



Paramount Apollo and Paramount Duo User Guide

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S O F T W A R E B I S Q U E

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Renderings on cover: The universal mounting plate on the Paramount Apollo and the telescopes on the Paramount Duo are sold separately.

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Introduction

The Paramount Apollo series mounts are the state-of-the-art in modern astronomical altazimuth designs. Apollo achieves superior performance in astronomical data acquisition through precision machining, high-resolution absolute encoders, and high-torque direct-drive motors on all axes plus the world's most advanced and versatile software for observatory control. Apollo employs the TPoint Telescope Pointing Kernel (TCSpk) and SLALIB astronomical library, which is the same multi-axis technology that makes many of the world's largest professional telescopes function superbly.

The Paramount Apollo is available in two designs:

- The Apollo Altazimuth Fork mount.
- The Paramount Duo that can be mounted in an altazimuth or equatorial orientation.

Altazimuth vs. Equatorial Mount Designs

The goal of any robotic telescope mount is precise pointing and stable tracking, whether the system follows a single object for hours or quickly darts between, or tracks, fast-moving targets.

As the optical telescope assembly or other payload increases in size and weight, the physical size of the mount must also be larger to increase rigidity, minimize flexure and vibrations. The altazimuth design is ideal for telescopes 0.50 m (20 in.) and larger because the telescope's center of mass is directly above the azimuth axis. This provides optimal stability in small physical space compared to other mount designs.

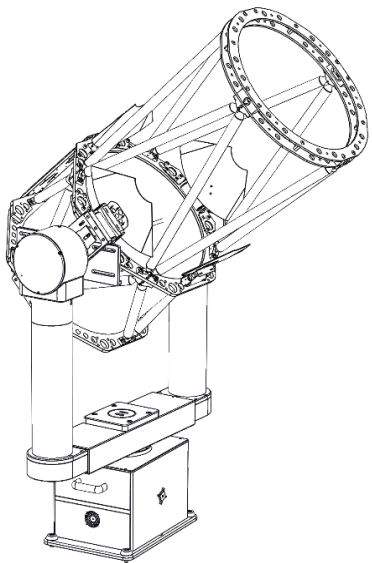


Figure 1: Altazimuth fork mount.

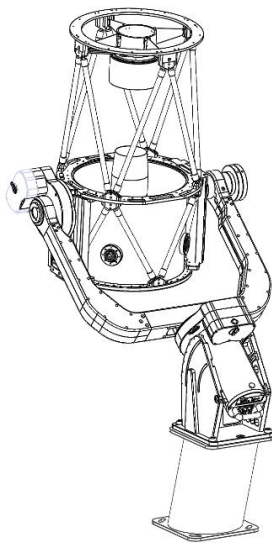


Figure 2: Equatorial fork mount.

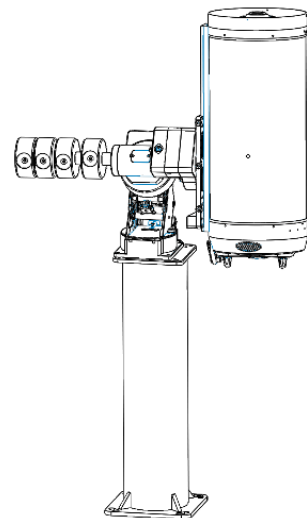


Figure 3: German equatorial mount.

Altazimuth Mounts

Altazimuth mounts have several key benefits when carrying larger telescope systems. The telescope's overall size and weight grow exponentially with increasing aperture, the equatorial design becomes impractical for large telescopes. The inherently stable altazimuth design rules this space.

One big challenge of the altazimuth design is that instead of tracking in a single axis at a slowly changing speed, three axes (azimuth, altitude, and instrument rotation) must be changed to track objects, each with continuously changing rates. And though the mathematical transformations that convert between the celestial coordinate system and the mount coordinate system are straightforward, in practice, accurately driving the three axes to account for all things astronomical, layered with system imperfections, becomes an extreme computational challenge.

Note the altazimuth design is exceptionally suitable for small robotic systems but driving three axes precisely makes such systems more expensive.

Equatorial Mounts

Equatorial mounts align their primary axis with the earth's rotational axis and, for the most part, tracking an object requires only the hour angle (HA) axis to rotate. In practice, the second axis (declination) must be adjusted to account for various geometric errors and other physical realities that influence the tracking rates in both axes for example tube flexure and refraction.

As equipment payloads become heavier, the exercise of accurately aligning the HA axis of the mount with the earth's axis, or polar alignment, is burdensome. In the case of an equatorial fork mount, polar alignment is latitude dependent and requires a significant cantilevered mass. In the case of a German equatorial mount, the counterweights effectively double the payload mass and require larger and more massive components to optimize system stability.

Direct Drive Motors

The Apollo employs two direct-drive motors (three when the rotator is used), each with high-resolution (26-bit) on-axis absolute encoders. Direct drive motor control is an exceptional choice for most telescopes. Although traditional, larger worm-gear driven systems can be manufactured with exceptional accuracies, a direct-drive motor coupled with a high-resolution encoder has a lower noise floor and negligible backlash.

Direct drive motors offer exceptional performance when high-speed slewing and tracking rates are required. Where worm gear driven systems typically have top speeds around five degrees per second, direct drive systems can move at 50 degrees per second and beyond. And, with no material-to-material drive contact in the drive train, mounts with direct drive motors require little maintenance.

Telescope Control System

Telescope control systems (TCS) require extremely wide dynamic ranges of speeds, from stationary to rates at many degrees per second, or any speed in between. The demands of controlling a three-axis, direct-drive system for telescope control can only be met with a high-bandwidth system.

The Apollo mounts employ a very capable off-the-shelf industrial controller with a built-in computer to service the servo control and external communications. This controller has been integrated with TheSky astronomy software that computes TCS position demands to a fraction of an arc second, all the while correcting both slewing and tracking demands for system imperfections.

TheSky Astronomy Software

The Apollo series of mounts employs TheSky for mount operation and is currently used in observatories across the globe. The world-renowned TPoint™ and TCSpk™ technologies are fully integrated into the TCS control loop, supported by a host of tools, and features an advanced user interface to ease setup and nightly operation. TCSpk has been developed over the last forty years and all or a part of this software is used on most three-meter and larger systems deployed over the last quarter century.

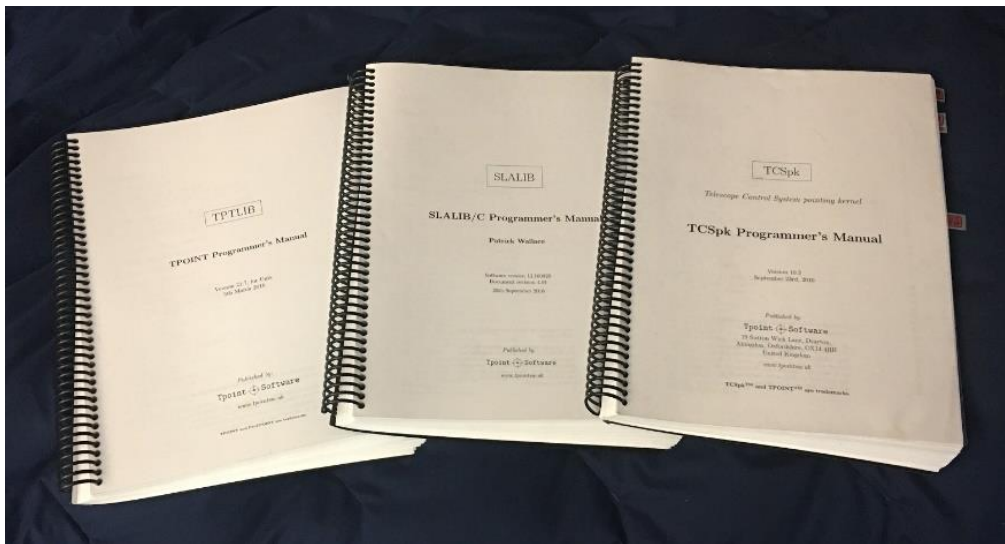


Figure 4: TPoint, TCSpk and SLALIB library are integrated into TheSky astronomy software.

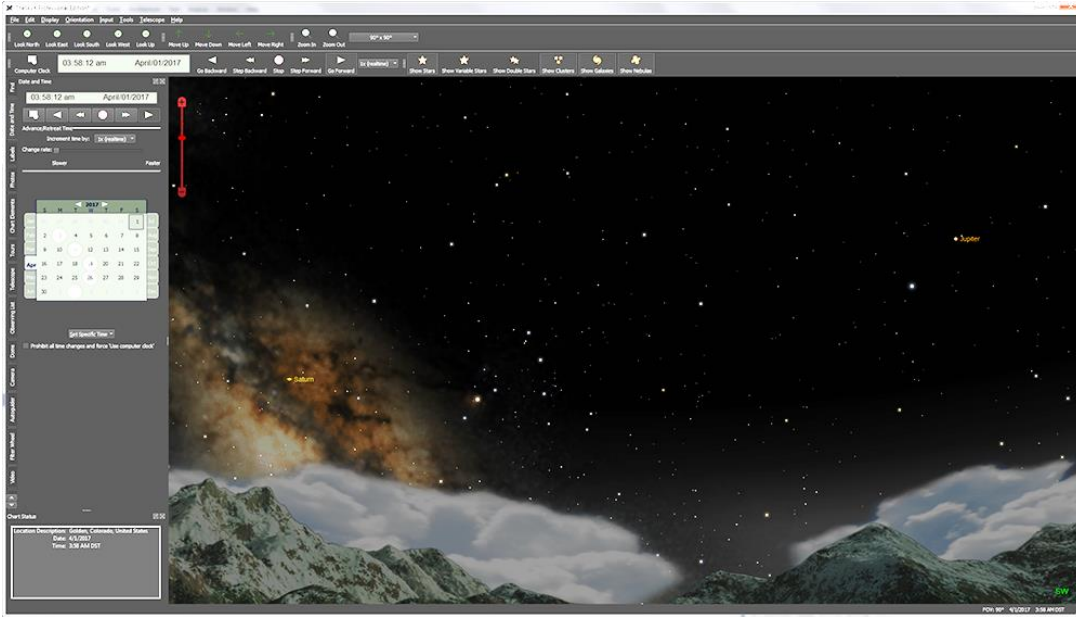


Figure 5: Sample screen capture of TheSky astronomy software.



Figure 6: Wide field view from TheSky astronomy software.

The Paramount Apollo Mount



If you purchased the Paramount Duo, skip ahead to “The Paramount Duo” on page 49.

The Apollo mount is shipped as four separate components, each in a separate box. The main components include:

- The *drive tine* which holds the direct drive motor.

- The *support tine* which holds a self-aligning bearing and a brake.
- The *fork center* is mounted to the top of the base and accepts the tines on both sides.
- The *base* which is secured to a horizontal surface in the observatory.
- The gray-colored plate is an optional *Universal Mounting Plate* that can be permanently mounted to the observatory floor or other flat surface.

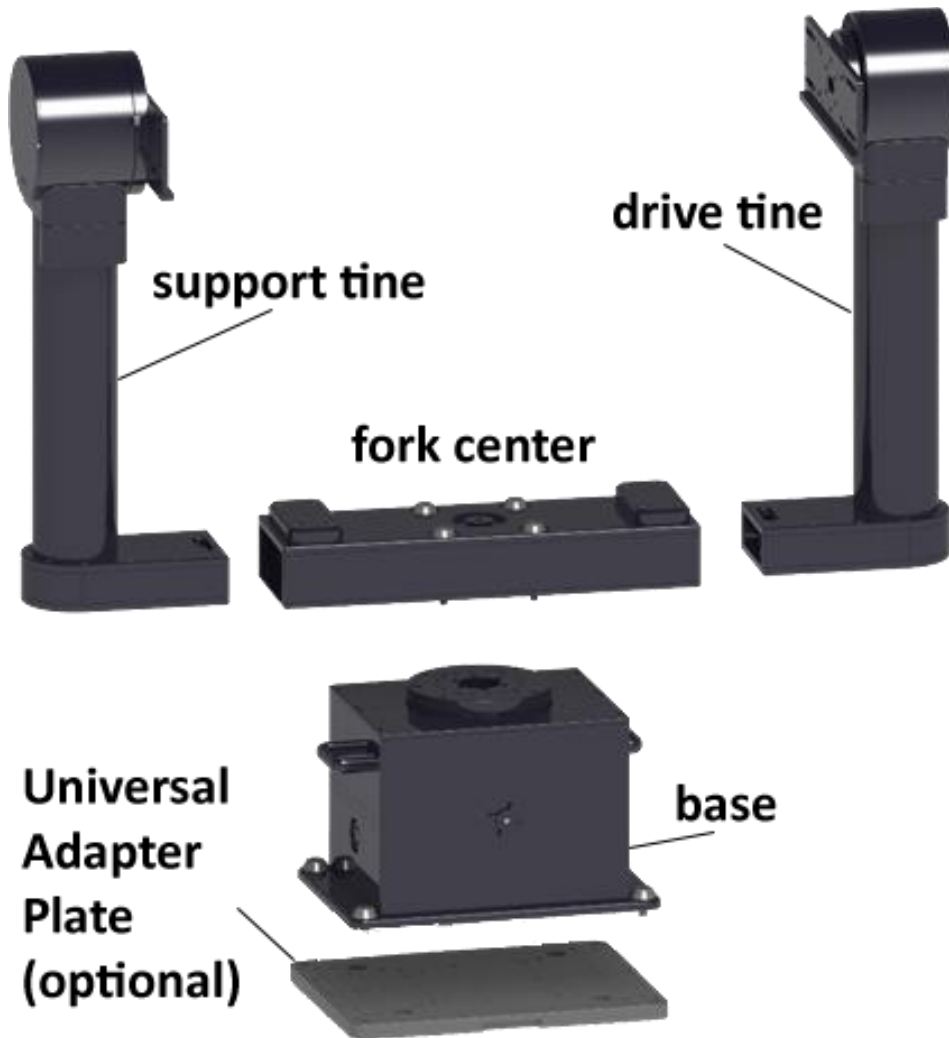


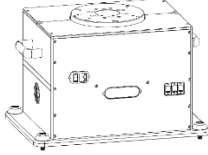
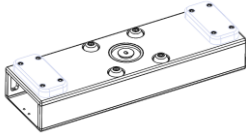
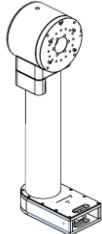
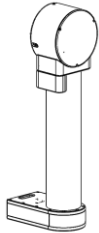
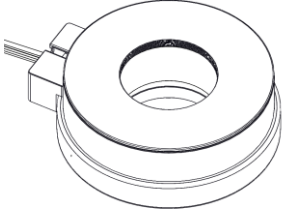

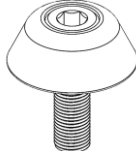
Figure 7: Exploded view of the Apollo fork's main components.



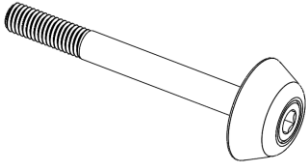





All of the tools needed for assembly are included in the included accessory kit. Assembly involves lifting the four major components into place and adding the fasteners connect them together, as well as directing the cables from the fork tines down through the azimuth axis into the controller compartment found at the base of the mount.



Software Bisque recommends using two people to perform the assembly. The first-time setup process may take as few hours once the components are unboxed and staged.

Apollo Fork Mount Packing List

The table below lists the components that are included with the Apollo fork mounts.

Item	Quantity	Notes	Graphic
Apollo base	1	Holds the control electronics and PCB distribution board.	
Fork center	1	Fork center includes fork clamps on each end.	
Drive tine	1	Holds the motor, instrument rotator interface panel and internal cabling.	
Support tine	1	Holds the altitude brake and cabling.	
Instrument rotator (optional)	1	The instrument rotator has two cables that connect to the <i>rotator interface panel</i> on the drive tine.	
Cover	3	Cover to the cable access.	
Base mounting screws with stainless clamp nut	4	1.5-in. x 1/2-in., 13 TPI SHCS	

Axis lock pins	2	Azimuth and altitude lock pins.	
Axis lock hole cover	1	Cover for the azimuth axis locking component.	
Fork mounting screws with stainless clamp nuts	4	Fork center to base SHCS (5 in. x 1/2-in., 13 TPI).	
Power cord	1	Power Cable for the Power Supply Unit (NEMA 5-15 male plug).	
Hex key set	1	Imperial hex key set.	
Small screwdriver	1	Flathead screwdriver to tighten the motor and brake wires to the terminal connectors.	
Security key	1	This USB security key must be plugged into one of the computer's USB ports so that TheSky can control the Apollo. See page 71 for details.	
CAT 6 cable	1	Cable to connect the PC's NIC to the Apollo's Ethernet port.	

3/8-in. ratchet	1	Both 3/8-in. and 1/4-in. drives included.	
3/8-in. hex wrench	1		

Note: See *Appendix B: Apollo OTA Mounting System* on page 98 for the *Scope Rail* packing list.

Apollo Fork Mount Base Mounting Hole Pattern

The Apollo system is normally mounted permanently to the floor of an observatory or other adapter plate using four socket head cap screws (SHCS) with 1/2-in. x 13 threads per inch (TPI).

