these to be stored in a logs\ sub-folder with your acquired image data.

Unfortunately, despite the Master application (and Camera/Observatory which we will discuss later) logging errors, the script that is executing is unable to be informed about these errors and it will continue executing and will very likely have unexpected results.

Master Errors: This logfile contains any script parsing or runtime errors that occur while executing scripts. It is a good idea to occasionally check this logfile to see if there are any errors occurring that might otherwise go un-noticed. Generally, since this logfile mainly displays script syntax and parsing errors, once the scripts have been run for a night they will continue to do so error-free.

Master Results: This logfile contains the result of every executed script. As such, it can often grow to be fairly large in size. The contents of this file is only really useful if trying to debug a particular script error that might be occurring.

Master User 1, 2, and 3: These three logfiles are optional and are generated on demand if the running script requests it by logging information to them. We use these as a way to display useful

information to the operator while a script is running since they are displayed on the main Master GUI (see 4.3.1.2).

4.3.1.2 GUI Overview

The Master GUI can be broken down into a number of different elements as shown in Figure 42.

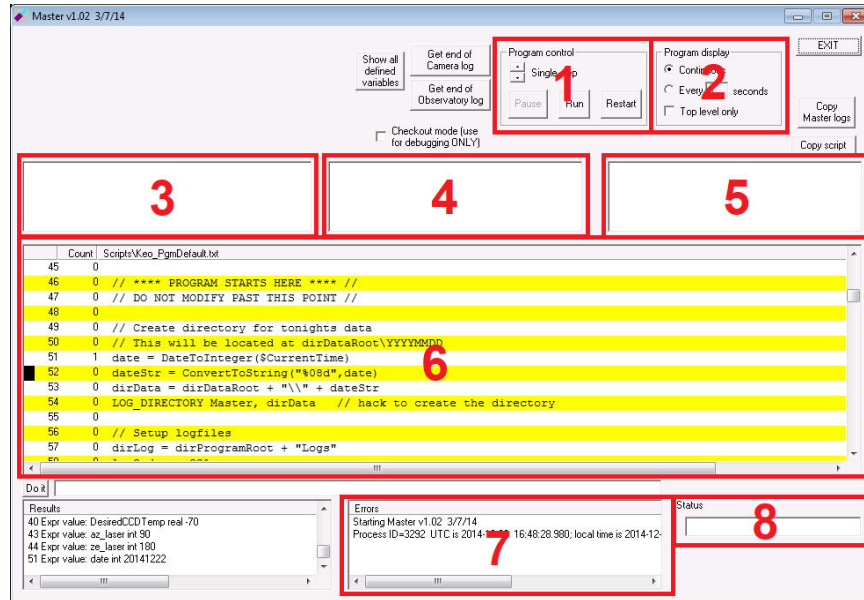


Figure 42: Master GUI

1. **Program Control**

This section lets you run, pause, and restart a script. In general, only the Run button should be used.

2. **Program Display**

This section lets you adjust how the program is displayed in section 6 of the GUI. With the default settings (“Continuous” and “Top level only” disabled), the program display will update for every line of the script that is executed so that you can see exactly what line is currently being executed. For routine operations this is not required and we suggest setting these options to “Every 5 seconds” and to enable the “Top level only” setting. This will reduce the frequency at which the display updates and speed up processing of the scripts.

3. **Master User 1 Log**

This box will display messages from the scripts that target the “Master User 1” log file.

4. **Master User 2 Log**

This box will display messages from the scripts that target the “Master User 2” log file.

5. **Master User 3 Log**

This box will display messages from the scripts that target the “Master User 3” log file.

6. **Script Program Display**

This is where the actively executing script is displayed. Depending on the program display settings (section 2 of GUI) this will either display the current file or it will be scrolling and

displaying every line that is currently executing.

7. Master Error Log

This box will display script error messages. Normally these are limited to script parsing errors (invalid variable names, missing script files, etc.).

8. Script Status

This box will display “Running” when the script is executing or if a `DELAY` command is in progress (i.e., currently delaying for some period of time), this box will display the time remaining on before execution of the script will resume.

Any other buttons not mentioned above can safely be ignored unless otherwise instructed.

4.3.2 Camera

The Camera application is responsible for all communication with the camera on the FPI system. The user controls on the left side of the interface are only to be used when manually testing the camera functions. Under normal operation you will not need to use any of these controls. The large white area contains the log for this application, which can be useful for debugging problems with the software.

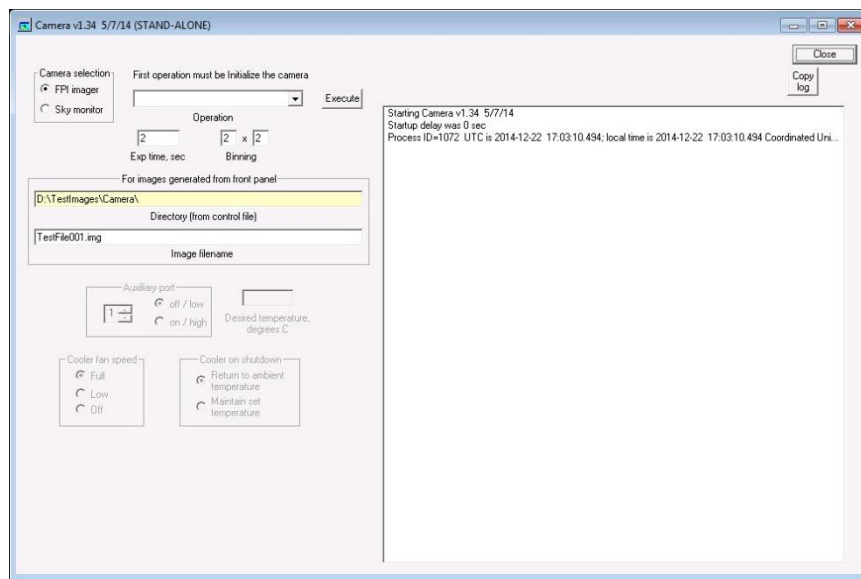


Figure 43: A3O Camera Program

4.3.2.1 Camera Configuration File

There is a configuration file for the Camera application called `CameraControlFile` which is located in the program root directory. The parameters in this file that are important for proper system configuration are:

FPIMake: ‘Princeton’ or ‘Andor’, depending on the type of camera attached to the FPI.

All other parameters are either not important to Keo Scientific FPI systems, or they are otherwise controlled through the A3O scripts and the values in `CameraControlFile` are thus not important.