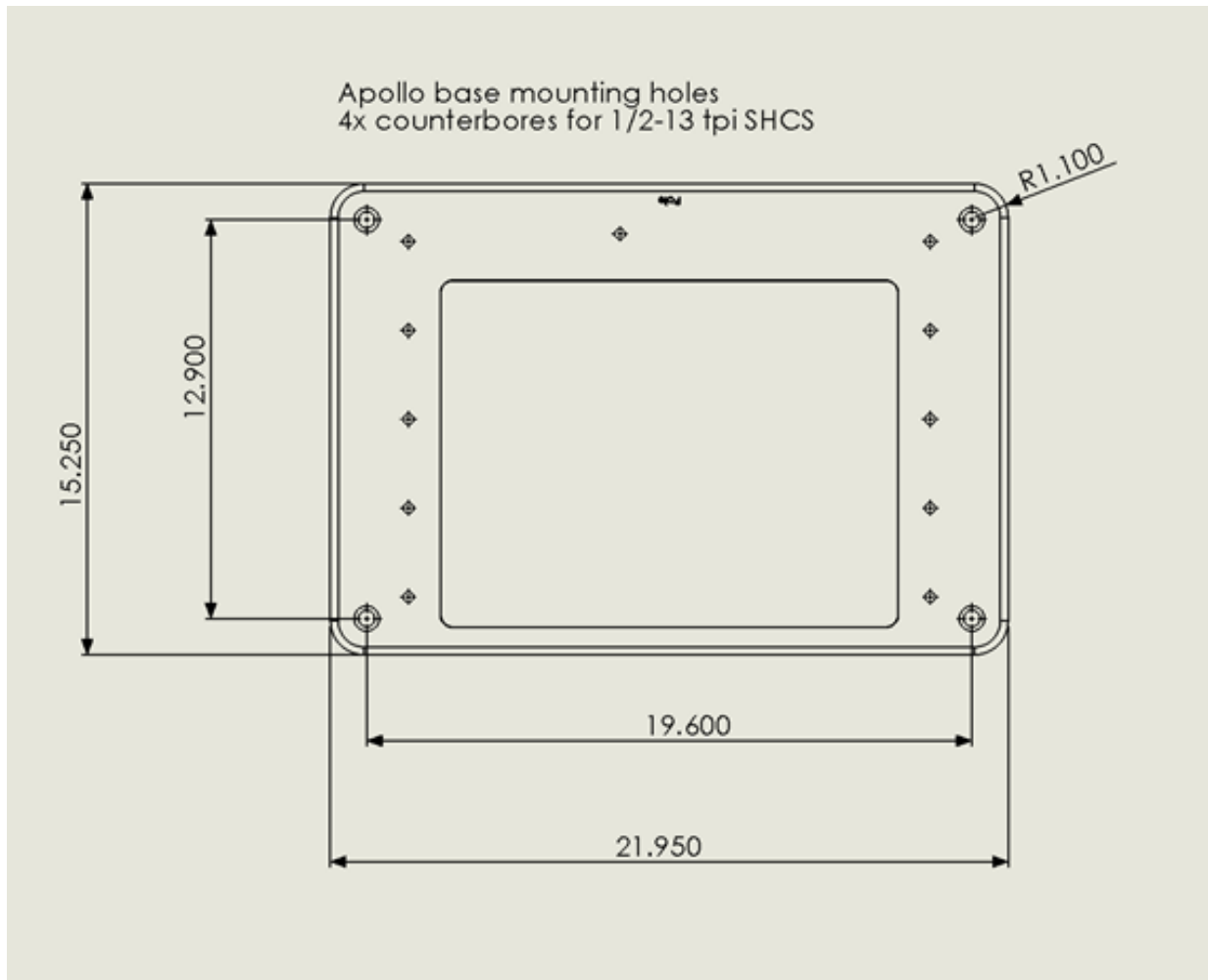


Figure 8: Apollo base mounting holes.

Software Bisque offers an optional Universal Mounting Plate that is designed to directly accept the Apollo base, as well as all other Software Bisque mounts and can be mounted at the site. This plate has overall dimensions of 22.4-in. x 17.5-in. (56.9 cm x 44.5 cm) and should be mounted to the floor of the observatory with 4 x 1/2 in. by 13 TPI SHCS or M12 screws inserted into the plate's counterbores that are spaced 14 in. x 12 in. (35.6 cm x 30.5 cm).

At the corners of this plate are four threaded holes (3/4-in. x 10 TPI) that are used to level, stabilize, and ground it to the floor. This results in an effective push/pull system in conjunction with the central SHCS.

The normal orientation of the base is to place the side which has the word **Pole** engraved in it towards the south. The maximum rotational range of the Apollo's azimuth axis is a bit more

than -90 to 450 degrees (or ± 270 degrees from mid-travel), so the base plate *could be* rotated 90 degrees in either direction and still run nominally. If you want the azimuth axis to follow standard astronomical azimuth coordinates (north is 0 degrees, increasing through east), the mount's zero point will have to be reset from TheSky (see page 87).

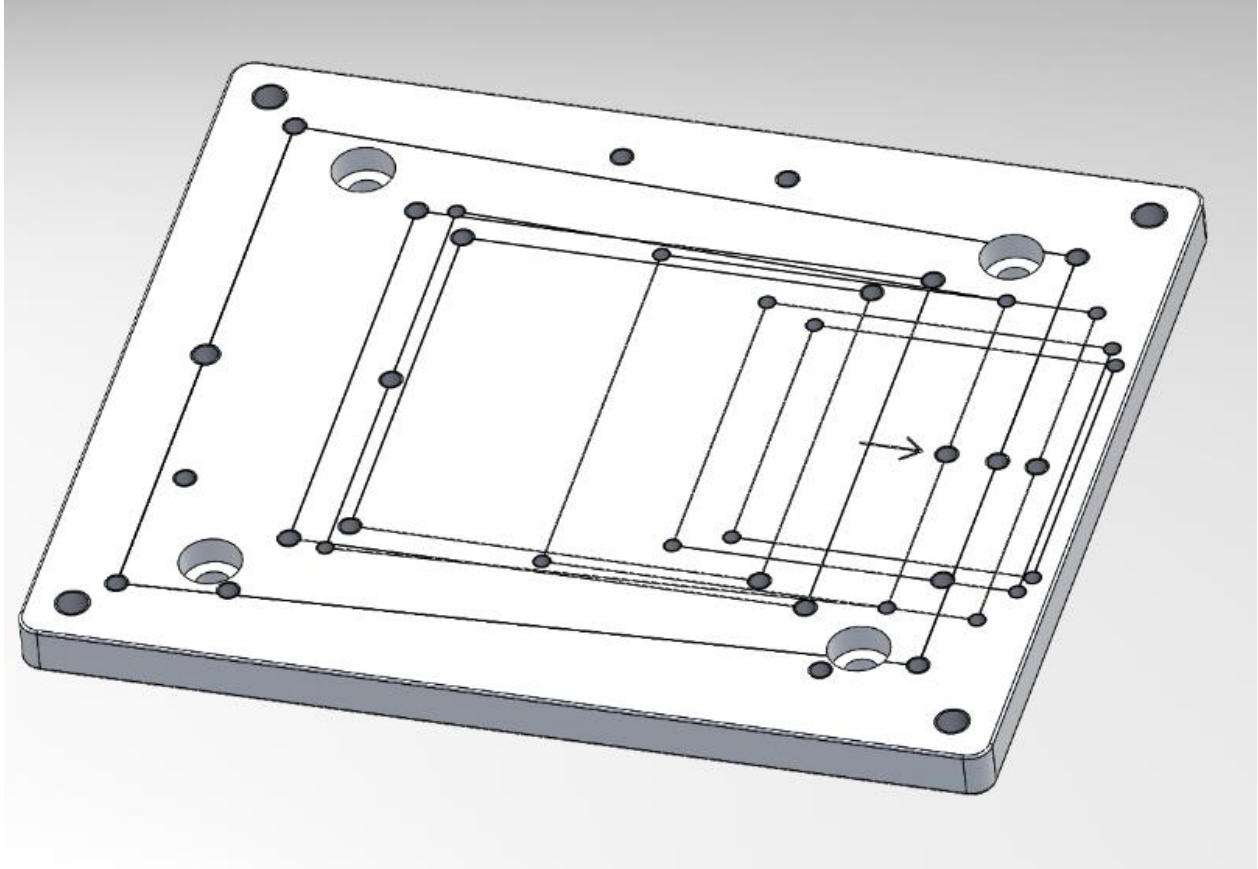


Figure 9: Universal Adapter Plate that accepts all Software Bisque Paramount model mounts.

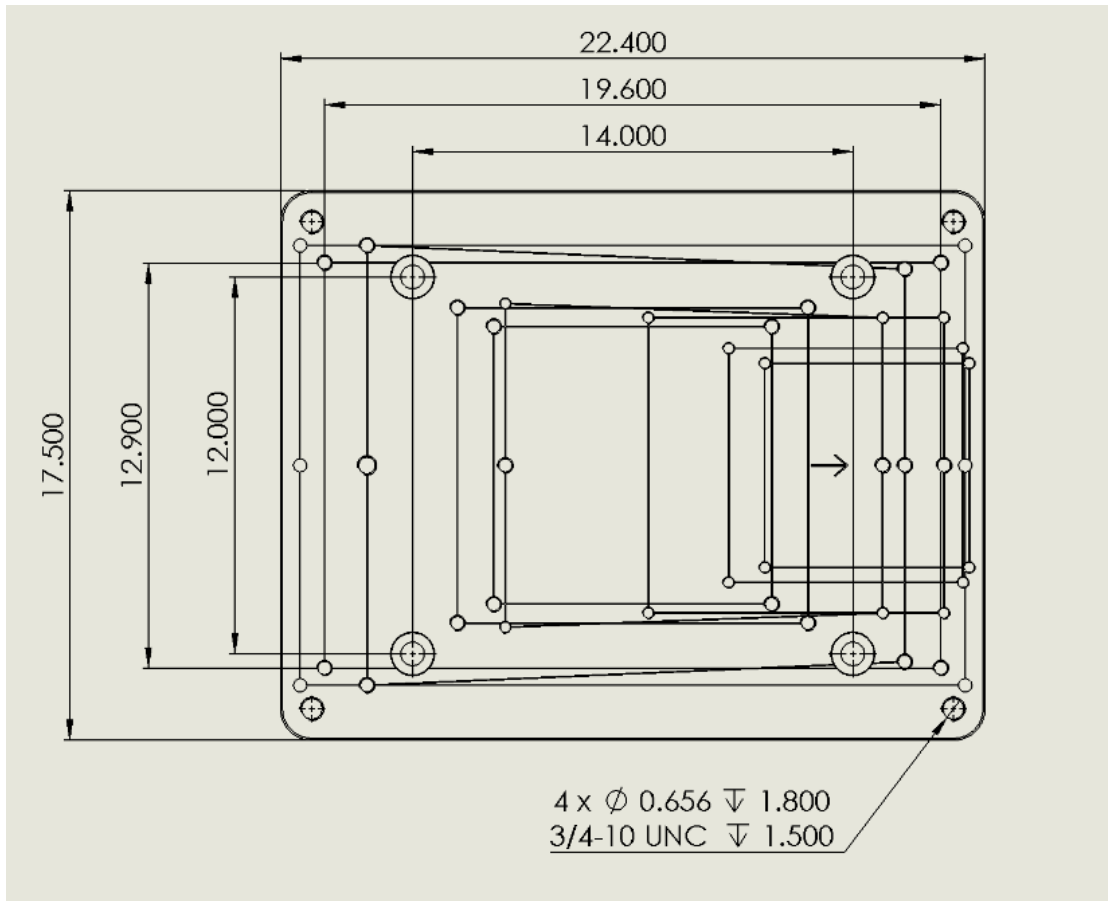


Figure 10: Universal Adapter Plate hole spacing.

Once the base has been securely fastened to the observatory floor, the mount can be assembled so that it is ready accept the optical tube or sensor assembly.

The Universal Adapter Plate (SKU: SB11113) can be purchased from the Software Bisque Store at <https://www.bisque.com>.

Apollo Fork Mount Assembly

Mount Base

The Apollo base holds the industrial controller, connections and distribution of the power and signals for all three axes, as well as the azimuth drive motor. An internal distribution printed circuit board (PCB) routes most of the internal wiring using standard off-the-shelf cables. Each axis has cables for motor power, sensors, and encoder input. The drive tine holds the cables for connecting the altitude drive and the rotator to the controller.

The switched power input block (120V or 220V AC) and Ethernet connection can be found on the rear panel of the Apollo base. Other panels (2 Keystones and a through-panel slot) permit adding custom “through-the-axis” cabling for various instrumentation. Space for more cables is available in the conduit running up through the azimuth drive, through the fork center and through each of the fork tines.

The front panel of the base has a single knob that can be unscrewed, and the panel removed for easy access when assembling the mount. Though most of the cabling comes from the factory already connected and in place, once the tines are physically placed in position, the altitude drive and the instrument rotator cabling must be connected.

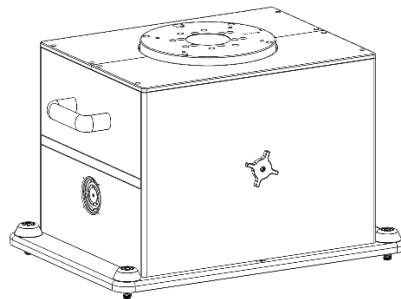


Figure 11: Apollo base front.

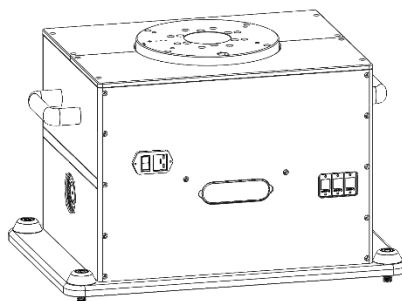


Figure 12: Apollo base rear.

Attaching the Fork Center

Once the base is securely fastened to the ground, the next step is to attach the fork center to the base. This is done using 4 5-in. x 1/2-in. 13 TPI screws, each with an integrated stainless steel clamp nut. The four screws pass through the fork center mounting plate and the fork center to be threaded into the azimuth drive plate (Figure 13 and Figure 14).

The hole pattern for attaching the fork center to the circular drive plate is symmetric, so it is possible (likely!) that the fork center can be mounted incorrectly.

To make sure the base is oriented properly, there are two grooves in the *azimuth drive plate* (Figure 13) that must be parallel with the edges of the fork center when it is oriented properly. The fork center is also symmetric and can be attached in either of these two permissible orientations.

All four screws should be rotated and tightened lightly before applying the final torque.

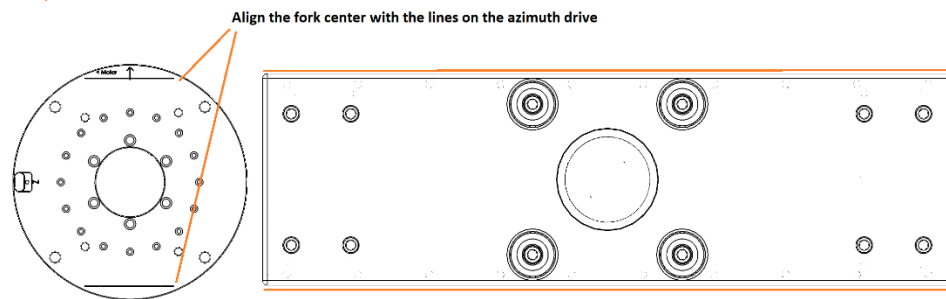


Figure 13: Align the holes in the Mount Base with the holes in the Fork Center.

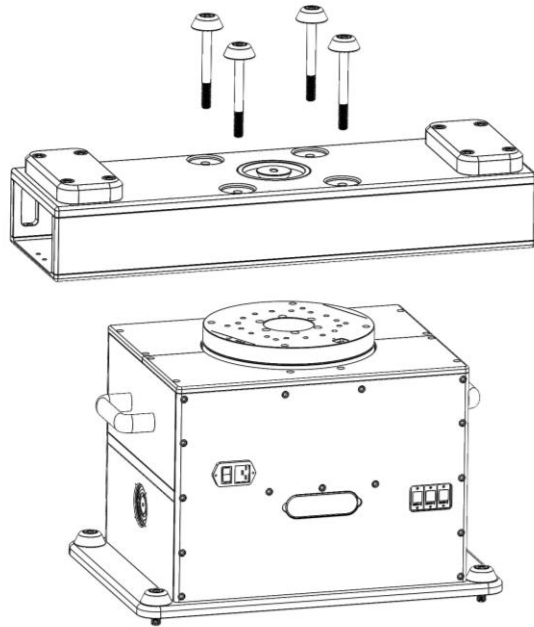


Figure 14: Side view of the Base to Center assembly.

Attaching the Drive Tine

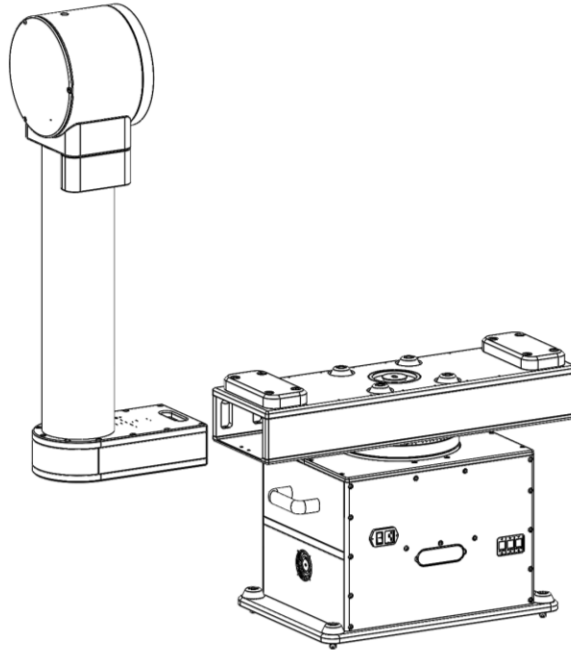


Figure 15: Attaching Apollo's drive tine.

The enclosure at the top of the drive tine holds the direct-drive motor, the high-resolution encoder, and a precision bearing assembly.

The drive tine and support tine are physically and mechanically different. If you are not sure which is which, use the following characteristics to identify each.

- The drive tine has a through hole in the top to accept the axis lock pin.
- Cables for the altitude motor, instrument rotator motor, encoders and two sensor cables come out of the base of the drive tine.
- The drive tine has an instrument rotator interface panel and connectors on the underside of the panel to attach the instrument rotator cables (Figure 16).

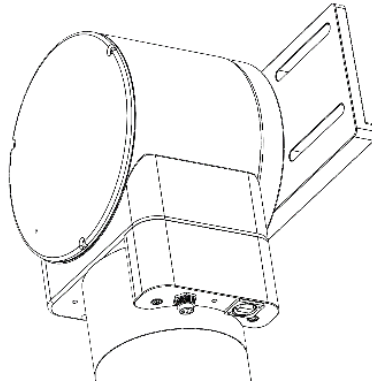


Figure 16: The instrument rotator interface panel and cable connectors.

Once you have positively identified the drive tine, the following steps must be completed before attaching it to the fork center.

1. Remove the cable bundle from inside of the drive tine base assembly and take off the protective shipping material.
2. Temporarily snake the cables through the bottom of the drive tine circular *cable access opening* so that they are out of the way while the drive tine is lifted into place. Alternatively, the cables can be unwrapped and then carefully tucked into the fork base to keep them out of the way.

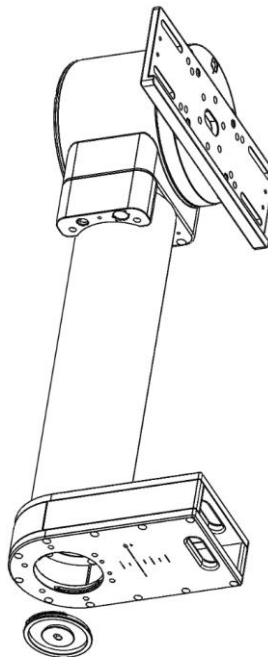


Figure 17: Cable access opening and cover.

The drive tine must be attached in the correct orientation with respect to the azimuth drive plate. The azimuth drive plate has an indicator that specifies on which side the drive tine must be attached. The small arrow next to the word Motor (< **Motor**) points to the side of the base that holds the drive tine.

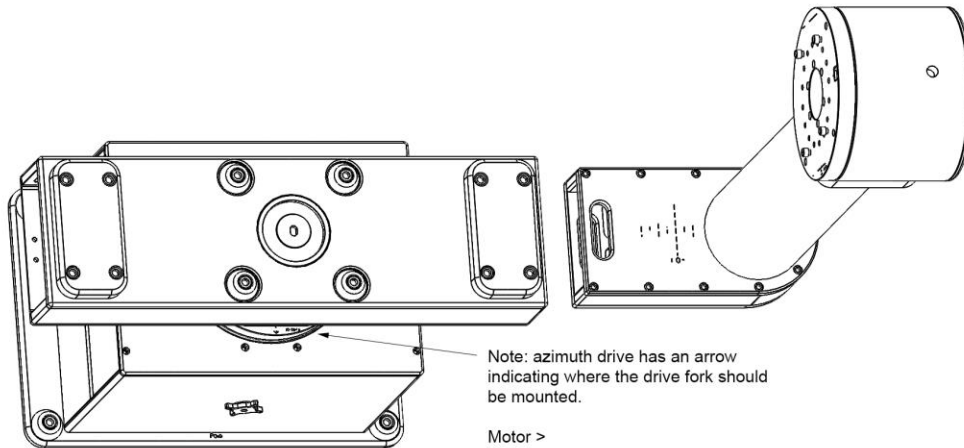


Figure 18: The “less than” symbol in front of the word Motor points to the drive tine.



Figure 19: Close up view of the engraved < Motor text.

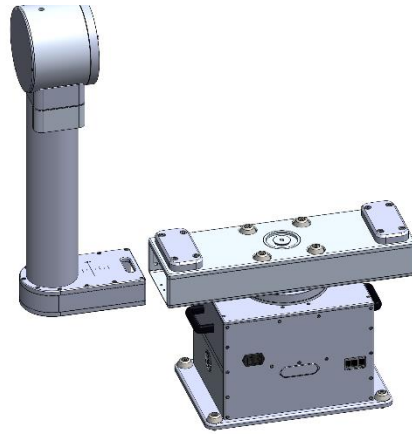


Figure 20: Inserting the drive tine into the fork base.

Lift the motor tine and gently guide the base into the hole in the fork center (Figure 20) until the edge of the fork base is near the zero-mark inscribed on the top of the tine (Figure 21).

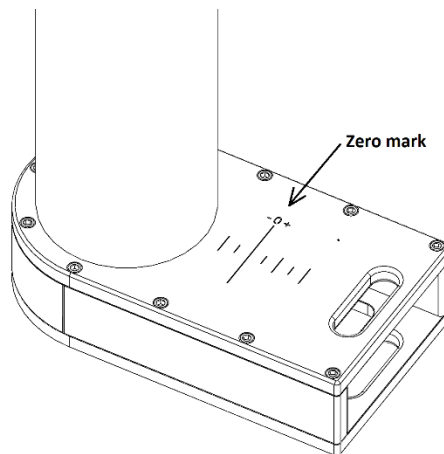


Figure 21: The zero mark on the tine base. Each increment is 0.5 inches (13 mm).

When mounting the telescope, the tines may have to be adjusted slightly to accommodate the width of the optical assembly. Each tine can be moved inward or outward by approximately 4 cm (1.6 in.).

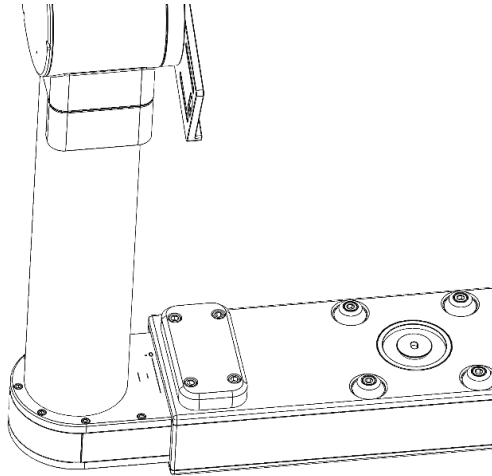


Figure 22: The drive tine inserted near the zero mark.



Caution!

If the mount is not fastened to the floor or to a permanently mounted Software Bisque Universal Adapter plate, the base is unstable when a single tine is in place.

The motor tine is heavy and when the azimuth axis is rotated so that the fork center is perpendicular to the long axis of the fork base, the entire assembly can tip unexpectedly.

Installing the Support Tine

Once the drive tine is in place, install the support tine as described above. The support tine has a single harness that must be routed through the fork center into the drive base. These wires power the altitude axis brake. If necessary, additional instrument cables can be routed through the support tine.

Routing and Connecting the Cables

Once the tines have been attached to the fork center, cabling for the altitude axis and the rotator axis must be routed into the base and connected to either the distribution PCB or the controller.

The first step is to route the cables through the fork center, then down through the azimuth axis. There are three access holes in the fork assembly which can be used to reach in and guide the cables into the base.

The drive tine holds most of the cabling including:

- Altitude motor cable
- Altitude encoder cable
- Altitude sensor cable
- Rotator motor cable
- Rotator encoder cable
- Rotator sensor cable

Remember, the support tine has two wires for the braking mechanism. On the drive tine, if the instrument rotator is not used, no rotator cabling connections are necessary.

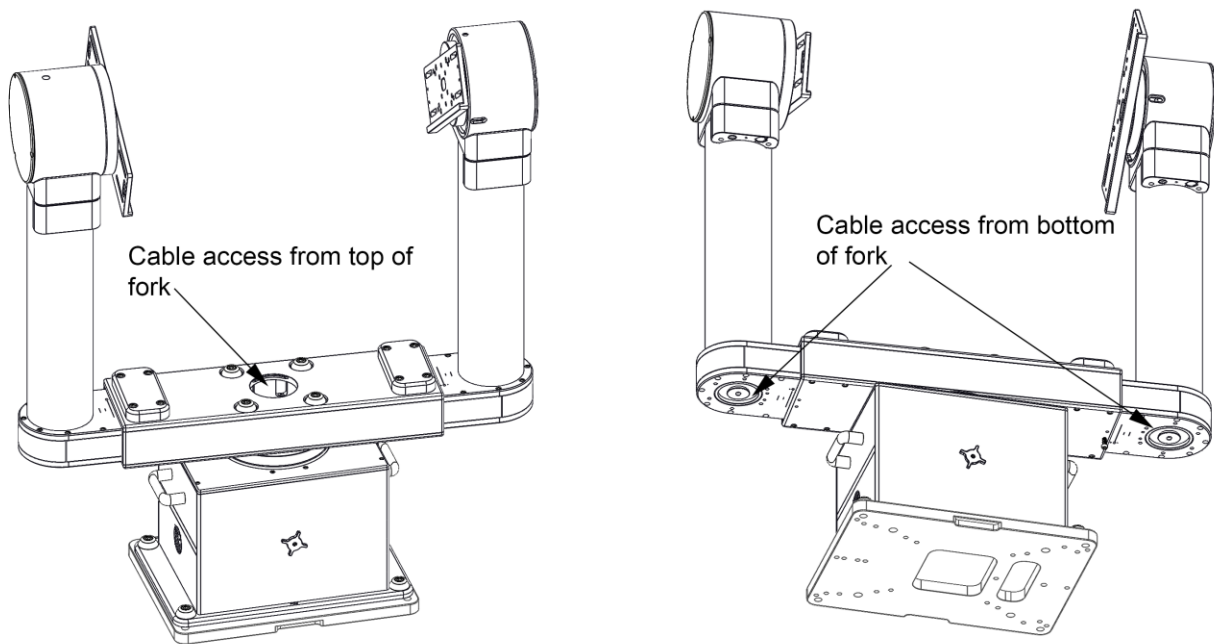


Figure 23: Cable access locations.

Routing the cables requires reaching into the circular access covers and guiding each cable first to the center of the fork, then downwards towards the controller in the base where they must take a sharp turn towards the front of the drive base (between the top of the controller box and the middle plate on the base) where the connections to the controller are made.

Cable Distribution PCB

When the access panel is removed from the base, the cable distribution PCB is found on the upper left side (Figure 25) of the enclosure.

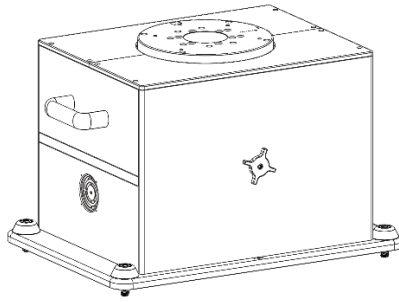


Figure 24: Base access panel.

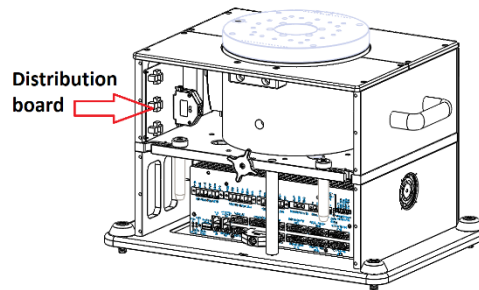


Figure 25: Location of the cable distribution PCB.

The cable distribution PCB is split into the three inputs, one for each axis, on the left side of the board with additional inputs on the right side. The Apollo is shipped from the factory with the azimuth axis and controller cables fully connected. The altitude and rotator axes are contained in the separate drive tine, and their cables must be routed down through the azimuth axis before connecting them to the controller panel.

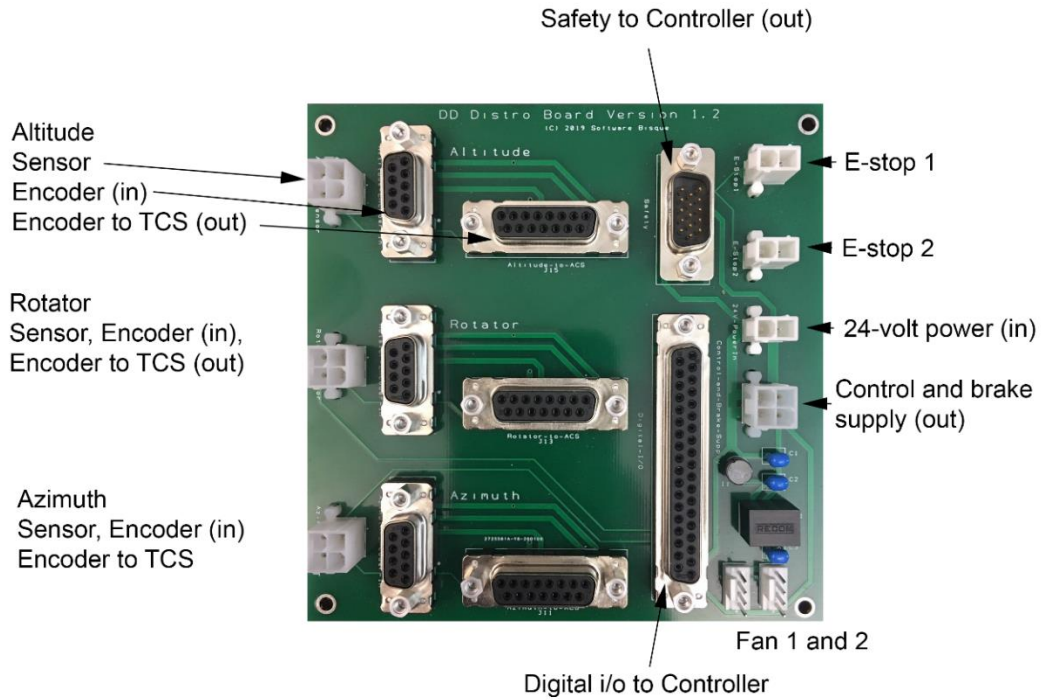


Figure 26: The Apollo cable distribution PCB.

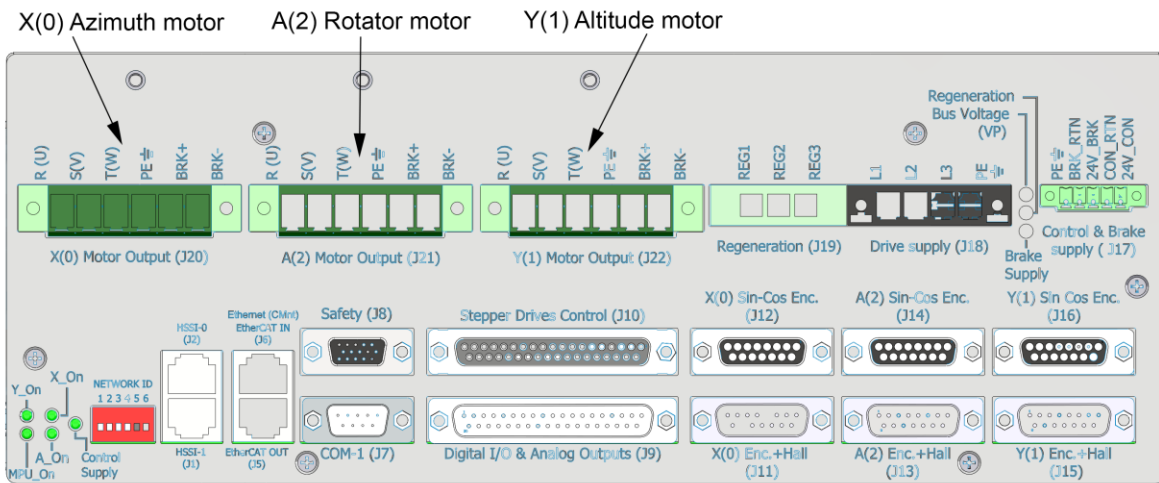


Figure 27: Controller Panel connections.

Apollo Fork Cable Connections

Once the cabling has been routed from the altitude drive line into the Apollo base, the following connections must be made to attach the altitude axis, rotator axis and brake. The azimuth cables should already be connected in their correct positions.

Step One

Once the motor, encoder and sensor cable have been routed from drive tine down through the azimuth shaft, insert the two brake wires departing from the support tine into the altitude motor connector (pins 5 and 6, see Figure 28)

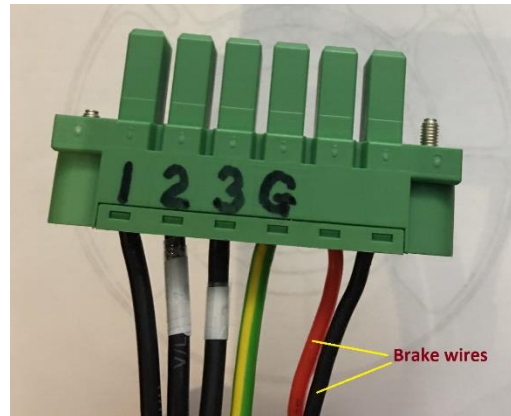


Figure 28: Altitude motor connector with brake wires in positions 5 and 6 (red and black, polarity not important). In the controller, the lines 1, 2, 3 are labeled R(U), S(V), T(W).

Step Two

With the two brake wires attached, plug the altitude motor connector into J22 on the controller.

Step Three

Plug the altitude encoder connector (9-pin D-sub) into the “Altitude-encoder-in” on the distribution board.

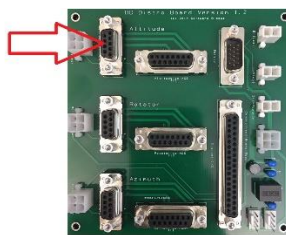


Figure 29: Plug in the 9-pin D-Sub altitude encoder connector here.

Step Four

Plug the altitude sensor connector (4-pin Molex) into the “Altitude-sensor” connector on the distribution board (top-most position).

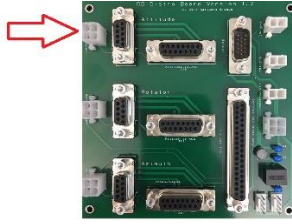


Figure 30: Plug the 4-pin Molex Altitude sensor connector here.

Step Five

Plug the rotator motor connector into J21, or A(2), on the controller.

Step Six

Plug the rotator encoder connector into the “Altitude-encoder-in” 9-pin D-Sub on the distribution board.

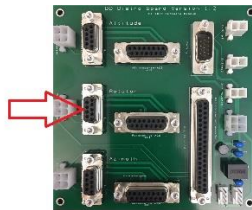


Figure 31: Plug the 9-pin D-Sub Altitude-encoder-in plug here.

Step Seven

Plug the rotator sensor connector into the “Altitude-sensor” 4-pin Molex on the distribution board.

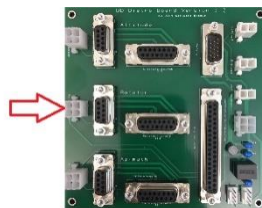


Figure 32: Plug the 4-pin Molex Altitude sensor here.

Apollo Fork Motor Wiring

The motor leads are labeled as shown in Figure 33. They may also be labeled using the letters R, S, T instead of 1, 2, 3 so that they match the inputs annotated on the controller where the motor plugs in.

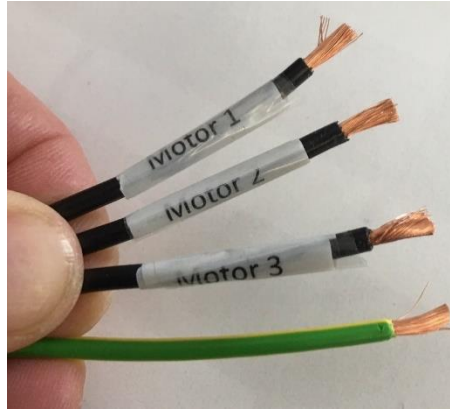


Figure 33: The motor wire leads.

Normally, when passing the cables down through the azimuth axis, there is sufficient space so that the altitude and rotator motor connectors do not have to be removed from the motor leads. If you find that you must remove the large connector, do so while routing the cables. Be sure to return each wire to the correct position. Use the labeling on the Controller (J20-J22) to see the order from left to right. The green wire is ground and should go into the fourth position.

Note about Screw in Terminals

Do not tin the ends of the cables before they are inserted into the terminal connectors.

- *Tinning changes over time and will cause the cable to become loose.*
- *When tinned, the actual points of electrical contact end up being smaller compared with using a bare wire.*
- *If these cables need to be removed from the connector, quite a bit of torque on the small screws is required to make full contact and retain the wires. The required torque is about as much as one can muster when using a small screwdriver and without breaking or stripping the screw.*

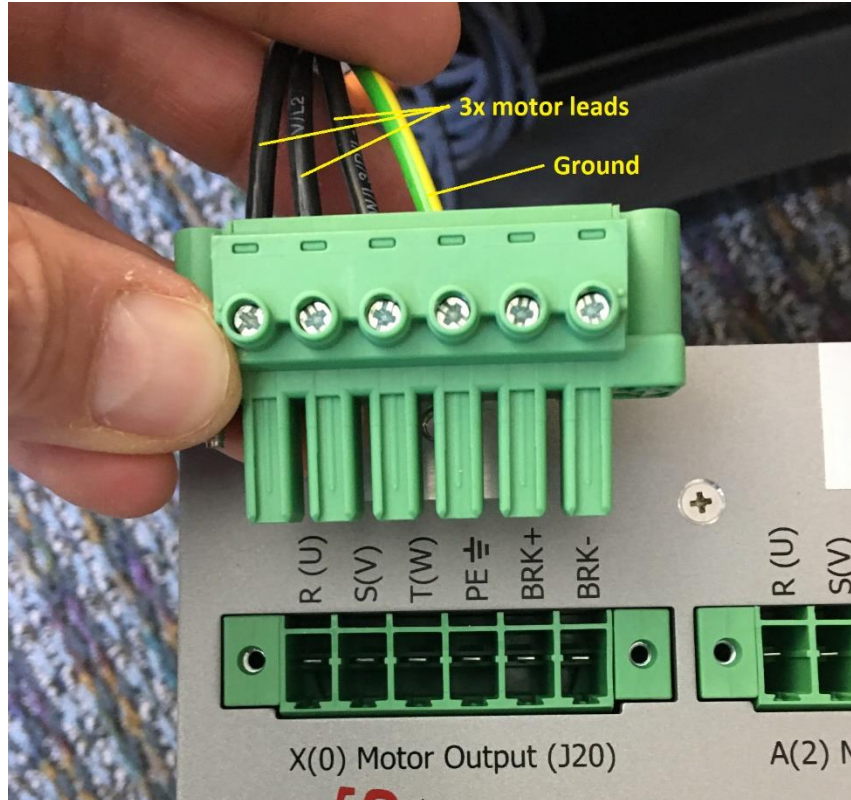


Figure 34: Cable connection terminals.