4.3.2.2 Camera Log File

The Camera application creates a log file that is stored in the same location as the Master log files. The contents of this log file are simply everything that is logged in the logging window.

Any errors that are logged in Camera are not sent to the Master application so Master and the running script are often unaware that problems are occurring. It is important to occasionally check the Camera log file to see if there are any errors occurring.

4.3.3 Observatory

The Observatory application is responsible for communicating with the various other pieces of observatory hardware that constitute the FPI system. This includes the pointing head, filterwheel, and laser shutter. As with the Camera application, the user controls in this program are only to be used when testing Observatory functions. Under normal operation you will not use any of these controls.

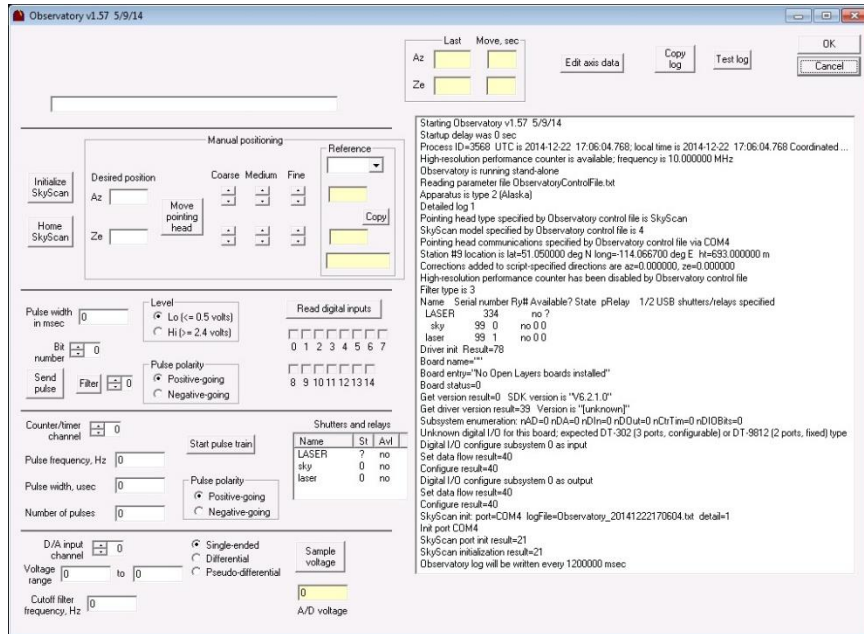


Figure 44: A30 Observatory Program

Note that when Observatory launches, the error below is always displayed. This is considered normal and the message will automatically disappear after a few seconds (or you can click OK to dismiss it immediately). This message is a result of the Keo FPI system not using a certain data acquisition module that Observatory was originally designed to be used with.

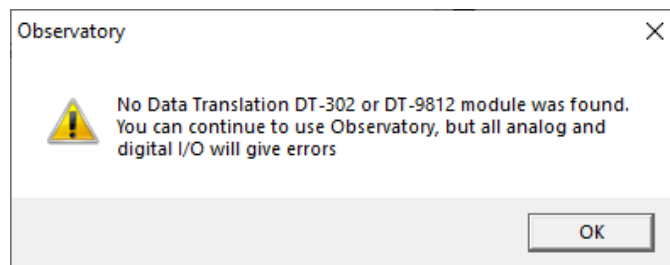


Figure 45: Observatory Data Translation Error

After this error is dismissed, the Observatory program will appear to not have launched, but after a while (up to 10 seconds later) it will re-appear. This is due to it running some background processes to detect connected devices when it launches. Again, this is normal and expected behavior.

4.3.3.1 Observatory Configuration File

There is a configuration file for the Observatory application called `ObservatoryControlFile` which is located in the program root directory. There are several parameters in this file that must be configured for proper operation with a Keo FPI system. Any parameters not mentioned below can be safely ignored and left to their default values as provided with the installation.

Parameter Name	Default Value	Comments
<code>apparatusType</code>	2	<i>'Alaska Style' FPI</i>
<code>PHType</code>	1	<i>'SkyScan' type pointing head (aka. Panhead)</i>
<code>SkyScan_model</code>	4	<i>Keo SkyScan panhead</i>
<code>AzCorr</code>	0	<i>Offset from device home to north (clockwise = positive) in degrees. This will be adjusted as part of the setup procedure (see Section 2.4.1).</i>
<code>PHCommPort</code>	COM3	<i>The COM port to use for the Keo SkyScan</i>
<code>ShutterName</code>	LASER 388	<i>The name and serial number of the laser shutter. The name should always be LASER for use with the Keo scripts.</i>
<code>FilterCommPort</code>	COM5	<i>The COM port to use for the filterwheel</i>
<code>FilterType</code>	5	<i>Keo Scientific filterwheel type</i>
<code>FiltSlots</code>	6	<i>Number of filter slots in the filterwheel</i>
<code>stationLatitude</code>	51.0404	<i>Geodetic latitude in degrees, north positive</i>
<code>stationLongitude</code>	-114.0589	<i>Geodetic longitude in degrees, east positive</i>
<code>stationHeight</code>	1045.0	<i>Height of station in meters</i>

4.3.3.2 Observatory Log File

The Observatory application creates a log file that is stored in the same location as the Master log files. The contents of this log file are simply everything that is logged in the logging window.

Any errors that are logged in Observatory are not sent to the Master application so Master and the running script are often unaware that problems are occurring. Additionally, the Observatory log file can be hard to understand unless you are intimately familiar with its operation. If you suspect that errors are occurring in Observatory, please contact the Keo Scientific support team for assistance.

4.3.4 Analyze

The Analyze application provides real-time display and basic data reduction of captured images. Each image captured by the FPI system will be displayed in Analyze.