Attaching the Instrument Rotator to the Telescope

Like the altitude axis, the Apollo instrument rotator has encoder, motor and sensor wires that are contained in the drive tine. The rotator interface panel has two connectors that are placed at the bottom. The rotator plugs into these two connectors (a 9-pin D-sub connector and a round 7-pin connector). Take care ensure that the cables are screwed into place as they may otherwise become disconnected.

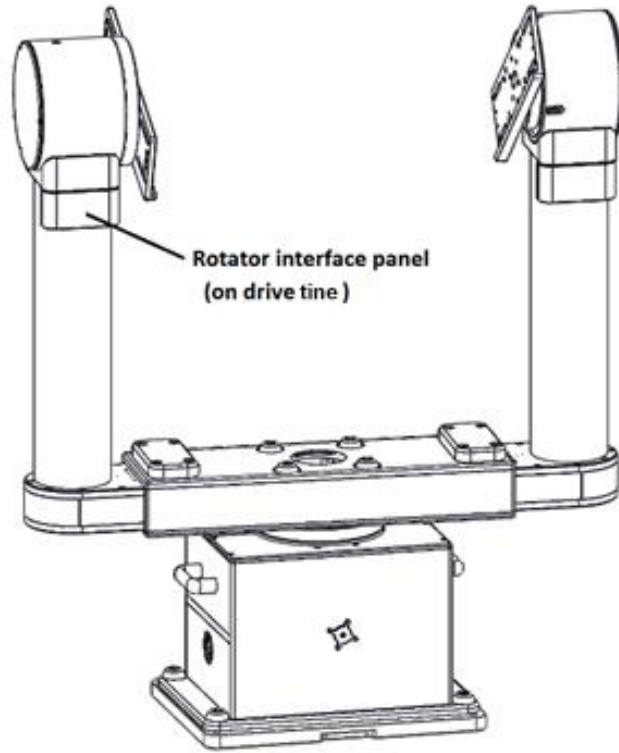


Figure 35: Location of the instrument rotator interface on the drive tine.

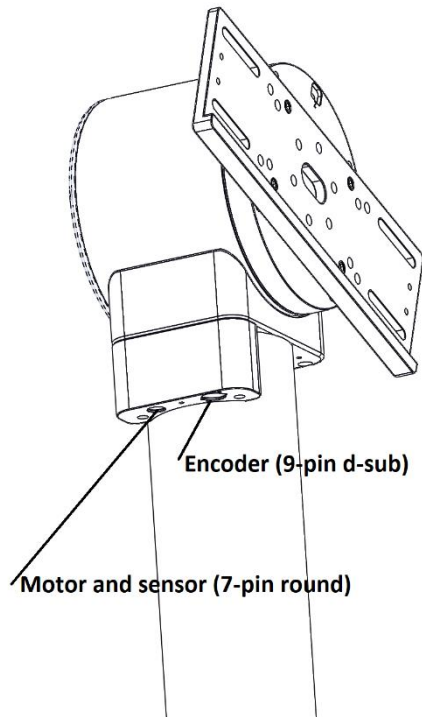


Figure 36: Instrument rotator connections.

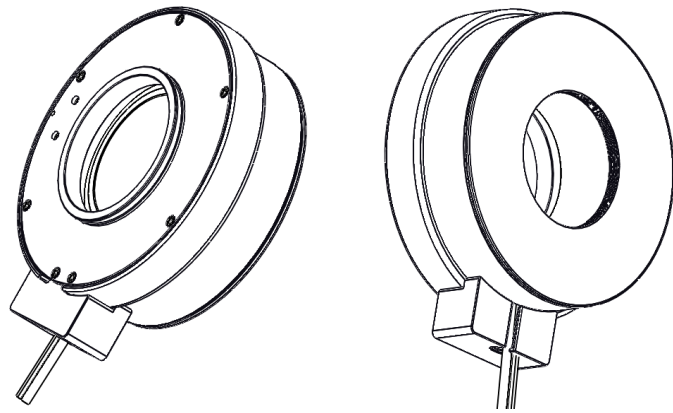


Figure 37 - Left image OTA side with dovetail, right image is the image train side with 3.5-in. thread (24 TPI)

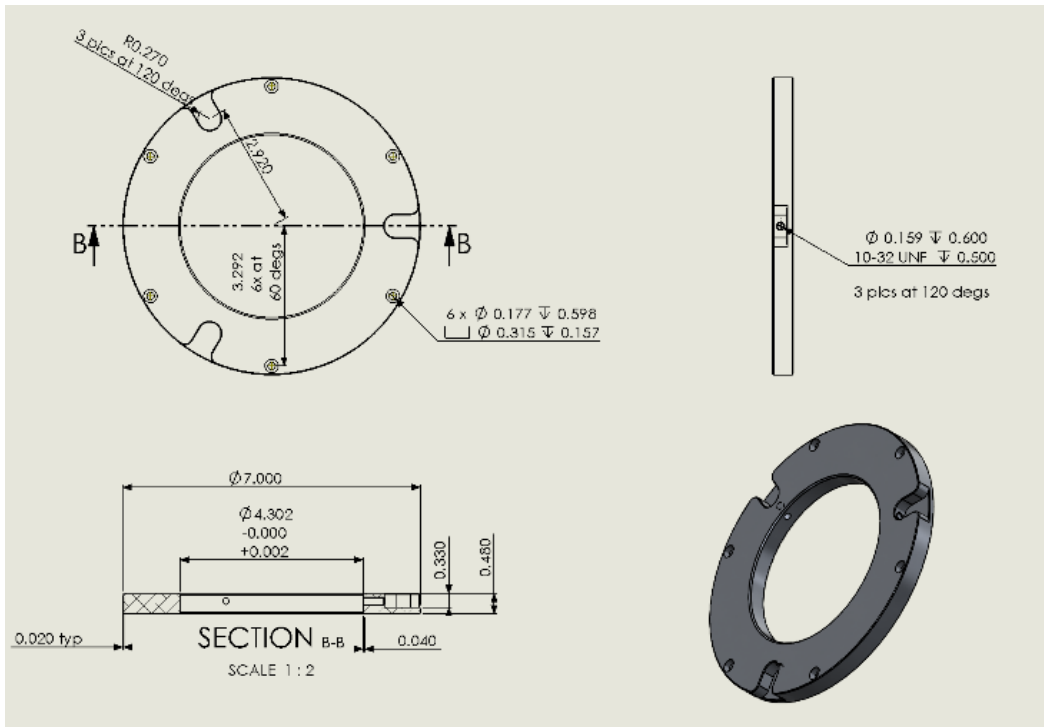


Figure 38 - OTA Plate is compatible with the Optec 4300 dovetail.

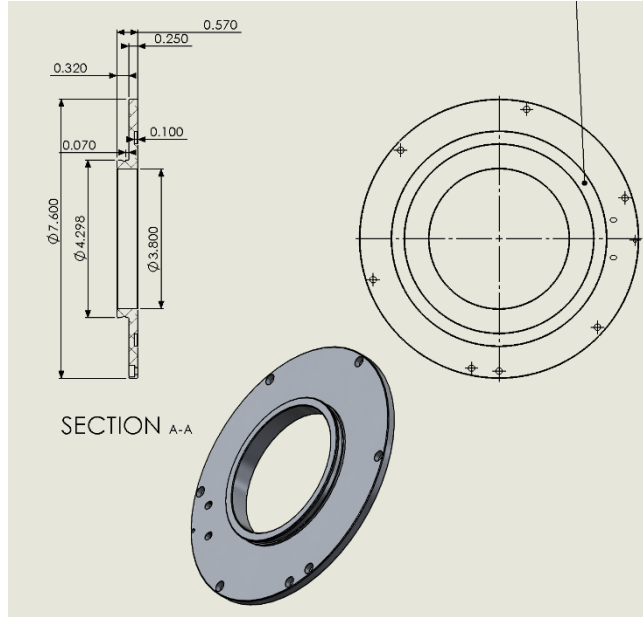


Figure 39 - OTA mounting dovetail dimensions (Optec)

Mounting the Optical Tube Assembly



Caution!

Attaching a large, cumbersome, and heavy optical telescope assembly or sensor package can be the most dangerous step in assembling the Apollo mount. Before the payload is in place and balanced, it may unexpectedly rotate, spin, slide, or drop.

Anytime a large mass, for example, when installing a maximum Apollo payload of 200 kg, is moving but not in balance, stopping the motion can be difficult and potentially cause severe harm.

Each axis has a lock pin that, when in place, restricts the rotation of that axis. These safety pins are especially important to install on the altitude axis before attaching the payload.

The Scope Rail System has some safety pins that can stop the payload from dropping through the fork, but extreme care must be taken during this process.

The *Scope Rail System* provides an effective means to attach payloads to the Apollo and achieve balance. Please see *Appendix B: Apollo OTA Mounting System* on page 98 for more information on the Scope Rail System.

While there are many different ways to mount an OTA or other sensors between the tines, the following section describes how to attach an OTA to the Apollo using the Software Bisque Scope Rail System.

Mounting a Scope Rail Equipped OTA

Mounting a telescope between the tines using the Scope Rail System involves the following steps.

1. Attach the scope rails to the OTA.
2. Add the fork rails to both tines.
3. Adjust the tines so that the spacing is approximately 12 mm (0.5 inches) wider than the measured distance between the two scope rails that are mounted on the optical tube.
4. Tighten the fork clamp on the drive tine (see page 40).
5. Install the loading pins on the scope rails.
6. Insert the axis lock pin to both the altitude and azimuth axes.
7. Lift the OTA above the fork rails and lower it into position so that the safety pins are resting on the fork rails.

8. Add at least one clamp nut (which pass through the fork rails and thread into the scope rails) to each side of the telescope.
9. Gently push and rock the support tine inward until the fork rail contacts the OTA.
10. Roughly balance the OTA by sliding it parallel to the optical axis.
11. Tighten the support tine clamp.
12. Relieve the stress on the system by loosening the support tine plate, then re-tighten it.

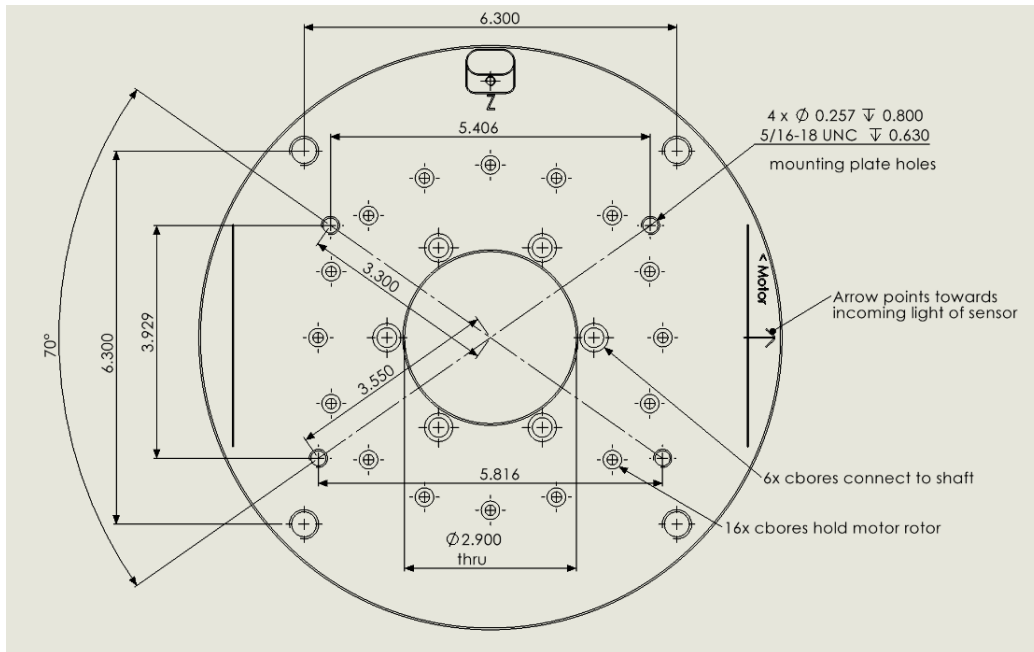


Figure 40 - Drive plate and support plate hole pattern

The drive plate and support plate have four tapped holes (5/16-18 TPI) that accept the mounting plate. This pattern is not symmetric which ensures that the scope rail plates are attached in the correct orientation. If custom mounting plates are fabricated for attaching the sensor package, the required dimensions are shown above.

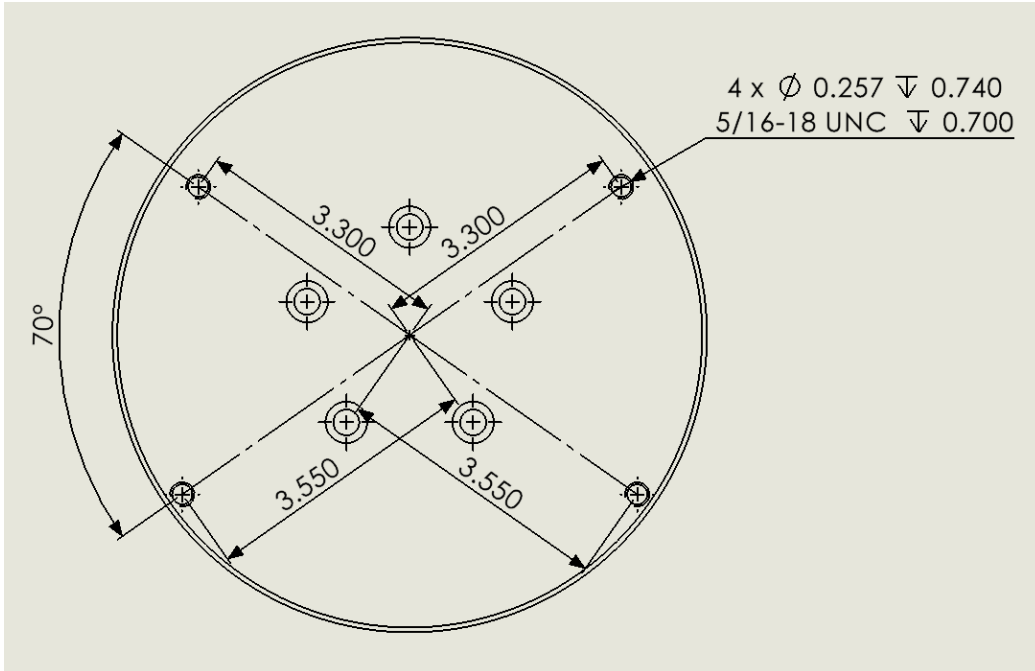


Figure 41: Drawing showing the support plate hole specifications.

The support plate hole pattern is same as the drive plate.

Step 1: Attach the scope rails to the OTA

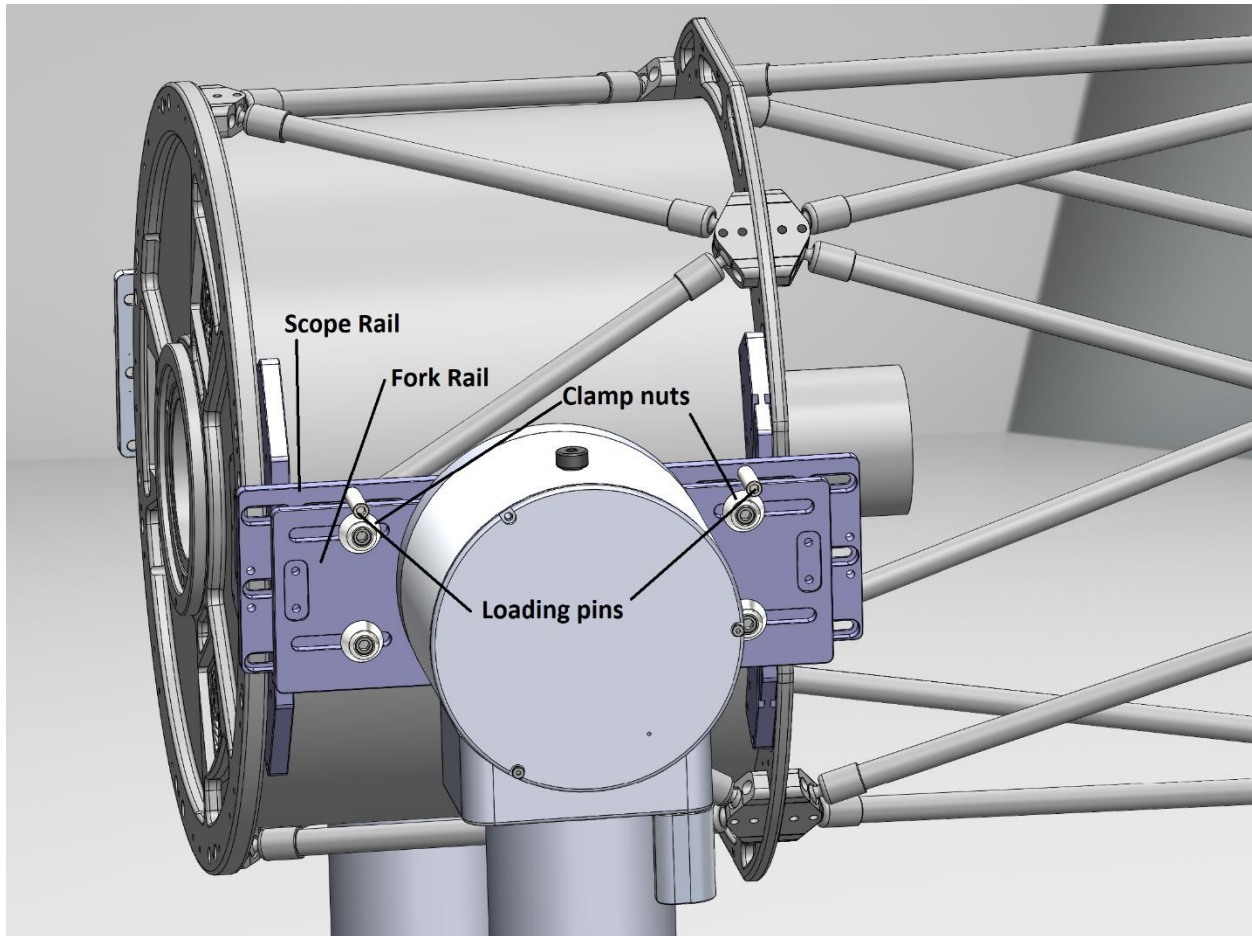


Figure 42: Add the fork rails before installing the telescope.

Step 2: Fine-Tune the Tine Spacing

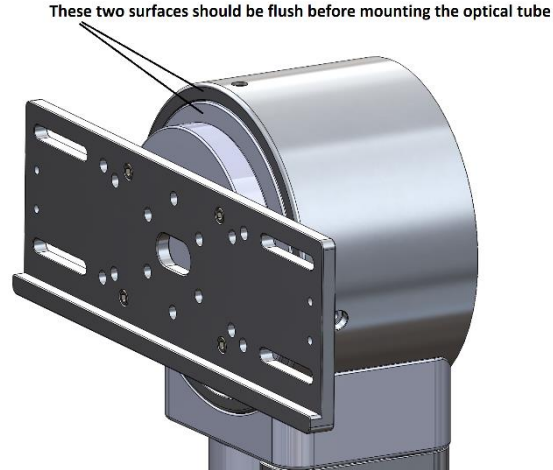


Figure 43: Fine-tuning the tine spacing.

The distance between the tines should be adjusted so that the optical tube fits comfortably between them. In practice, make this dimension about 12 mm (0.5 inches) wider than the width of the plates on the optical tube. Also, be sure the support tine width adjustment mechanism is near the center of travel. At mid-travel, the adjustment plate is flush with the edge of the support tine housing (Figure 43).

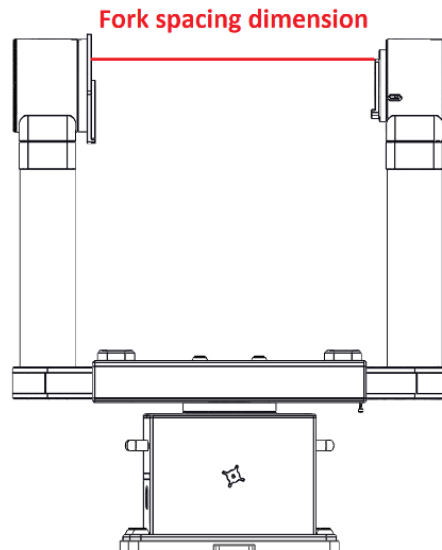


Figure 44: The red line defines the distance to measure between the tines.

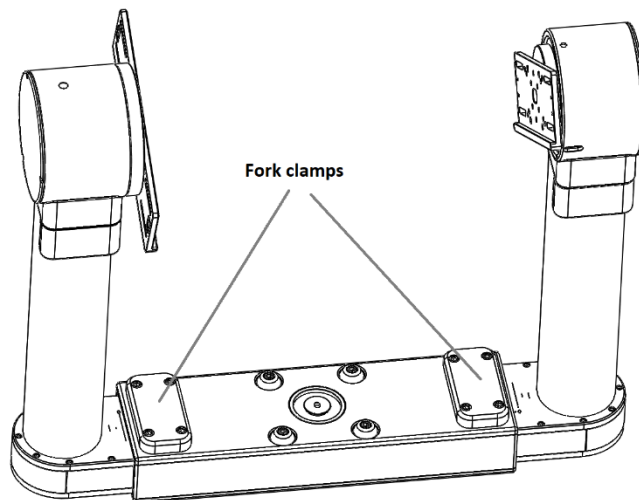
Step 3: Tighten the Drive Tine Clamp

The next step is to tighten the drive tine clamp. When the clamp is tightened, the “sag” in the drive tine will be removed and the clamping assembly will move slightly inward towards the other fork. Note that there will still be sag in the support tine until it is tightened.

Fork Clamping Mechanism

Each fork is adjustable to accommodate a limited range of instrument package diameters. The prevailing dimension is that of the *fork center* which dictates the distance between attachment plates on the optical telescope assembly. The correct size should be specified when ordering the Apollo mount. The *Fork Rails* are described later in this document. The total amount of adjustment is approximately 40 mm (1.6 inches) per fork for a total of 80 mm (three inches).

The fork clamps are designed to provide very robust clamping by tightening the four socket screws that are visible on the end of the fork center. The clamping mechanism is also designed to align each of the tines as the clamp is tightened.



Tightening the Fork Clamps

There are four screws on each of the fork clamps which require a 3/8-inch hex drive. Each of these screws has a thrust bearing between the screw and the fork top plate. Therefore, the amount of torque needed to achieve full clamping pressure is likely less than one would expect. **Do not overtighten these screws.** The torque specification is 8 to 11 Nm (6-8 foot-pounds) per screw. First lightly tighten all four screws before final applying the full torque to all four screws.

As the fork clamps are tightened, the fork tines will straighten and become vertical. Removing the sag in each tine will slightly reduce the fork spacing.

Step 4: Add the Loading Pins

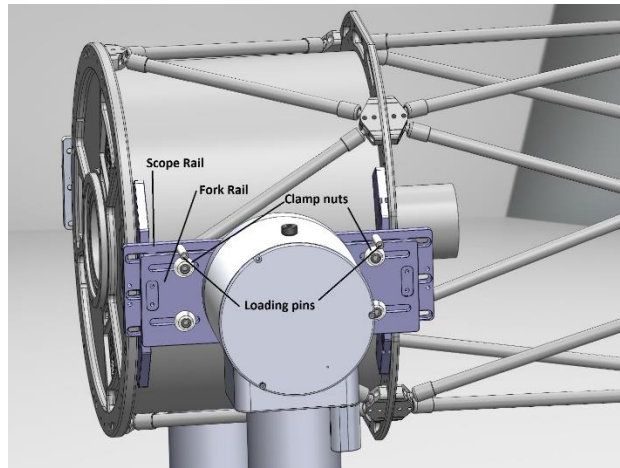


Figure 45: Temporarily set the telescope on the Loading Pins while installing the telescope clamp nuts.

Step 5: Add the Axis Lock Pin

Insert the Axis Lock Pin into the hole on top of the Drive tine then rotate the Fork Rail until the pin drops into the axis when the fork rail is close to horizontal as shown in Figure 46.

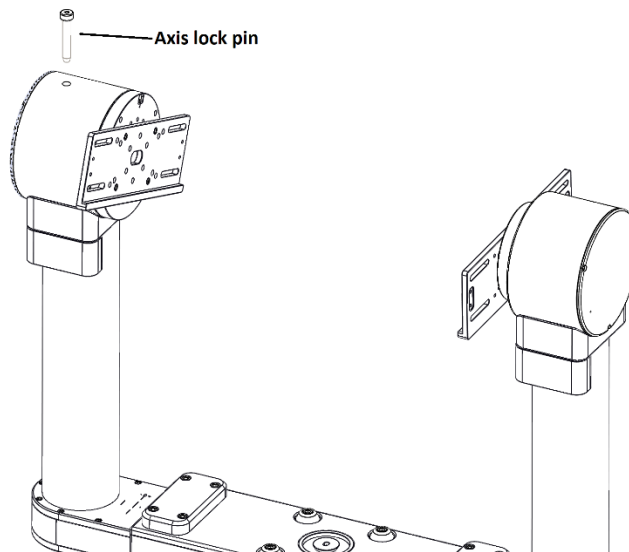


Figure 46: Location of the Axis Lock Pin.

Step 6: Lift the OTA into Place

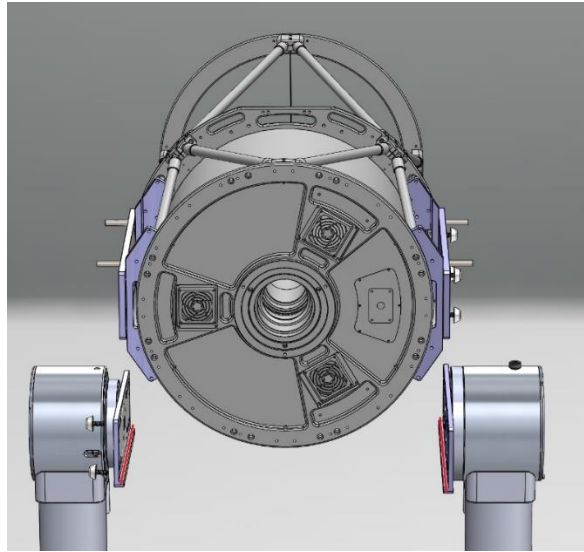


Figure 47: The fork plate spacing is the distance between fork plates; the OTA plate spacing is the outer distance between the two plates on the OTA.

The tines should be adjusted so the *fork plate spacing* is about 1-2 centimeters wider than the *OTA plate spacing*. This helps avoid collisions between the telescope and the tines when lowering the telescope into place. Also, with the tines at this width, the Loading Pins attached to the Scope Rail are long enough so they will still contact the top of the Fork Rail when the OTA is lowered into place.

Carefully lower the OTA until the *Loading Pins* rest on top of the *Fork Rails*.

Once the Loading Pins contact the Fork Rails, the weight of the OTA rests on the tines, but the OTA is not yet unattached. At this point, the OTA can be pushed towards the Drive Tine so that one or more clamp nuts can be threaded into the holes in the OTA Scope Rail.

Step 7: Add Clamp Nuts

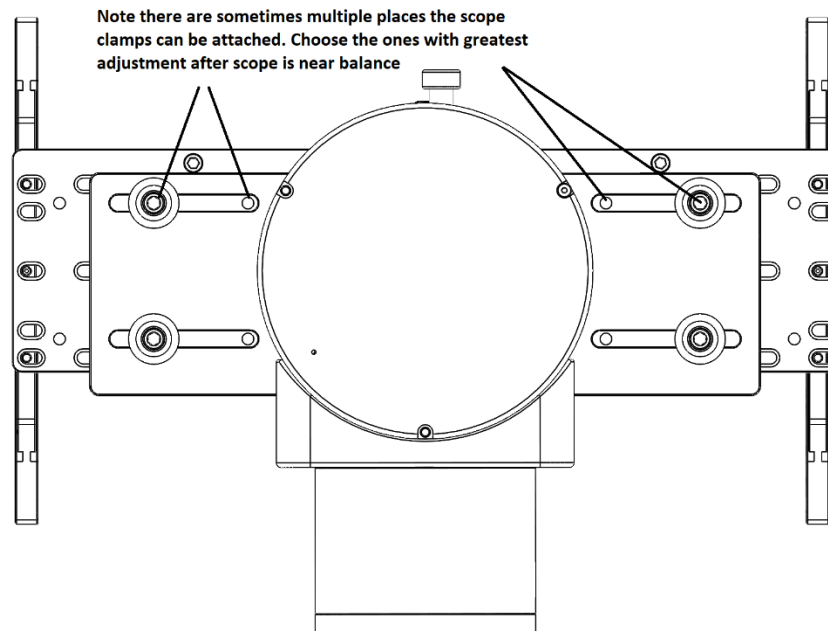


Figure 48: Attach the clamp nuts in the hole that provides more adjustment to the telescope's position.

When the OTA is close to the balance position, the four fork rail clamp nuts should be fitted through the slots in the Fork Rail where there is a visible threaded hole.

There may be more than one threaded mounting hole that is accessible on both sides of the fork center. Choose the hole with the largest amount of adjustment on both sides.

When the clamp nuts are tightened on both sides of the OTA, the weight of the telescope rests on the bottom of the Scope Attach plate.

During final assembly of the imaging train, the holes the Clamp Nut are initially installed in may need to be changed so that the system can be balanced.

Step 8: Push Support Tine Inwards

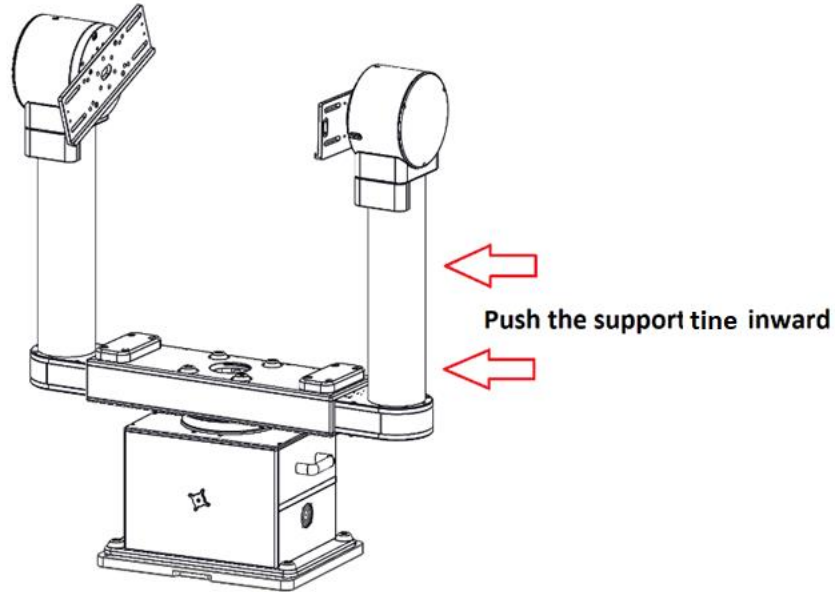


Figure 49: Adjusting the support tine.

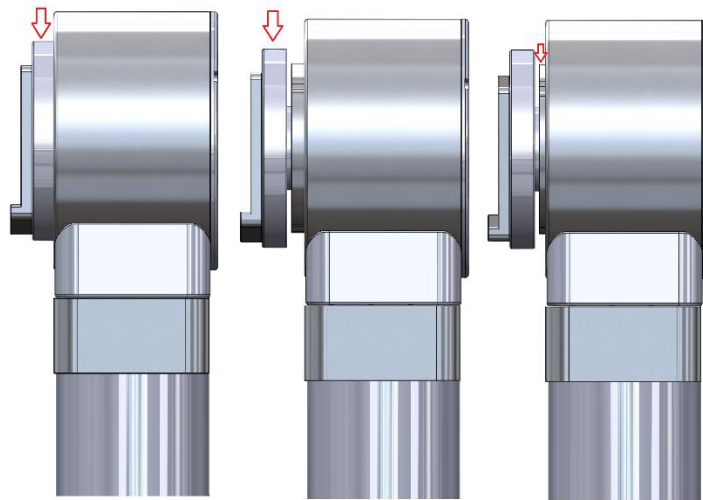


Figure 50: Minor adjustments for the fork spacing.

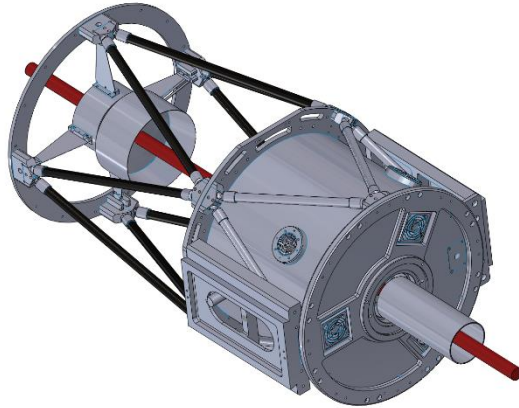
In addition to the “macroscopic” tine spacing adjustment in the fork base, the position of the fork tine plate can also be adjusted using a spacing mechanism that is built into the support tine bearing. The purpose of this adjustment is to ensure that, once the tines are tightened to the mount base, a small amount can be made to the tine spacing mechanism so that there is little or no stress on the optical tube, or undue stress between the two tines.

Figure 50 shows the limits of this adjustment. In the graphic on the left, the circular OTA plate is as close to the support tine as possible. The center graphic shows the maximum distance the plate can be adjusted from the tine. The starting position should be in between these two

positions, with approximately 6 mm (0.25-in.) of the bearing plate exposed. The small red arrow in the right-most graphic shows the location of the bearing plate.

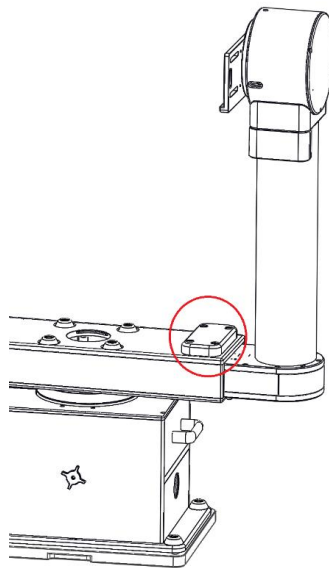
Step 9: Roughly Balance the OTA

Slide the tube assembly fore and aft along the optical axis to achieve a reasonable balance. Final balance will happen after the rotator and other components of the optical train have been added.



Step 10: Tighten the Support Tine Clamp

Please refer to the directions in Step 3 for tightening this clamp.



Step 11: Relieve Strain Between Tines

Using a ¼-inch hex drive, loosen the support tine plate screw to relieve stress between the tines. If the fork width is not exactly the same as the spacing on the telescope or instrumentation, the drive plate should move inward or outward a small amount. Retighten the screw once the stress is relieved.

If there is not enough adjustment in the support plate to accommodate the current fork spacing, the distance between both tines must be adjusted that the support plate is within its adjustment range.

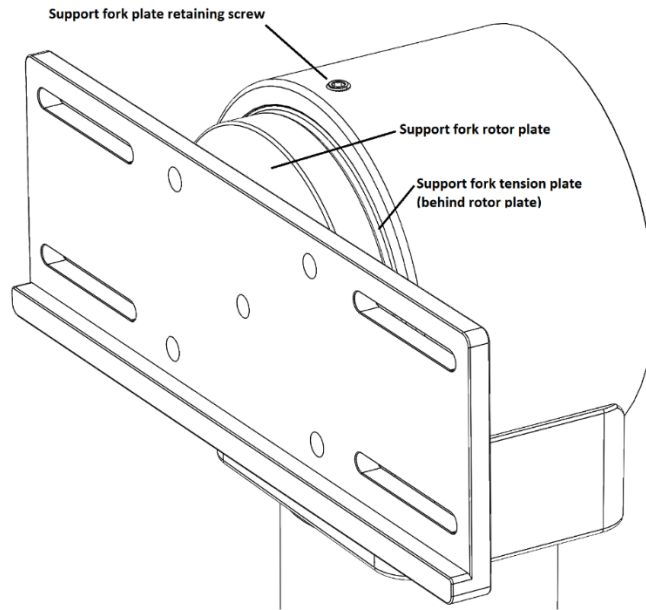


Figure 51: Tine width strain relief mechanism.

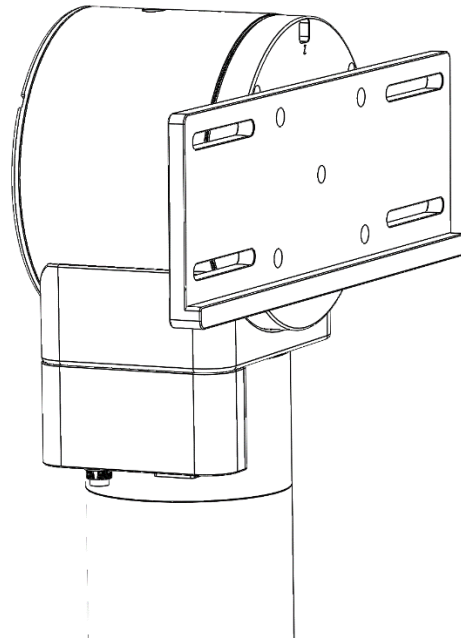


Figure 52: The support plate on the drive tine does not have a strain relief mechanism.