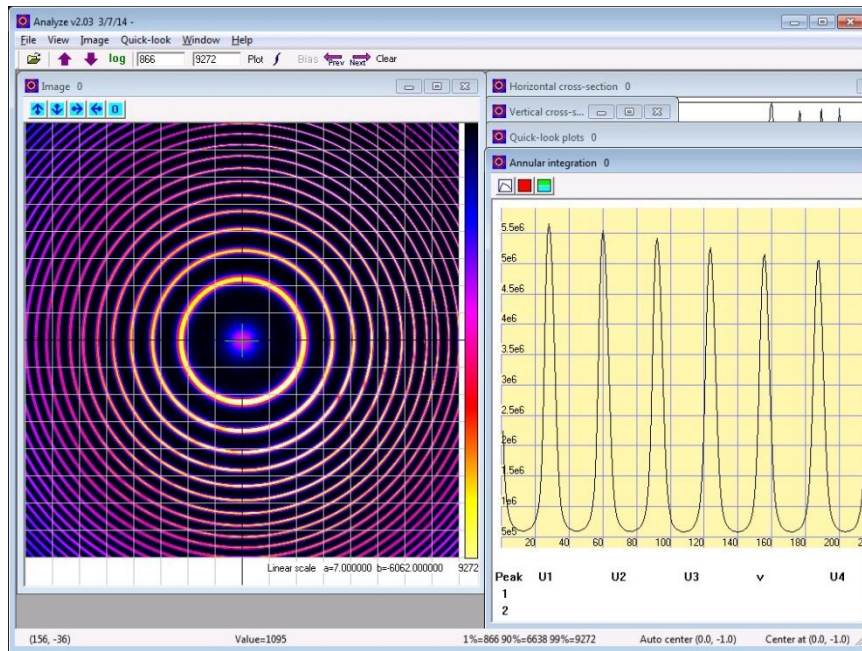


Figure 46: A30 Analyze Program

4.3.4.1 Analyze Configuration File

There is a configuration file for the Analyze application called `AnalyzeControlFile` which is located in the program root directory. Most of this file can be safely ignored except for the section that defines image processing parameters.

When an image is sent to Analyze from a script, it is sent with an 'Analyze Tag' that is used to tell Analyze how to process the file. For example, for sky dark frames (tag D), the image is just stored as a dark frame for sky data whereas for sky images (tag X), they subtract the previously stored dark data, perform annular integration, peak locating, and other processing. This is all defined in this configuration file.

The default processes provided are shown below.

```
// **** IMAGE PROCESSING PARAMETERS **** //
// Possible options are darkStore, darkSubtract, annularIntegrate, peakLocate,
//    zenithProcess, laserProcess, and nightGlowProcess

// bias data
Process B annularIntegrate

// laser dark and laser
Process K darkStore annularIntegrate // laser dark
Process L darkSubtract annularIntegrate peakLocate laserProcess // laser
//Process L

// sky dark
Process D darkStore annularIntegrate // 630 dark
Process E darkStore annularIntegrate // 732 dark

// sky zenith
Process Z darkSubtract annularIntegrate peakLocate zenithProcess // 630 zenith
Process Y darkSubtract annularIntegrate peakLocate // 732 zenith

// sky
```

```

Process N darkSubtract annularIntegrate peakLocate nightGlowProcess // 630 sky
Process M darkSubtract annularIntegrate peakLocate // 732 sky

```

Note that Process L has a second definition that is commented out with no processes defined. This is used when performing ring centering and focussing to minimize the time spent processing images.

Also note that the comments referring to 630 and 732 are assuming that this particular FPI has 630nm and 732nm filters installed. In fact, any wavelength could use any process, should you wish – the standard however is that 630 uses processes D, Z, and N for dark, sky zenith, and sky images, respectively.

4.3.4.2 Analyze Log File

The Analyze application does not have a log file like the other A3O applications. Instead it creates a log file in the same directory as the captured data that represents the quick-look results. Please refer to A3O help documents (A3O.chm file) for assistance understanding this file.

4.3.5 Communicate

The Communicate application provides support for transferring data to a remote FTP server. You do not need to execute this application unless you require this functionality.

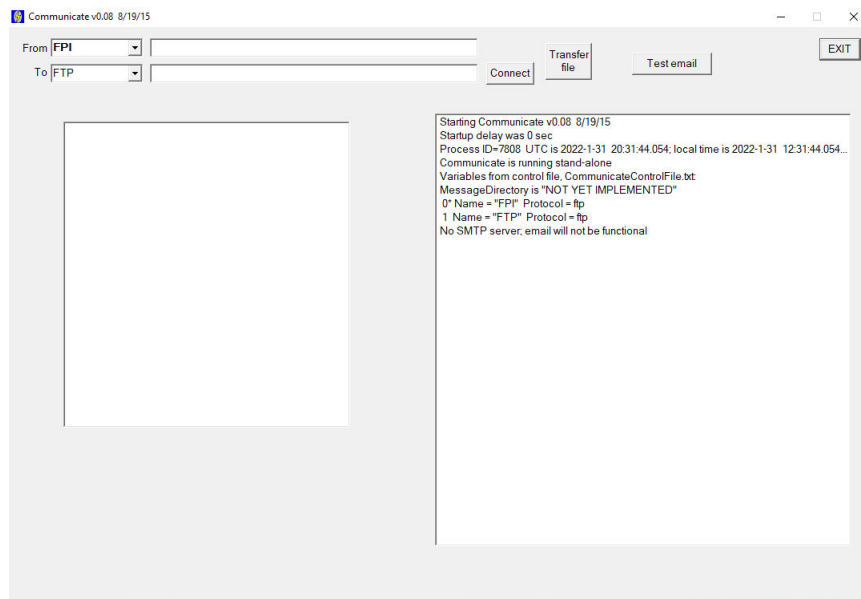


Figure 47: A3O Communicate Program

4.3.5.1 Communicate Configuration File

There is a configuration file for the Communicate application called `CommunicateControlFile` which is located in the program root directory. Communicate is different from the other applications in that this file is not directly editable, as it is encrypted. Instead, it is generated using the `CommunicateControlFile_Setup.exe` application. The intent of this is to prevent FTP login credentials from being stored in plain-text on the FPI system.

The idea behind this is that `CommunicateControlFile_Setup.exe` and the un-encrypted `CommunicateControlFile_In.txt` should not reside on the target FPI system. Instead, the

encrypted `CommunicateControlFile` would be generated on a different computer and transferred to the FPI system.

4.3.5.2 Communicate Log File

There is no Communicate log file, so if problems are occurring, please contact Keo support to help diagnose the problem.

4.4 Starting A3O

Since A3O consists of multiple separate applications, it is required that each be started before you start running scripts in Master. The procedure for starting the full A3O suite of programs is to first start Master and then start each of the other processes: Camera, Observatory, Analyze, and Communicate (if FTP file transfer is desired). *It is important that Master always be the first script started since the other programs look for and connect themselves to it upon initial startup.*

If you start Camera, Observatory, or Analyze before Master, you will get a message similar to the one shown below, informing you that the Master application was not found to be running. Close the application and start Master before continuing to start the other applications.