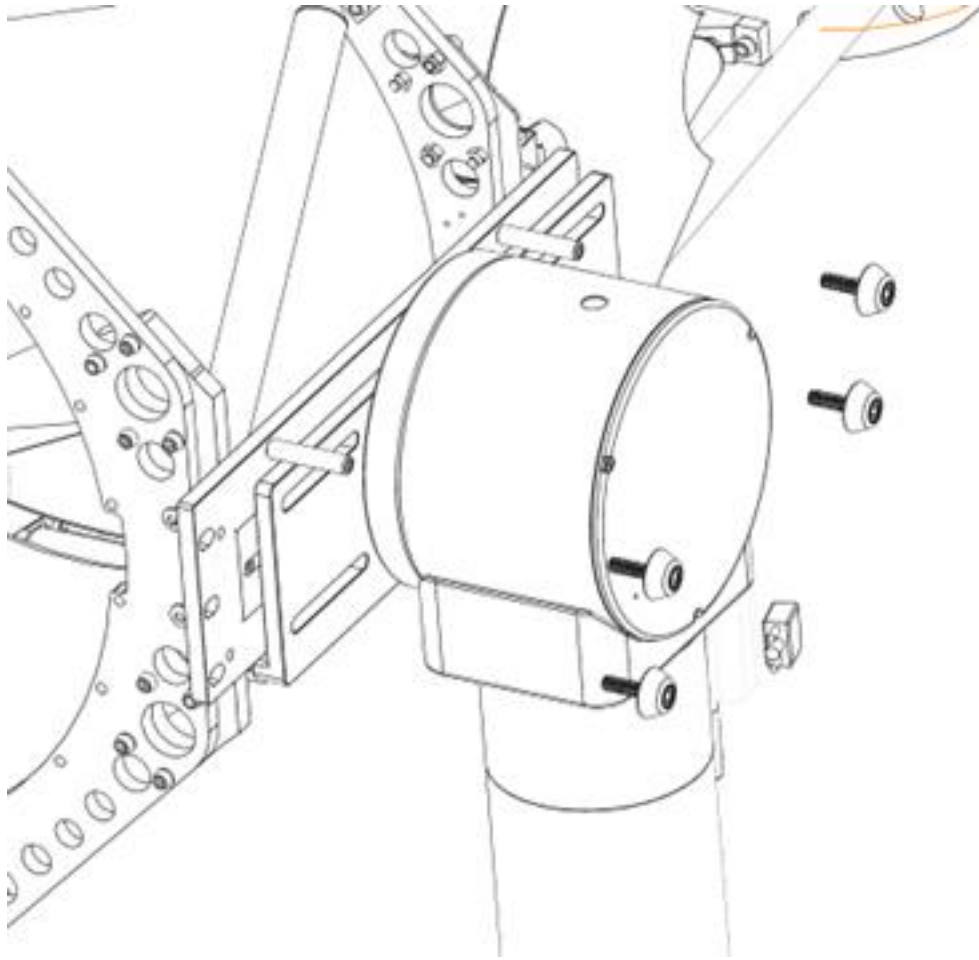


Figure 53: Attaching the telescope to the support plate.

The Paramount Duo Mount



Figure 54: The Paramount Duo with two 0.4 m telescopes (sold separately).

Introduction

The Paramount Duo is a compact and flexible version of the Apollo series of direct-drive mounts. The Duo can carry tandem payloads with a capacity of up to 70 kg (150 lbs.) per side. Figure 54 shows the Duo mounted in an altazimuth orientation.

With the addition of the optional Duo equatorial wedge (page 59), the head can also be mounted equatorially to allow horizon to horizon tracking.

The Duo shares the same motors, encoders, bearings, and complete set of software for accurate astronomical pointing and tracking as the Apollo fork mounts. Like the Apollo altazimuth fork mount, it can also be controlled directly with a very complete and robust set of motion commands.

Paramount Duo Components

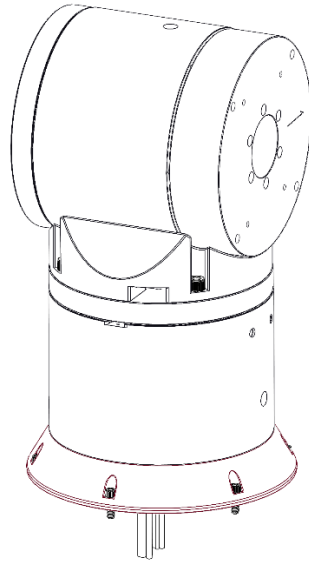


Figure 55: Duo head.

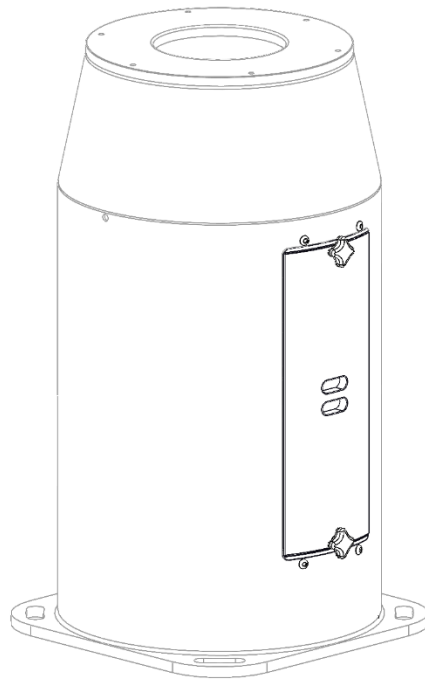
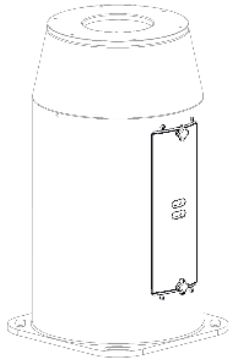
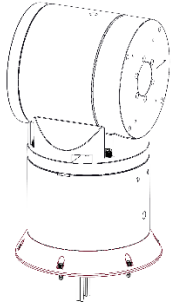
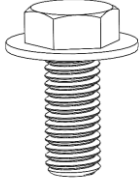











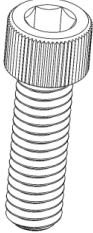
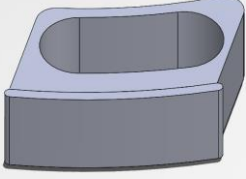
Figure 56: All of the mount's electronics are housed inside the Duo pier.

Paramount Duo Packing List

The table below lists the components that are included with the Paramount Duo mounted in the altazimuth orientation.

Item	Quantity	Notes	Graphic
Duo Pier with electronics	1	Bolts to the floor of the observatory, and also holds the control electronics and PCB distribution board. Weighs approx. 41 kg. (92 lbs.)	
Duo Head	1	Contains both drives for the roll and pitch axes. Weighs approximately 54 kg. (120 lbs.)	
Base mounting bolts and washers	4	5/8-in. x 1.5 in. bolt and washer	
Axis lock pins	2	Azimuth and altitude lock pins.	
Axis lock hole cover	1	Cover for the azimuth axis locking component.	

Item	Quantity	Notes	Graphic
Power cord	1	Power Cable for the Power Supply Unit (NEMA 5-15 male plug).	
Hex key set	1	Imperial hex key set.	
Small screwdriver	1	Flathead screwdriver to tighten the motor and brake wires to the terminal connectors.	
Security key	1	This USB security key must be plugged into the computer's USB port before TheSky is started. See page 71 for details.	
CAT 6 cable	1	Cable to connect the PC's NIC to the Apollo's Ethernet port.	
3/8-in. ratchet	1	Both 3/8-in. and 1/4-in. drives included.	
3/8-in. hex wrench	1	A standard size hex wrench for tightening the mounting bolts.	

Item	Quantity	Notes	Graphic
Duo head to pier mounting screws (altazimuth configuration).	6	5/16-18 x 7/8-inch SHCSs.	
Through axis cable covers	2		

Mounting the Duo Pier to the Floor

The base of the Duo Pier is 15 in. x 15 in. (38 cm x 38 cm), with a slot at each corner that has a radius of 8.3 in. (21 cm). The recommended means of mounting the pier is to install four concrete anchors in the floor of the observatory for 0.50-in. or 0.625-in. bolts.

Duo Pier Base Dimensions

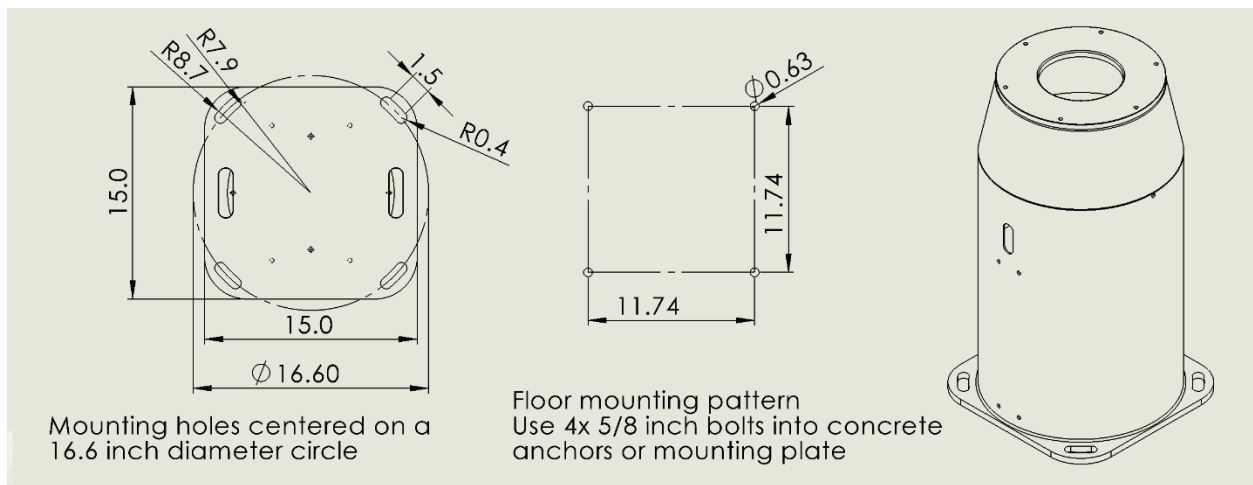


Figure 57: Duo hole mounting specifications.

The hole pattern is a 11.74 in. (29.82 cm) square. One edge of the mounting plate must be oriented along a north-south line.

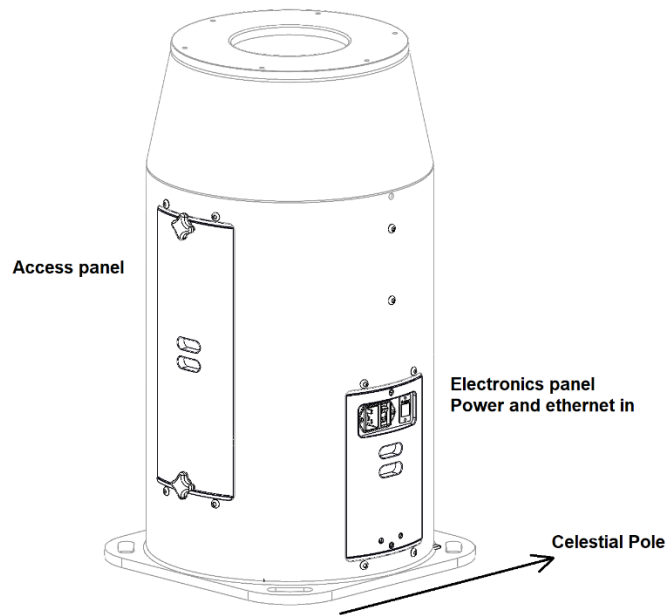


Figure 58: Preferred orientation of the Duo base.

Once the Duo pier is fastened securely to the concrete flooring, the Duo head can be loaded into place on top of the pier. As the Duo head is heavy and cumbersome to hold, this step requires at least two people. When the head is attached to the wedge (see Figure 67), three helpers are ideal. While two helpers lift the head into position, the third person can direct the cables at the bottom of the Duo down through the hole in the top of the pier.

Duo Assembly Overview (Altazimuth)

The Duo can be shipped as a single unit (no assembly required) or as two separate components.

When placing the Duo head on top of the pier, make sure to align the azimuth lock pin hole with the access panel on the pier (Figure 59). The lock pin hole is at the center of travel of the azimuth axis, which should be on the opposite side from the celestial pole.

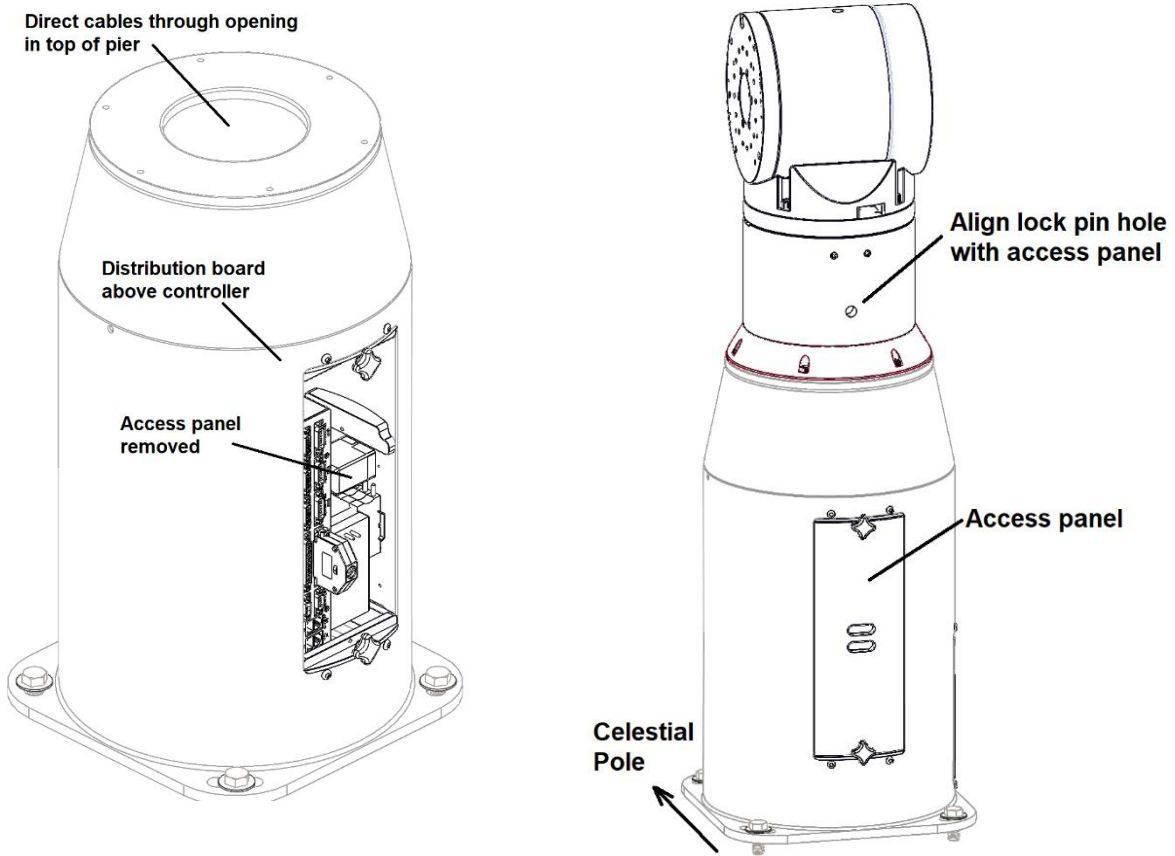


Figure 59: Orientation of the pier (left) and when the Duo is attached (right).

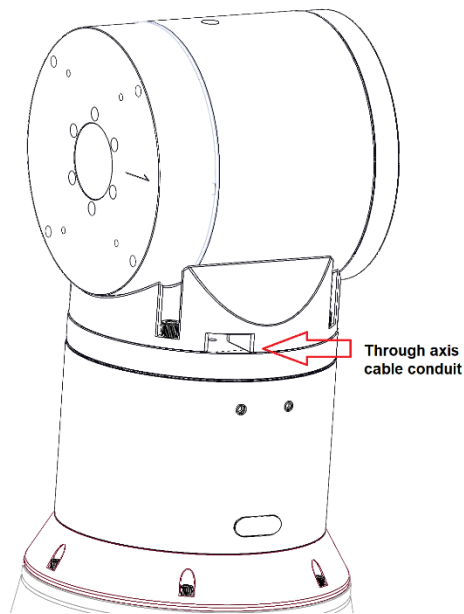


Figure 60: Location of the cable conduit.

Through Axis Cable Conduit

The Duo Head has two cable conduits for passing cables up through the main axis (Azimuth or HA), exiting through the conduit. The conduit is 38mm x 18mm (1.5" x 0.7") making it large enough to accommodate many different cable and connectors sizes. Two covers are provided to prevent unwanted debris or insects from entering the internal area of the Duo.

Duo Assembly Overview (Equatorial)

Here are the basic differences between mounting the Duo in an altazimuth orientation versus an equatorial orientation.

- When mounting the pier to the concrete flooring, the pier's main panel should face in the opposite direction compared to the celestial pole (Figure 60).
- The optional Duo equatorial wedge must be installed. When attaching the Duo wedge to the pier, the wedge top plate must point towards the celestial pole. It follows that the altitude adjuster is also opposite the celestial pole side.
- The wedge is attached directly to the top of the pier using six 5/16-18 TPI x 1.125 SHCSs. Note that the two screws that are on the pole side are partly obstructed by the wedge, and a shortened hex wrench must be used.
- When attaching the Duo Head to the Duo Wedge, the lock hole in HA must be upwards. This places the point of mid travel towards the celestial meridian. The motion of HA is then ± 9.5 hours from the meridian.