Figure 48: Master Not Running

Note

To simplify the task of starting and stopping the A3O applications, there are two batch scripts located in the program root directory for automating this task: `StartA3O.bat` and `StopA3O.bat`. Running either of these scripts will automatically start or stop all the required applications.

Additionally, these scripts can be customized as required to launch additional programs. Below is the default contents of the `StartA3O.bat` file. Lines prefixed with `::` are comments and will be ignored so in the example below the Communicate application is set to *not* start automatically.

```
:: StartMaster.bat
:: Starts up the A3O applications automatically
::

:: Start Master
START C:\FPIPrograms\Master.exe

:: Wait 5 seconds (1 sec between each ping)
PING 127.0.0.1 -n 6 > NULL

:: Start other A3O applications minimized
```

```
START /MIN C:\FPIPrograms\Camera.exe
START /MIN C:\FPIPrograms\Observatory.exe
START /MIN C:\FPIPrograms\Analyze.exe
::START /MIN C:\FPIPrograms\Communicate.exe

:: Start Boltwood cloud sensor software
::START /D "C:\Program Files\Boltwood Systems\Clarity II\" ClarityII.exe

EXIT
```

4.5 Script Organization

Operation of the A3O applications is governed by a user-written scripts. Keo Scientific has spent considerable effort developing a default script that can be used in most if not all FPI operational modes. All that is required is that the user edit some configuration scripts to define the instrument hardware and desired data to acquire.

Script files are simple plain-text files with `.txt` file extensions. Throughout this manual, and in the scripts themselves, the file extension will often be omitted. It can be assumed that if we're talking about a script, then it also has a `.txt` file extension whether explicitly shown or not. Additionally, script file names will be styled like this for clarity: *ThisIsAScriptFile*.

All script files are organized within the `KeoScripts\` folder within the program root directory and are further organized based on their classification of being either "Configuration", "Testing", or "Utility" scripts.

Configuration scripts are to be edited by the user to configure the system as desired. These include scripts that define the instrument hardware as well as the ones that define the desired operational acquisition schedule.

Testing scripts are only used during the testing phase of instrument deployment and serve the purpose of testing components of the system.

Utility scripts are called throughout the other scripts and can be thought of as functions that we reuse in many places in the main scripts. The user should not need to ever edit these scripts unless they are altering the core-functionality of the system.

The *Keo_PgmDefault* script located in the root of the `KeoScripts\` folder is the main script that we will configure Master to run for routine operations of the FPI system. This file should not need to be edited under normal circumstances.

4.6 Selecting a Script to Run

The Master application will always run the *PgmDefault* file located in the program root directory. By modifying this script file we can choose any script of our choice to be run. Below you can see the default contents of this file. Any line that is prefixed with `'\'` is interpreted as a comment and will not be executed by Master.

This script starts by initializing a few variables that are used throughout the scripts and then it will call one of a series of `OVERLAY` commands to call the actual script to execute.

```
//
// PgmDefault.txt
// This is the program that is run by Master
// Use OVERLAY to insert your own script to be run

// root directory for FPIPrograms
dirProgramRoot = "C:\\FPIPrograms\\"

// root directory for KeoScripts
dirKeoScripts = "C:\\FPIPrograms\\KeoScripts\\"

// initialize log folder variable
dirLog = ""

// initialize date variable
date = 0

//
// Master script
//
OVERLAY (dirKeoScripts + "Keo_PgmDefault")

//
// Test scripts
//
//OVERLAY (dirKeoScripts + "Testing\\testSkyScan")
//OVERLAY (dirKeoScripts + "Testing\\testFilterwheel")
//OVERLAY (dirKeoScripts + "Testing\\testLaserShutter")
//OVERLAY (dirKeoScripts + "Testing\\testCamera")
//OVERLAY (dirKeoScripts + "Testing\\testPDU")
//OVERLAY (dirKeoScripts + "Testing\\testRingCenteringAndFocus")
```

After initializing the few variables, this script will execute this line which calls the default Keo master script:

```
OVERLAY "Scripts\\Keo_PgmDefault"
```

The **OVERLAY** script command will load the specified script file in place of the current file and begin execution of it. This provides an easy way to change which script Master will execute. Simply change which **OVERLAY** line is not commented out to run a different script. For example, if we want to run the *testLaserShutter* script then we just comment out the “Keo_PgmDefault” line and un-comment the “testLaserShutter” line as shown below (these changed depicted with **bold font**)

```
// [...]

//
// Master script
//
//OVERLAY (dirKeoScripts + "Keo_PgmDefault")

//
// Test scripts
//
```

```
//OVERLAY (dirKeoScripts + "Testing\\testSkyScan")
//OVERLAY (dirKeoScripts + "Testing\\testFilterwheel")
OVERLAY (dirKeoScripts + "Testing\\testLaserShutter")
//OVERLAY (dirKeoScripts + "Testing\\testCamera")
//OVERLAY (dirKeoScripts + "Testing\\testPDU")
//OVERLAY (dirKeoScripts + "Testing\\testRingCenteringAndFocus")
```

4.7 Running a Script

When the Master application launches, it will automatically start executing the *PgmDefault* script after a period of about a minute. You can also manually start a script with the buttons on the Master application interface.

If you wish to change which script is running or restart a script, you must first close the Master application, then modify the script to run by editing the *PgmDefault* script, and then relaunch the Master application. Due to the interlinked nature of the A3O applications, it is recommended that you stop and relaunch all the A3O applications each time you do this. There are times when simply restarting Master will work, but other times it may not and you will be forced to restart all the applications.

4.8 The A3O Scripting Language

The scripting language used by A3O is not a standard one but instead is one developed by Peter Sherwood. It is similar in many ways to C or FORTRAN but it is not exactly the same. The *A3O.chm* help file is the best reference for fully understanding the language. Here, we merely touch upon a few idiosyncrasies of the language.

4.8.1 Variables

Unlike most programming languages, variables in A3O are defined when they are first used. This means they take on the type and value of when you first use them. Also be aware that the type of a variable can change! If you first use a variable as type *int* (e.g., “a = 5”) and then later assign it as a *real* (e.g. “a = 6.0”) then your ‘a’ variable now has type *real*. This may cause problems when trying to use these variables for indexing into arrays.