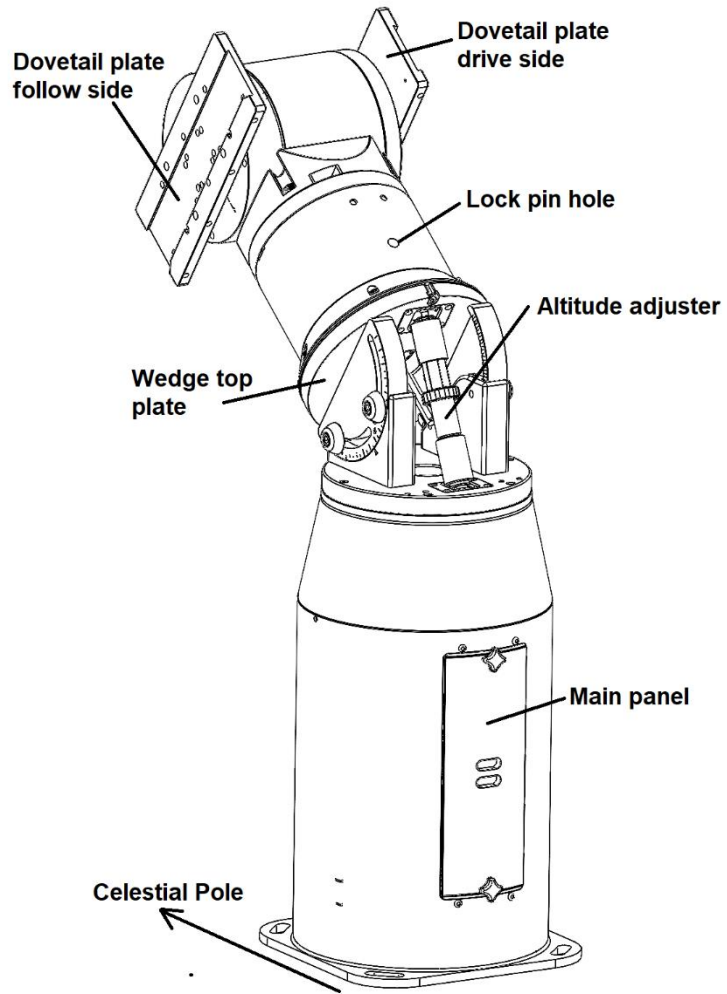


Figure 61: Attach the Duo wedge and head in the orientation shown above.

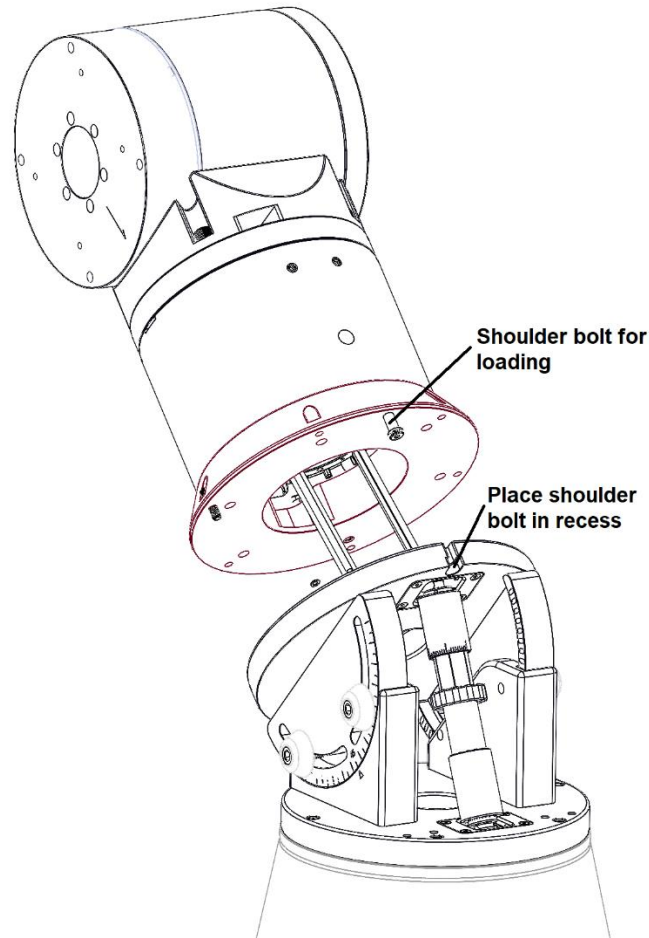


Figure 62: When mounting the Duo head, carefully pass the cables through the wedge and into the pier.

Loading the Duo head onto the equatorial wedge requires a minimum of two people or the aid of a small adjustable gantry crane.



Caution!

Be sure the pier is firmly mounted to the observatory floor, and the Duo wedge is connected to the pier using six socket head screws before adding the Duo head to the wedge, otherwise the system will be out of balance and tip over.

With the cumbersome external cables, temporarily placing the Duo head on a sturdy table or other flat surface before attempting to place it on the wedge can be helpful. While the Duo head is lifted into place, the cables must be carefully passed through the wedge and not get caught or pinched between the Duo head and the wedge.

Once the Duo head's bottom-plate is in contact with the wedge, place the loading shoulder bolt into the corresponding recess at the top of the wedge (Figure 63). This holds the Duo head in place. The next step is to install and securely tighten the six 5/16-18 TPI x 1-in. SHCSs.

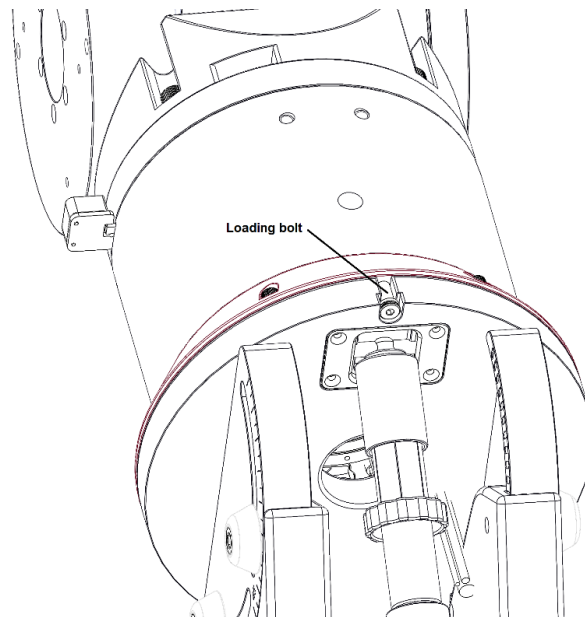


Figure 63: The location of the loading bolt on the base of the Duo head.

Paramount Duo Equatorial Wedge

The optional Paramount Duo equatorial wedge (or Duo wedge for short) allows the Paramount Duo to operate in an equatorial orientation. The wedge permits the latitude of the head's polar axis to be adjusted from 25 degrees to about 80 degrees. The Duo wedge attaches directly to the Duo Pier.

Using the Paramount Duo with the Equatorial Wedge

When using the equatorial wedge, the roll axis (HA) is restricted to +/- 145 degrees or about 9.6 hours in each direction. TheSky is configured to slew "beyond the pole" when the target past 8 hours HA. This is typical behavior for the fork equatorials mounts where reaching targets low and towards the celestial pole causes the telescope to go across the pole.

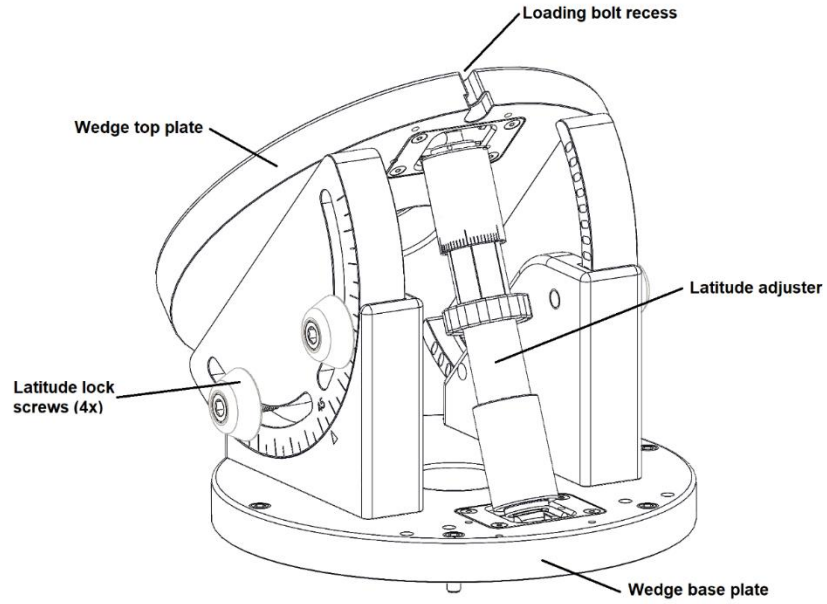


Figure 64: The Duo equatorial wedge components.

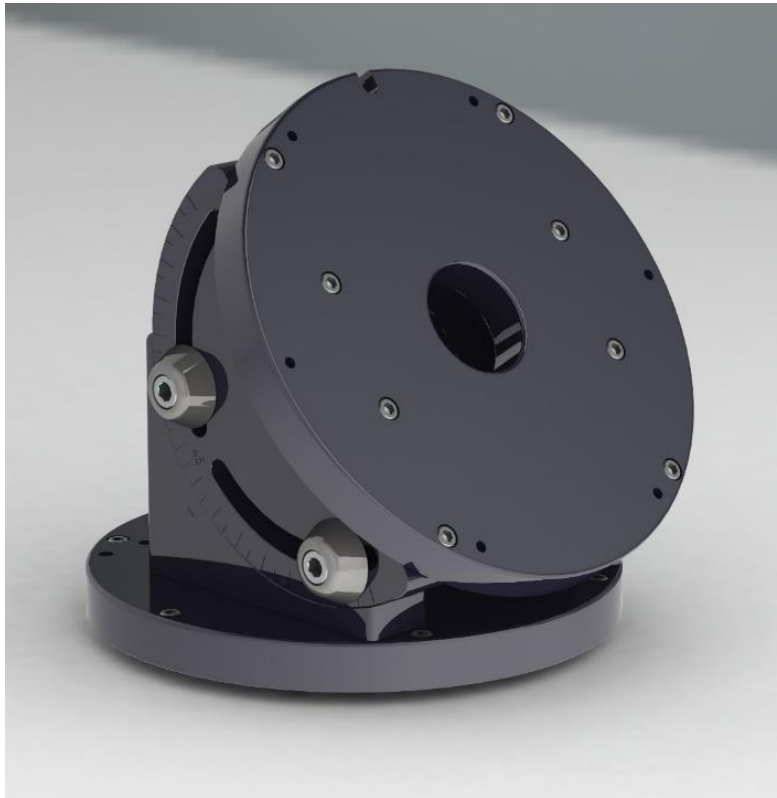
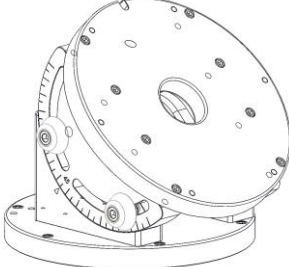
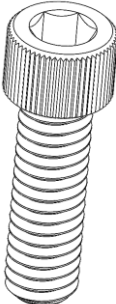
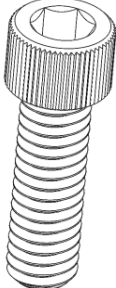
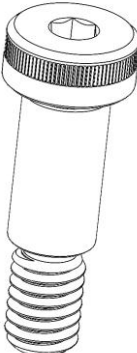


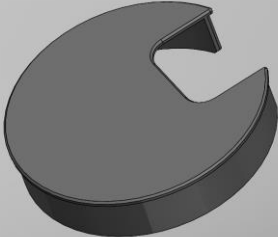


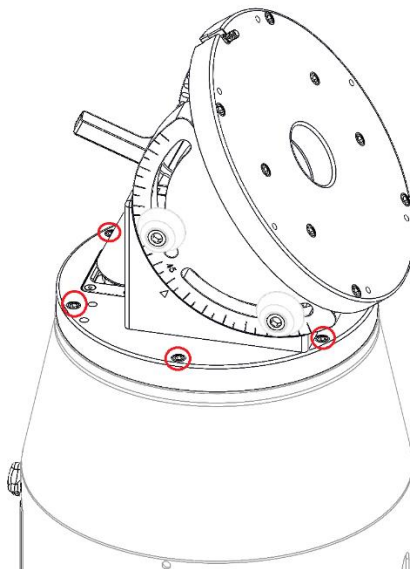
Figure 65: The Paramount Duo equatorial wedge.

Duo Wedge Packing List

The table below lists the components that are included with the optional Paramount Duo wedge.

Item	Quantity	Notes	Graphic
Wedge	1	This component is shipped fully assembled.	
Wedge to pier mounting screws	6	5/16-18 TPI x 1.125-in. socket head cap screws.	
Duo head to wedge mounting screws	6	5/16-18 TPI x 1-in. SHCSs.	
Duo head to wedge loading helper bolt	1	Shoulder bolt, 0.375-in. diameter by 0.75 inches long. This shoulder bolt may be pre-installed on the Duo Head.	

Item	Quantity	Notes	Graphic
Short hex wrench		Use this to access two SHCS on front of the wedge.	
Latitude adjuster wrench	1	See note about raising the latitude of the wedge using this wrench.	
Cable cover	2	Placed around cables on the duo wedge	



After placing the wedge on the top of the pier, use the six 5/16-18 TPI x 1.125 -in. socket head cap screws to attach the wedge base to pier top. Access to the two screws that lie below the flat portion of the wedge is restricted and require using the included short-end hex wrench to tighten these screws.

The wedge is adjustable from about 23 degrees latitude to 80 degrees latitude. The wedge should be adjusted to 1-2 degrees above the latitude of the observing site before the Duo Head is loaded. This is because it is easier to lower the cantilevered head than it is to raise it.

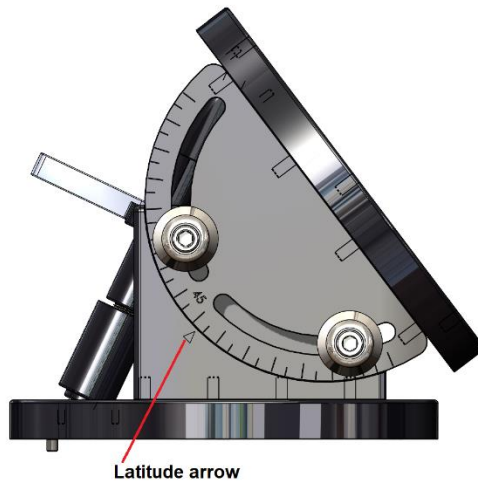


Figure 66: Duo wedge at 37 degrees latitude.

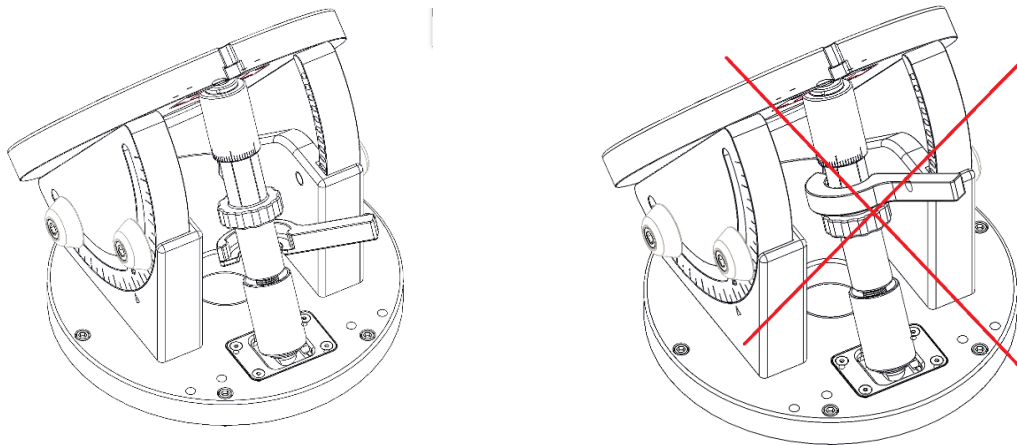


Figure 67: The graphic on the left shows the proper orientation of the latitude adjuster wrench when raising the load towards a higher latitude.

Note about raising the head using the Latitude Adjuster Wrench

After the Duo head has been loaded onto the wedge, the cantilevered weight makes it difficult to raise system. This is why it is recommended to adjust the wedge 1-2 degrees high before

loading the head onto the wedge. When lifting the load (i.e. towards a higher latitude) the latitude adjuster wrench that is included should be used in the orientation shown in the first graphic above, that is, from the bottom-up rather than top-down. In this orientation the wrench will grab the handle as it is rotated to raise the system. This clamping action does not work if the wrench is used as shown the second graphic. The second graphic is the correct orientation of the wrench for lowering the load, moving the wrench left to right.

Duo Cable Connections

Once the cabling has been routed from the Duo head into the Duo pier, the following connections must be made to attach the axes to the controller.

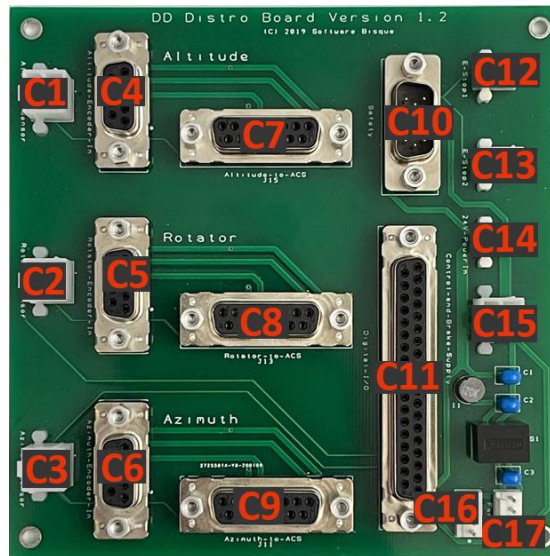


Figure 68: Paramount Duo distribution cable PCB.

Departing from the Duo head are six cables, two motor cables, two encoder cables and two sensor cables. The sensor cables are used to measure the temperature of the motor to insure it does not overheat. The Duo would rarely use a rotator so that is not discussed here.

The distribution board shown above is located inside of the Duo pier, above the main controller. The altitude sensor and encoder plug into C1 and C4. The azimuth sensor and encoder plug into C3 and C6.

Motor Wiring

The motor leads are labeled as shown in Figure 33. They may also be labeled using the letters R, S, T instead of 1, 2, 3 so that they match the inputs annotated on the controller where the motor plugs in.

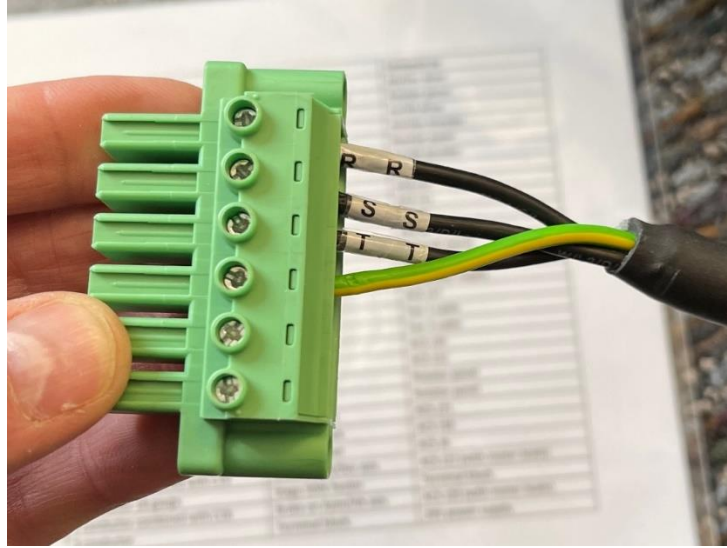


Figure 69: The motor wire leads (R,S,T).