Also regarding arrays, since there is no way to pre-declare an array as having a certain size, the size is assumed the first time you use the array. For example, let’s say we want to have an array called ‘b’ that has integers in it. First we use the b array like this “b(0) = 1” and now we have an array with size 11 (index 0 through 10). *Side note: in A3O scripting language, you access an element in an array with parenthesis ‘()’ instead of square brackets ‘[]’.* There is no way to expand this array further and the unused part of the array is uninitialized. If you wish to have an array of size larger than 11 then you need to access that array for the first time with an index of 11 or greater. For example, if we first access the b array by doing “b(11) = 1” then now we have an array of size 101 (index 0 through 100). It is not possible to have an array larger than 101 elements. Also note that as with regular variables, assigning an element of an array to a new type will change the type of the entire array and the values are not converted/cast when changed.

4.8.2 Strings

String functionality is fairly limited in the scripts. A string is really just an array of *char* values and that array has size 101. You cannot have a string longer than 101 characters and there are no functions built into the language to manipulate strings. The only operation you can do is to concatenate them together with the ‘+’ operator.

4.8.3 Functions and Commands

There are many functions built into the A3O language to provide things like date/time conversions, basic math functions, etc. (see the `A3O.chm` file for a complete listing). Additionally, there are what might be called “Script Commands” which have a specific purpose to the A3O programs. For example, the `OVERLAY` command which replaces the current script with a new one or the `CALL` command for calling a subroutine (a subroutine is just another script with a `RETURN` command at the end). These script commands are all UPPERCASE to easily distinguish them from variables and other basic functions.

4.8.4 Program Flow

- `If-Else-Endif` statements cannot have an `ElseIf` command block and you can only nest `If` statements 10 levels deep.

4.8.5 Misc.

- Script syntax errors are logged to the `MasterErrors` log when they are executed (there is no pre-scan for errors). Additionally, the line number provided in the error message is off by 2 lines (add 2 to the provided line number to find the line in the script file).
- Semi-colons are not required at the end of lines, they will be ignored if included.

4.9 Configuration Scripts

Before you can begin observations with the *Keo_PgmDefault* script, it is necessary to modify certain configuration scripts so that the system performs as required. This consists of opening each of the scripts in the “Configuration” folder and making changes as required. An overview of the purpose of each configuration script follows this section.

4.9.1 Keo_SetupData

This configuration file defines where collected data should be stored and the site identifier that should be used in file naming. Note that all paths must ‘escape’ the ‘\’ character by including two of them. For example, to store data in the `D:\FPIData\` directory, you would enter “`D:\\FPIData\\`”.

4.9.2 Keo_SetupHardware

This configuration file defines the hardware configuration of the FPI system. Please refer to the self-documenting comments in the configuration file for description of the available settings.

4.9.3 Keo_SetupPDU

This configuration file defines how the scripts will interact with a PDU, if one is installed. Note that this is only applicable if the `pduType` variable in the *Keo_SetupHardware* configuration script is set to something other than `PDU_NONE`.

4.9.4 Keo_SetupFilters

This configuration file defines a set of acquisition parameters to use for each filter in the FPI system. Please refer to the configuration file comments for full details. Below is an overview of the actions required to fully configure the system’s filters.

1. Set the `numFiltersMax` variable to the number of filter slots (positions) available (usually 1-6).
2. Define filters and assign to a filter position.

3. Define bias, sky, and laser exposure times for each filter.
4. Define camera settings for each filter.
5. Define sky and dark datatypes for each filter. The normal sequences to use are:
 Sky data: X/Y/Z/U/V/W
 Dark data: D/E/F/G/H/I
 Laser data: L
 Laser dark data: K
 Bias data: B

4.9.5 *Keo_SetupCompressAndSend*

This configuration script configures automatic data compressing (zip archiving) and transferring to remote FTP server. The system can either not do this at all, can only compress, or can compress and send.

4.9.6 *Keo_SetupSunEphemeris*

This configuration file defines the sun angles used to determine when a night begins and ends. By setting **EnableSunEphemeris** to 0 you can disable the ephemeris limits entirely which can be useful for testing purposes.

4.9.7 *Keo_SetupCycleAcquisition (and Pre/Post/Inter)*

This series of configuration files is used to define acquisitions to capture at various points in the execution of the main script.

Keo_SetupPreCycleAcquisition: Will be iterated through once at the start of each night.

Keo_SetupPostCycleAcquisition: Will be iterated through once at the end of each night.

Keo_SetupInterCycleAcquisition: If enabled, will be iterated through once at the specified time in the middle of a night's acquisition cycle.

Keo_SetupCycleAcquisition: Will be iterated through repeatedly after completion of pre-cycle and until start of post-cycle.

In each of these configuration files, acquisition parameters are added to a series of arrays to define each acquisition.

First, the total number of acquisitions in the cycle must be defined (**numCycleAcquisitions**, **numPreCycleAcquisitions**, etc.). This value must not exceed the number of defined acquisitions or a run-time error will occur. Note that this value can be set to a number lower than the number of positions, and in that case only that many positions will be used. E.g., if **numCycleAcquisitions=1** but there are 3 acquisitions defined, only one acquisition will ever be captured despite the additional definitions.

Each acquisition requires five pieces of information to define an acquisition:

az_pos(n): the azimuth position of the pointing head ($0.0 \leq \text{az_pos} < 360.0$).

ze_pos(n): the zenith position of the pointing head ($0.0 \leq \text{ze_pos} \leq 180.0$).

data_type(n): the datatype of the acquisition, must match the values defined in *Keo_SetupFilters*.

analyze_tag(n): the process tag used by Analyze application. See *AnalyzeControlFile* for valid options.

filter(n): the filter to use for the acquisition.

Note that the above names are only valid for the *Keo_SetupCycleAcquisition* script file. In the Pre/Post/Inter versions of this file, *_pre/_post/_inter* need to be appended to the names. E.g., *filter* becomes *filter_pre*.

These pieces of information are stored in an array in program memory. To save a value into this array, the index position for the current value must be included. This index is zero based so the first entry, which has $n = 0$, could be

```
// north sky
az_pos(0) = 0.0
ze_pos(0) = 45.0
data_type(0) = dataTypeX
analyze_tag(0) = "N"
filter(0) = FILTER_6300
```

while the second entry, which has $n = 1$, could be

```
// east sky
az_pos(1) = 90.0
ze_pos(1) = 45.0
data_type(1) = dataTypeX
analyze_tag(1) = "N"
filter(1) = FILTER_6300
```

To make re-arranging and adding new positions easier, using a variable for the index can simplify things. The example below shows the same two positions above, but defined using a helper index variable. The benefit of this is that the order of the acquisitions could be swapped by simply swapping the **acqNum** variable instead of having to change it for each line of each acquisition.

```
// north sky
acqNum = 0
az_pos(acqNum) = 0.0
ze_pos(acqNum) = 45.0
data_type(acqNum) = dataTypeX
analyze_tag(acqNum) = "N"
filter(acqNum) = FILTER_6300

// east sky
acqNum = 1
```

```
az_pos(acqNum) = 90.0  
ze_pos(acqNum) = 45.0  
data_type(acqNum) = dataTypeX  
analyze_tag(acqNum) = "N"  
filter(acqNum) = FILTER_6300
```

5 Warranty & Service

5.1 3 Year Limited Warranty

Keo Scientific Ltd. (Keo) warrants this product (see Exclusions below) with a 3 year Keo Scientific Warranty. The product is warranted to meet published functional specifications and to be free of defects in materials and workmanship as defined in the specifications for 3 years from the date of original shipment from Keo. During this time, Keo will arrange to have the product repaired or replaced without charge to you. The instrument must be returned to Keo for inspection and assessment. You are only responsible for shipping costs to return the product.

5.2 Exclusions

1. Damage resulting from accident, misuse, abuse, lack of reasonable care, subjecting the product to any but the specified electrical service, other than normal and ordinary use of the product, subjecting the product to abnormal working conditions or any other failure not resulting from defects in materials or workmanship.
2. Damage resulting from modification, tampering with, or attempted repair by anyone other than Keo.

5.3 Shipping Damage

Any damage occurring to the instrument while in transit from Keo to the customer must be reported to the shipping or courier company immediately upon receipt of goods. Shipments are separately insured, and such damage is covered under this insurance. Please immediately and thoroughly inspect the instrument upon arrival.

5.4 How to Make a Warranty Claim

1. Contact Keo by telephone or email to obtain support under warranty.
2. Deliver, mail, or ship the product to Keo's main office.

You must pay any postage, shipping charges, insurance costs, and other expenses to return the product to Keo Scientific, Calgary, Canada. However, if the necessary repairs are covered by the warranty, Keo will pay the return shipping charges to the original destination.

The product must be shipped back to Keo in the original shipping case.

5.5 Contact Information

Keo Scientific's main office is located at the following address:

Keo Scientific Ltd.
430 – 11979 40 ST SE
Calgary AB T2Z 4M3
Canada

Tel: +1 (403) 452-7222

Email: support@keoscientific.com

An up-to-date list of addresses and telephone numbers is available on our website at www.keoscientific.com/contact.php

5.6 Technical Support

In the event that you need technical support to troubleshoot a problem with your product, please do not hesitate to contact us at support@keoscientific.com.

Appendix A System Dimensions

The FPI system is quite large and requires ample room around the device and under the dome for it to fully function. The SkyScan (also called the pointing-head or panhead) on the top of the device rotates 360° around two axes and without sufficient clearance it will impact and damage the dome.

A.1 70mm FPI System Dimensions

Figure 49 shows the overall dimensions of the 70mm FPI system.

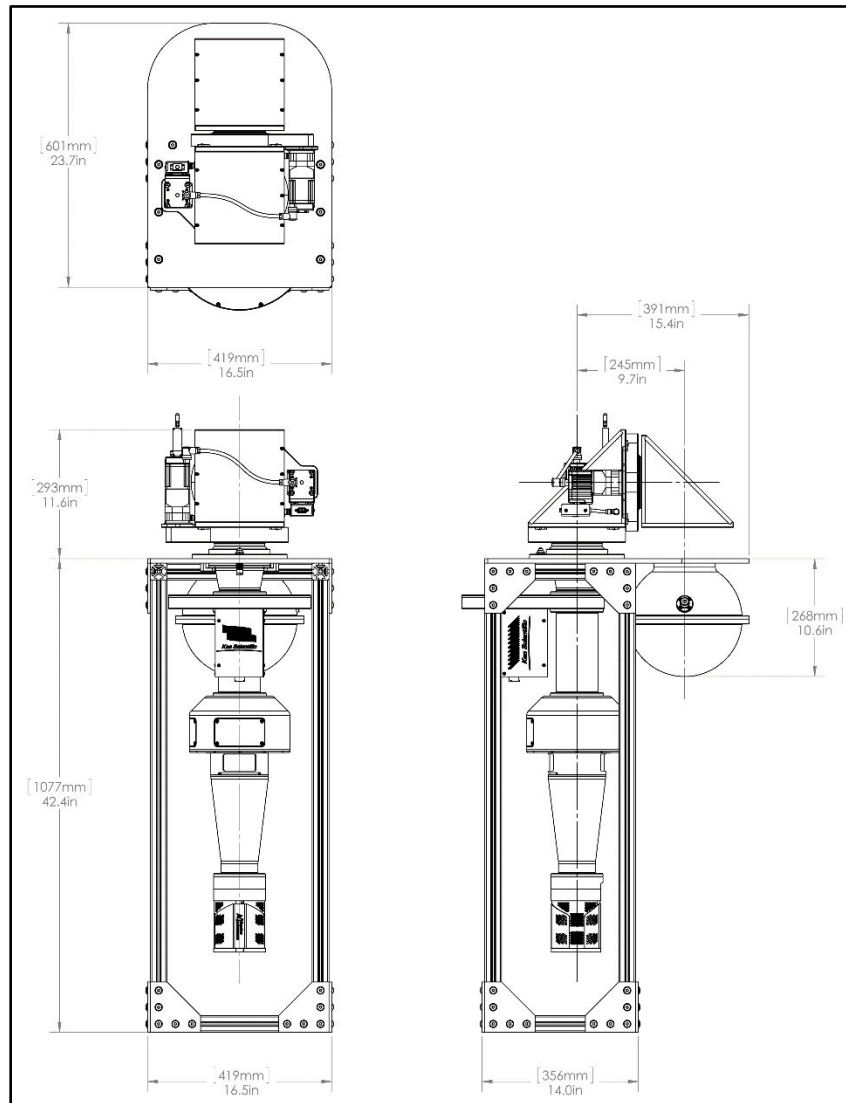


Figure 49: 70mm FPI System Dimensions

A.2 100mm FPI System Dimensions

Figure 50 shows the overall dimensions of the 100mm FPI system.

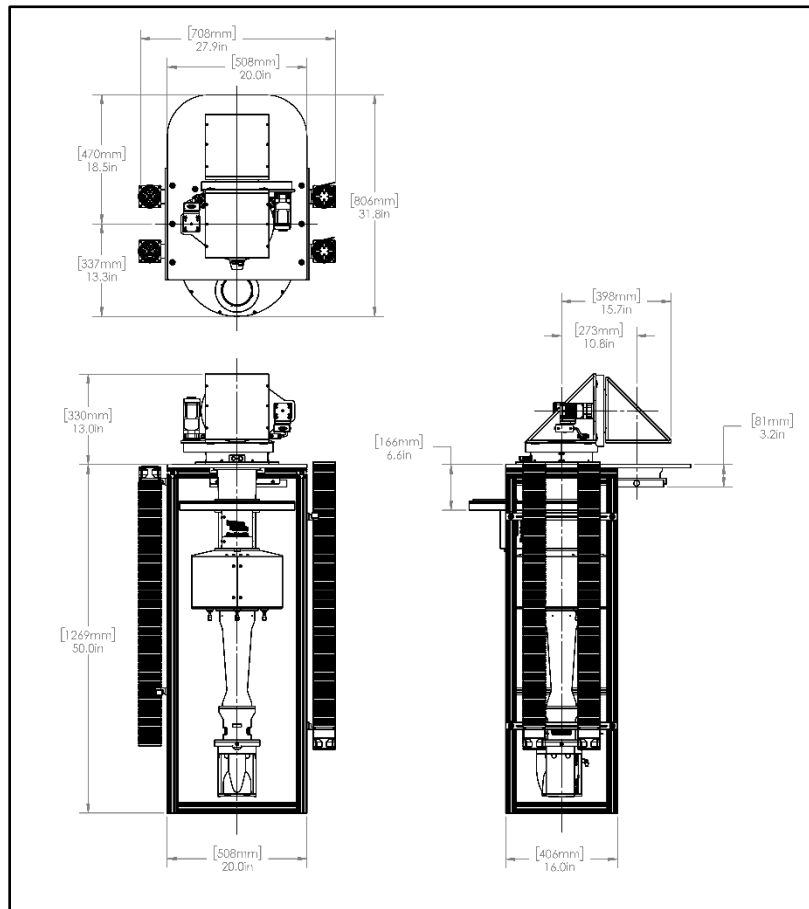


Figure 50: 100mm FPI System Dimensions

A.3 Controller Rack Dimensions

The control electronics for the FPI system (including PC computer) ships in a case that can be used to permanently house them. Simply remove the front and back covers from the case and the components can be used as-is. You will need easy access to this case from both the front and the back to make all of the required electrical connections.

We suggest leaving this case on the floor where it can be rolled out when needed to access the rear. Note that this case includes four caster wheels of which two of them are lockable to keep it in place.



Figure 51: FPI System Electronics in Case

The dimensions of this case (including caster wheels and removable front and back panels) are:

800 mm (H) x 600 mm (W) x 680 mm (D)
31.5 in (H) x 24 in (W) x 27 in (D)

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Appendix B Dome Selection and Installation

It is crucial that you select the correct size of hemispherical dome for your FPI system. If your dome is too small, you will risk damaging it during operation or not being able to observe certain parts of the sky. There is no solution to this problem other than using a properly-sized dome.

In this section, all references to ‘dome diameter’ are referring to the *inside diameter* of the dome. The outside diameter will vary based on dome material thickness, but this is not important to the operation of the FPI system.

B.1 FPI Dome Size Requirements

If possible, try to find a dome that meets the below *recommended minimum* diameter (inside diameter) requirements:

Recommended Minimum Dome Diameter:

70mm FPI System: 1,000 mm (39 inches)

100mm FPI System: 1,060 mm (42 inches)

These minimum dome sizes will allow you to position the FPI system far enough up into the dome that it can observe the entire sky from horizon to horizon while also maintaining a minimum 50 mm (2 inches) clearance between the SkyScan and dome at all times.

It is possible to install the FPI system under a dome smaller than these recommended minimums, but this will start to reduce the observable part of the sky. The *required minimum* sizes of dome that still allows you to observe zenith angles of 60° (elevation of 30°) are listed below.

Required Minimum Dome Diameter:

70mm FPI System: 800mm (31.5 inches)

100mm FPI System: 900mm (35.5 inches)

Any smaller than this size will further restrict the observable sky and you will not be able to use your FPI system adequately.

B.2 Chimney Size Requirements

‘Chimney’ refers to the inside area immediately below and around the dome. This is where the instrument will be mounted. Due to the SkyScan, it is required that a fairly large area be completely open to allow for unobstructed rotation of the panhead. This is especially important for domes smaller than the *recommended minimums* from Section B.1 because in that case the FPI system will have to be

lowered down further that it otherwise would be to provide adequate space in the dome for the panhead to rotate freely.

Even with a *recommended minimum* size dome, the FPI will be lowered slightly within the chimney by the following amounts. Lowered in this case referring to the position of the top of the FPI System Base Plate relative to the dome's flange (see Figure 52 for a depiction of this). Despite the FPI System being lowered slightly, as long as the dome meets the *recommended minimum* sizing, it will still be able to observe all the way from one horizon to the other.

70mm FPI System: 35 mm (1.5 inches)

100mm FPI System: 90 mm (3.5 inches)

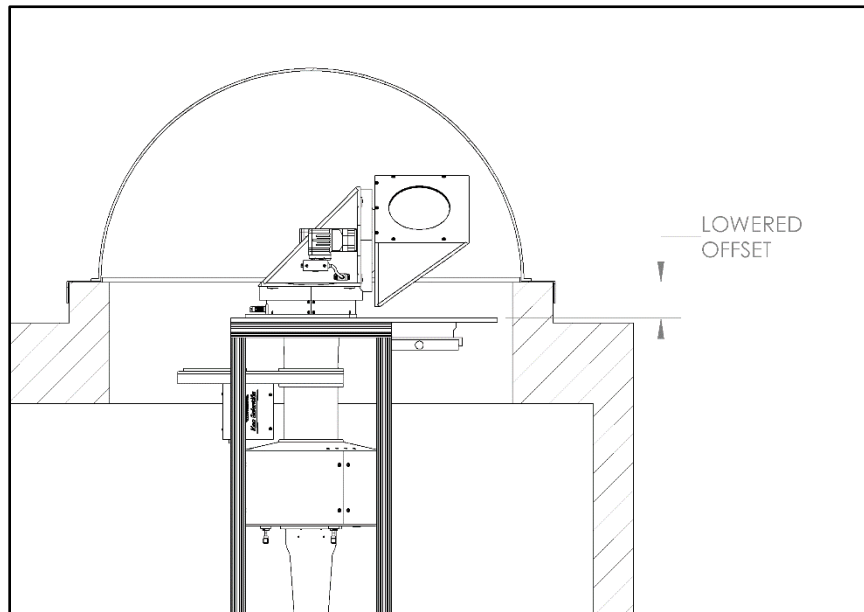


Figure 52: FPI System Lowered Offset

Ideally the chimney itself should have a minimum size as shown below. Whether the chimney is circular or rectangular, this same dimension applies (i.e. the provided dimension is both the minimum diameter of the chimney and the minimum length of the sides of a rectangular chimney).

Required Minimum Chimney Size:

70mm FPI System: 840 mm (33 inches)

100mm FPI System: 1,000mm (39 inches)

Note that although the FPI mounting plate is rectangular and you might think it would fit in a smaller rectangular chimney, the motion of the SkyScan *requires* these minimum sizes to be adhered to.

B.3 Dome Installation Suggestions

In our experience, the best dome installations have a few common features that make them reliable (do not leak water) and improve the FPI system installation.

1. Ensure there is adequate drainage from the dome flange so that any water in this area can drain away. If the water can pool along the dome flange then this will certainly start to leak after some time. We suggest building a raised protrusion from the top of your installation building upon which the dome can rest. See Figure 52 for an example of how this would look. Note the raised portion that the dome is resting on. This ensures that water cannot pool at the dome flange.
2. To make construction easier, rather than cutting a circular hole in the roof, we suggest cutting a square hole, larger than the dome, as shown in Figure 53 and then use a 'mounting plate' (made of metal) that sits over the top of the raised area. This mounting plate could be tapered in such a way as to prevent build-up of water at the dome flange area.

We would also suggest adding a lip to the mounting plate on the inside of the dome so that even if the seal between the dome and mounting plate were to leak it would not flow past the inner lip.

This method has several benefits:

- a. The dome can be affixed to the mounting plate in the lab or shop area. Sealing the dome to this plate would be much easier done in a dry environment with easy access to all sides of the dome. Doing this on a roof is much more difficult.
- b. If the mounting plate is equipped with a lowered lip around the outer edge, the potential for leaks along this interface can be eliminated. In fact, the mounting plate could be attached to the roof in such a way as to allow for easy removal which would make it very easy to access the SkyScan on the top of the FPI system if needed. Dome cleaning and replacement would also be easier to do.
- c. Using this dome attachment method is much less permanent, which makes it very easy in the future to modify it for a larger or smaller dome as necessary.

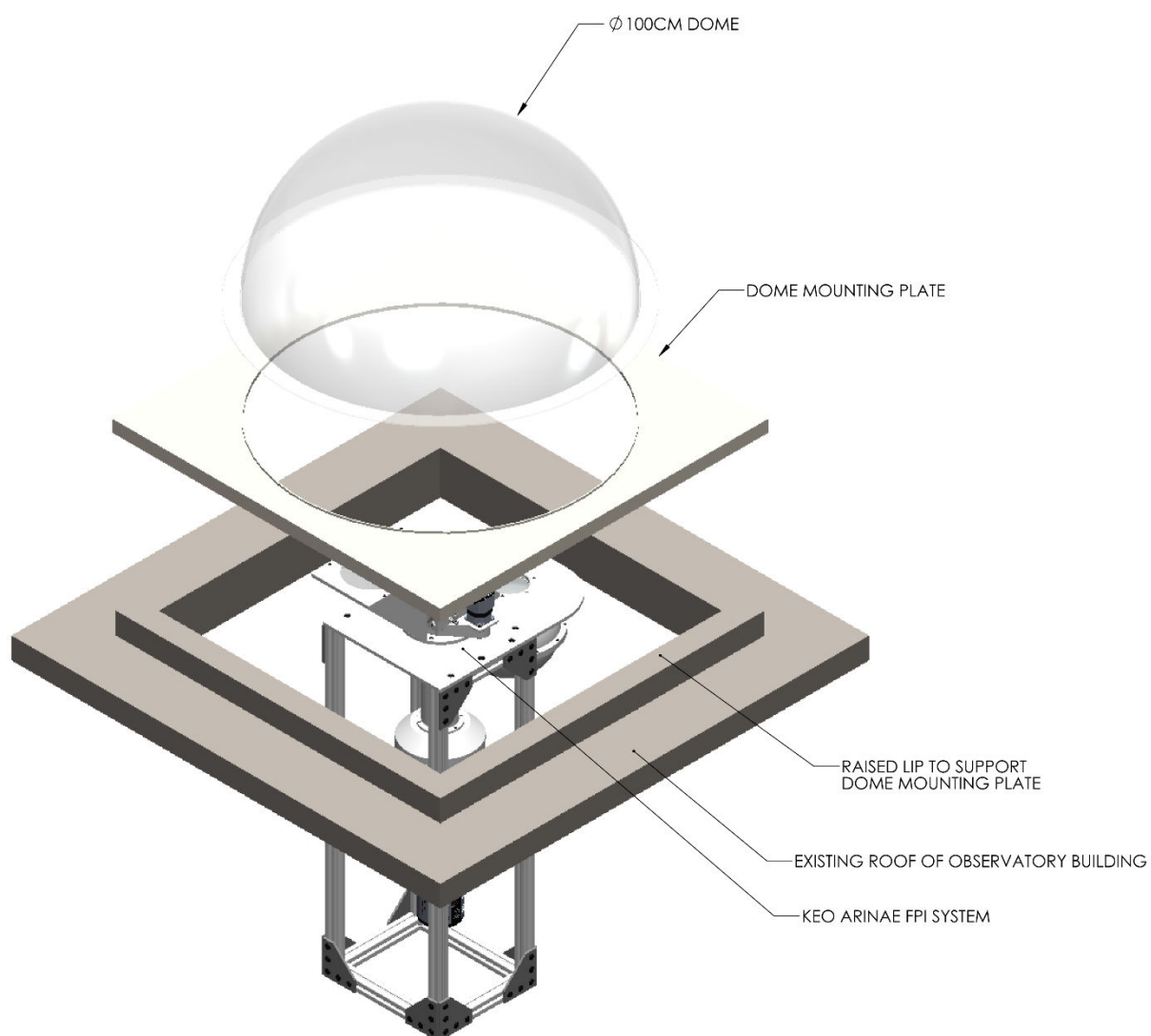


Figure 53: Dome Installation Overview