Normally, there is sufficient space so that the altitude and rotator motor connectors do not have to be removed from the motor leads. If you find that you must remove the large connector while routing the cables, be sure to return each wire to the correct position. Use the labeling on the Controller (J20-J22) to see the order from left to right. The green wire is ground and should go into the fourth position.



Note Terminal Wire Fasteners

Do not tin the ends of the cables before they are inserted into the terminal connectors.

- *Tinning changes over time and will cause the cables to become loose.*
- *When tinned, the actual points of electrical contact end up being smaller compared with using bare wires.*
- *If these cables ever need to be removed from the terminal and reconnected, be sure to apply significant torque to the small screws to ensure full contact and to keep the wires from pulling out. The required torque is about as much as one can muster when using the supplied small screwdriver and without breaking or stripping the screw.*

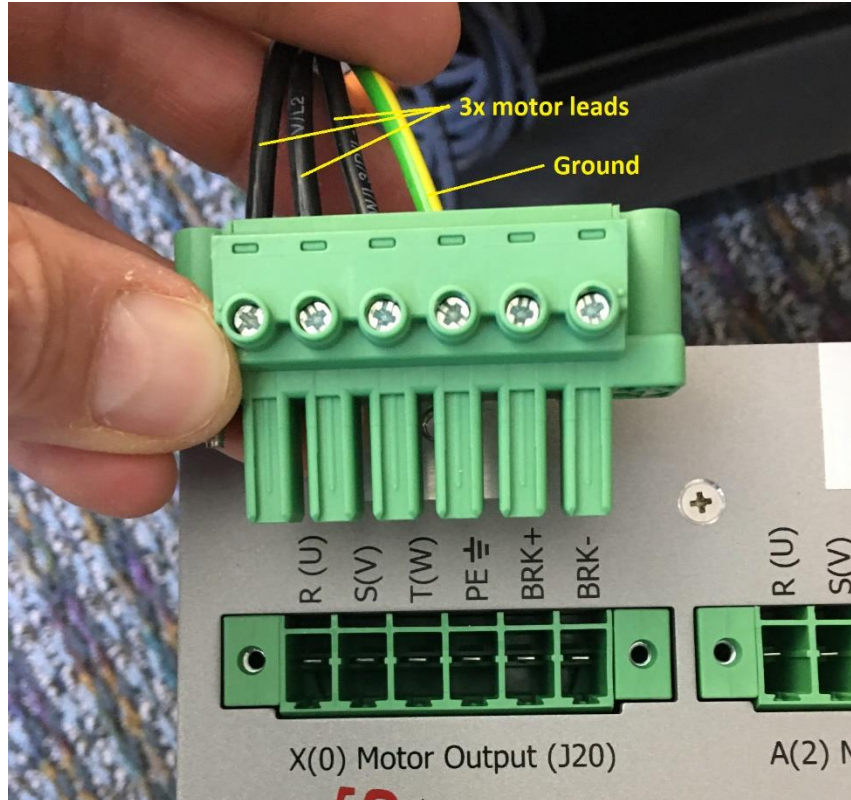


Figure 70: Cable connection terminals.

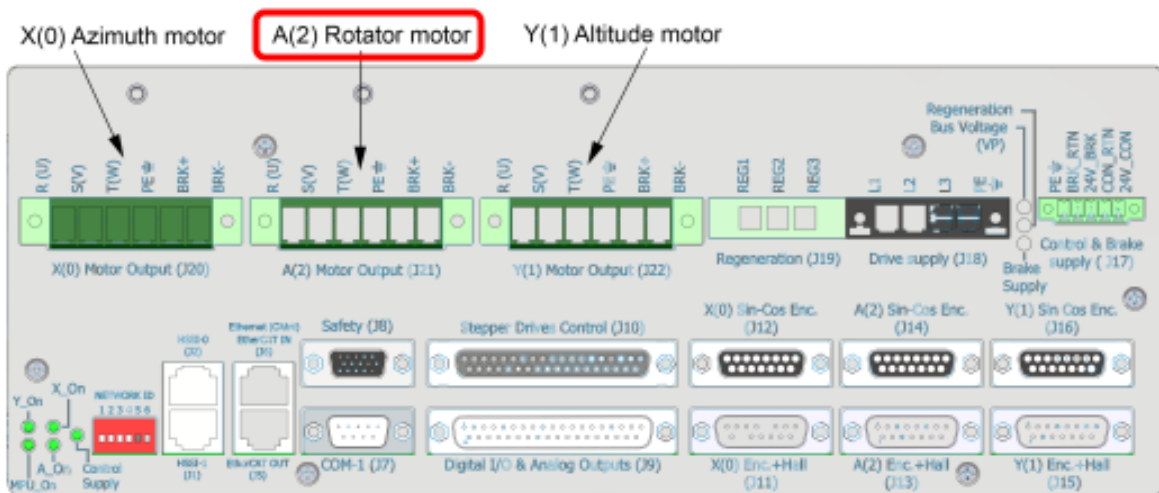


Figure 71: Note that the rotator motor cable occupies the **center plug!**

When plugging the two motors into the controller, make sure the azimuth/HA motor (labeled C18) is plugged into J20 (also labeled X(0)) on the controller. The altitude/declination motor must be plugged into J22 (also labeled (Y(1))) on the controller.

The Duo is shipped with cables connecting C7 to C7, and C9 to C9 and C11 to C11 between the distribution board and the controller.

Software Bisque Instrument Rotator

For three axis gimbals to work in concert, all axes must be precisely coordinated. The Apollo rotator uses a high torque density direct-drive motor and a high-resolution encoder to achieve accurate positioning and fast rotation (as fast as the azimuth axis).

Though the required precision of the rotator is relaxed compared with the azimuth and altitude axes, the rotator should have the same upper speed limit that the azimuth axis, otherwise the mount will complete its slew before the rotation is complete.

Note: The instrument rotator is integrated into the Apollo's three axis industrial controller. As such, the rotator is only compatible with the Apollo controller, and is not compatible with other direct drive controller.

If a rotator is not to be used, choose **No Rotator Present** on the **Bisque TCS/DD** window.

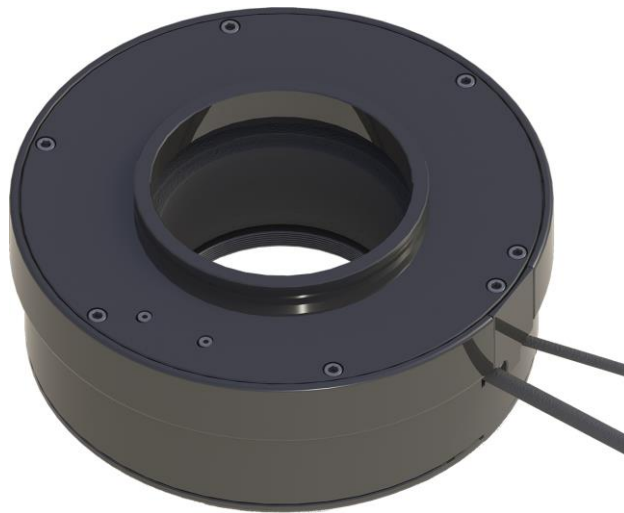


Figure 72: The Software Bisque instrument rotator.

Instrument Rotator Specification	Details
Clear aperture	89 mm (3.5 in.)
Physical size	200 mm (8 in.) OD, 70 mm (2.75 in.) thick
Weight	4.5 kg (10.2 lbs.)
Torque	9 Nm (7 ft-lbs.)
Telescope adapter	Optec-style 4300 dovetail
Camera adapter	89 mm (3.5 in.) 24 TPI
Back focus	70 mm (2.75 in.)
Resolution	26-bit absolute encoder
Power	Powered by the Apollo 3-axis industrial controller

Construction	Machined aluminum housing
Full travel	540 degrees
Control system	Commanded by a three-axis industrial direct-drive motor controller and powered by TheSky software or custom software.

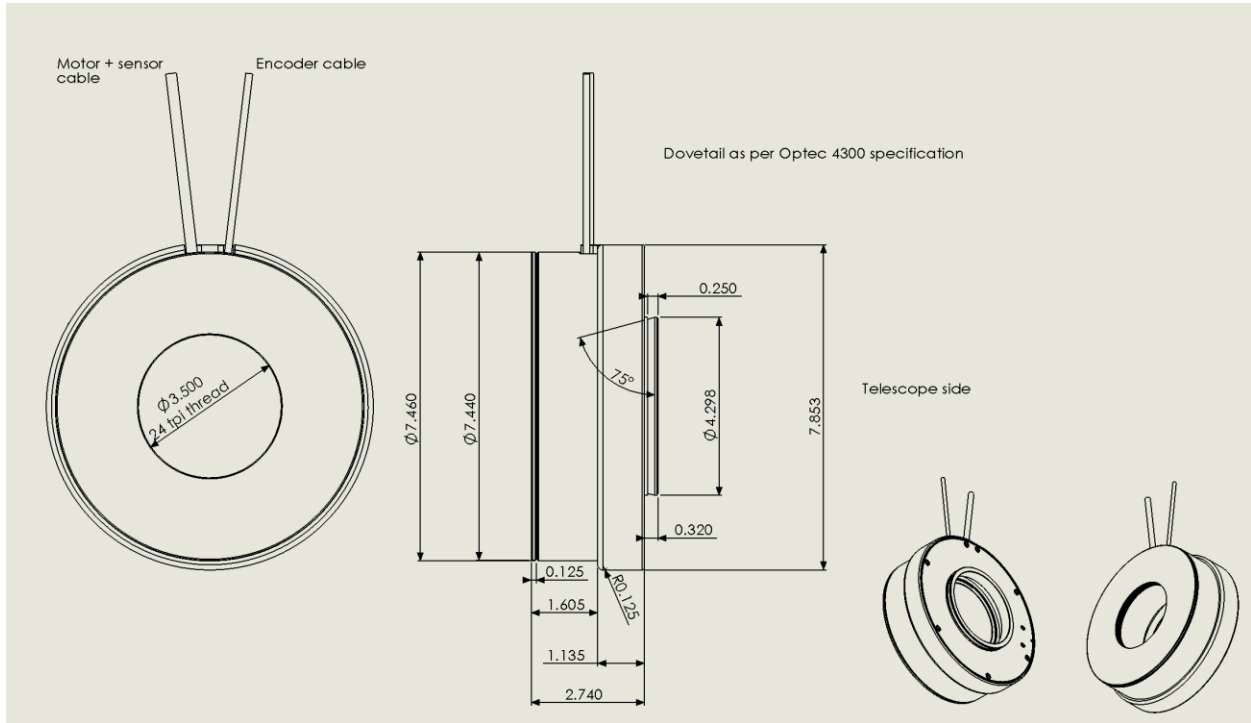


Figure 73: The instrument rotator dimensions.

Powering the Apollo Mount

The Apollo mount requires 110V-240V AC at 15A maximum for normal operation. The total amount of electrical current draw depends on several factors including the slew speed, acceleration and deceleration, total weight of the instrumentation, system balance, and inertia.

When the speed is 10 degrees per second or less and accelerations is 10 degrees per second per second or less, a balanced system of 100 kg (220 lbs.) draws less than 3 amps. Faster slewing and acceleration quickly increase the electrical current draw, as does an out of balance system. Note that altitude axis must be well balanced; azimuth balance is not as critical.



Figure 74: The axis-locking component.

Note: the axis lock cover should be placed in the axis lock pin hole once the telescope is mounted to prohibit insects or debris from entering the drive housing.

Tuning Direct-Drive Systems



Direct-Drive Tuning Disclaimer

The process of tuning can cause equipment damage or personal injury or death if not performed carefully. Tuning a system iteratively pushes the envelope of stability vs. instability and an unstable system can move quickly and unexpectedly. Although settings for safety have been set, Software Bisque cannot be held responsible for damages caused by tuning a system. Be ultra-careful. Always stand clear of a system being tuned. Always start out with conservative settings and gradually work up to more aggressive settings.

To achieve optimal performance, all direct-drive systems must be tuned. The nature of direct-drive motors necessitates the need for tuning primarily because there is no gearing. Therefore, the direct-drive control system itself must be able to accommodate all the differing aspects of given system that are unique to that system, including loads, inertia, balance, friction, varying speeds, external disturbances, etc.

In general, a well-tuned astronomical system quickly slews to its specified target and begins tracking with minimal overshoot/undershoot. It should also be said that a well-tuned system is one that meets the requirements, and there can be tradeoff and payoffs. For example, if

sidereal tracking is the utmost importance, some overshoot/settling in slews may be acceptable especially if tuning out the slew issues negatively effects sidereal tracking.

The following sections offer tips that have been used to successfully tune Apollo mounts with various instrument packages from less than 50 kg up to 300 kg.

System tuning can be performed by TheSky and or the OEM software called SPiiPlus MMI Application Studio that accompanies the direct-drive controller used by the Apollo.

Tuning in SPiiPlus MMI Studio

The Apollo comes with a separate software package (SPiiPlus MMI Application Studio) that has extensive controller functionality, but only a small subset of this functionality is necessary to turn your system. Remember, tuning is specific to the characteristics of your system (its mass, mass distribution, inertia, etc.). Advanced tuning with SPiiPlus MMI Application Studio goes beyond the scope of this document. For additional resources on tuning a direct drive system and additional tuning background, see www.bisque.com/direct-drive-tuning.

The following is an overview on how to use SPiiPlus to tune your Apollo system.

You will find the SPiiPlus tuning functionality under The *Adjuster Wizard* > *Axis Setup and Tuning* > *Position and Velocity Loops*. Note, all other features of the Adjuster Wizard, like Initialization, Axis Architecture, Components etc. have already been set at the factory. You will only need to perform tuning under as described below. Remember, motor tuning is dependent on the characteristics of your payload and cannot be pre-set at the factory.

There are two methods of Position and Velocity Loops tuning, namely Manual and Automatic. Each is described below.

Position and Velocity Loops: Manual Tuning

When connected to the ACS controller using the OEM MMI Application Studio, open the *Adjuster Wizard* from the *Workspace* window, then go to *Axis Setup and Tuning* > *Position and Velocity Loops* > *Select Tuning Method*, click *Manual*, then click *Next*.

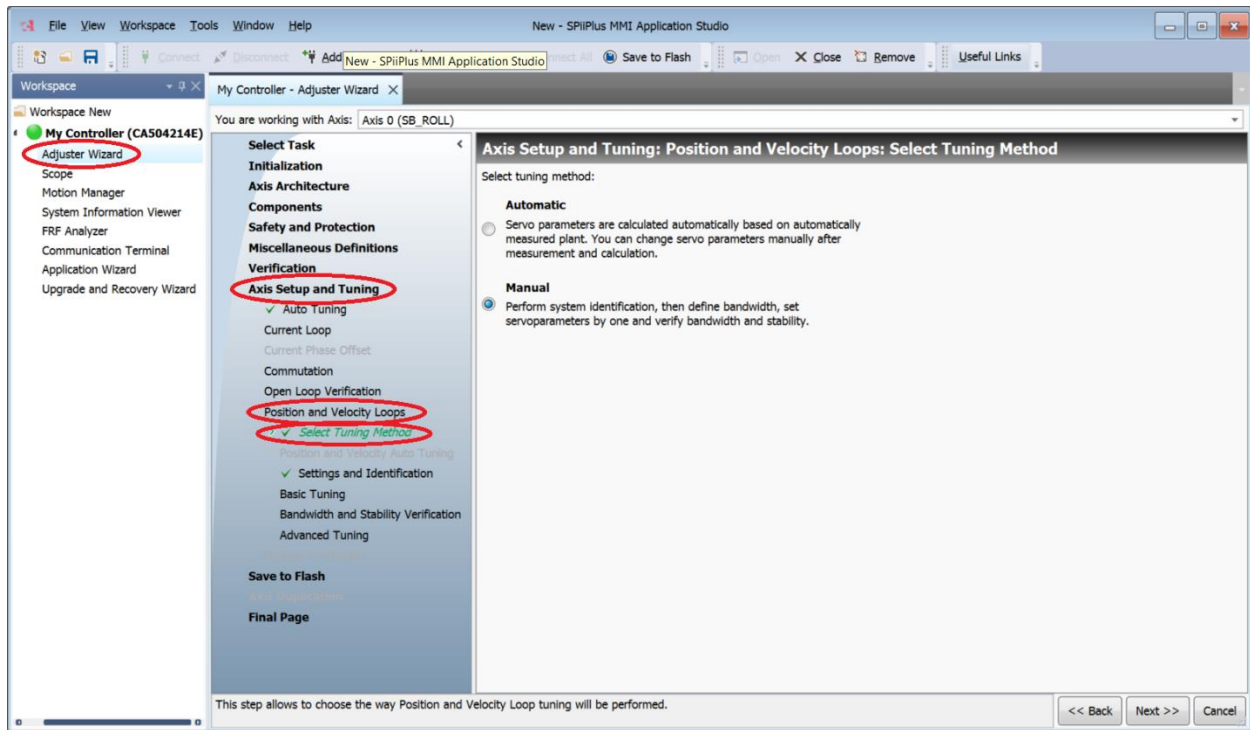


Figure 75: Choosing Manual Turning in SPliPlus. Adjuster Wizard > Axis Setup and Tuning > Position and Velocity Loops, select Tuning Method.

The first step in SPliPlus manual tuning is to perform a **System Identification**.

System Identification

A column of setup screens and utilities is listed on the **Adjuster Wizard** window. The first choice is **Axis Setup and Tuning**, followed by **Settings and Identification**. Use this option to have the software suggest values for five of the most typical tuning parameters. Note that the **Adjuster Wizard** works with one axis at a time. The selected axis is displayed near the top of the window next to the **You Are Working With Axis** text.

Before starting the identification process, the motion limits should be set so that they include the present feedback position. Simply subtracting and adding five degrees from the present feedback position typically works well. For example, if the **Feedback Position** is 236 degrees, the **Start Position** should be set to 231 and the **End Position** to 241 degrees.

The **System Type** should be set according to the load on the system. Typically, **Medium Load/Mildly Stiff System**, or **Heavy Load** work best. The azimuth axis has a reasonable load before adding any instruments, while the altitude may be lighter. Set the **Friction Level** option to **Low**.

Clicking the **Start Identification** button starts a several minute long process. The software imparts a range of frequencies to the controller and measures the response. As the frequencies

get into the audible range you may hear them as they increase in somewhat of a melodic fashion.

If the **Identification** process fails (the results are shown in the **System Identification Results** output screen at the bottom of the window) then consider a different **System Type**. If that does not work, try increasing the **Excitation Current** from 2.5 to 5.0, then slowly increase. On systems with heavy payloads, for example 300 kg, you may have to use a value as high as 10-12%. Refer to the ACS documentation for additional help.

After a successful system identification, the next step **Basic Tuning** on the following page. When asked to confirm resetting the current five base tuning parameters, click **Yes**. At the top of the **Basic Tuning** page, the **Bandwidth** input defaults to **30**. Setting this to **10** or so yields tuning parameters that typically work with Apollo mounts. In general, you strive for the highest bandwidth that does not lead to instability.

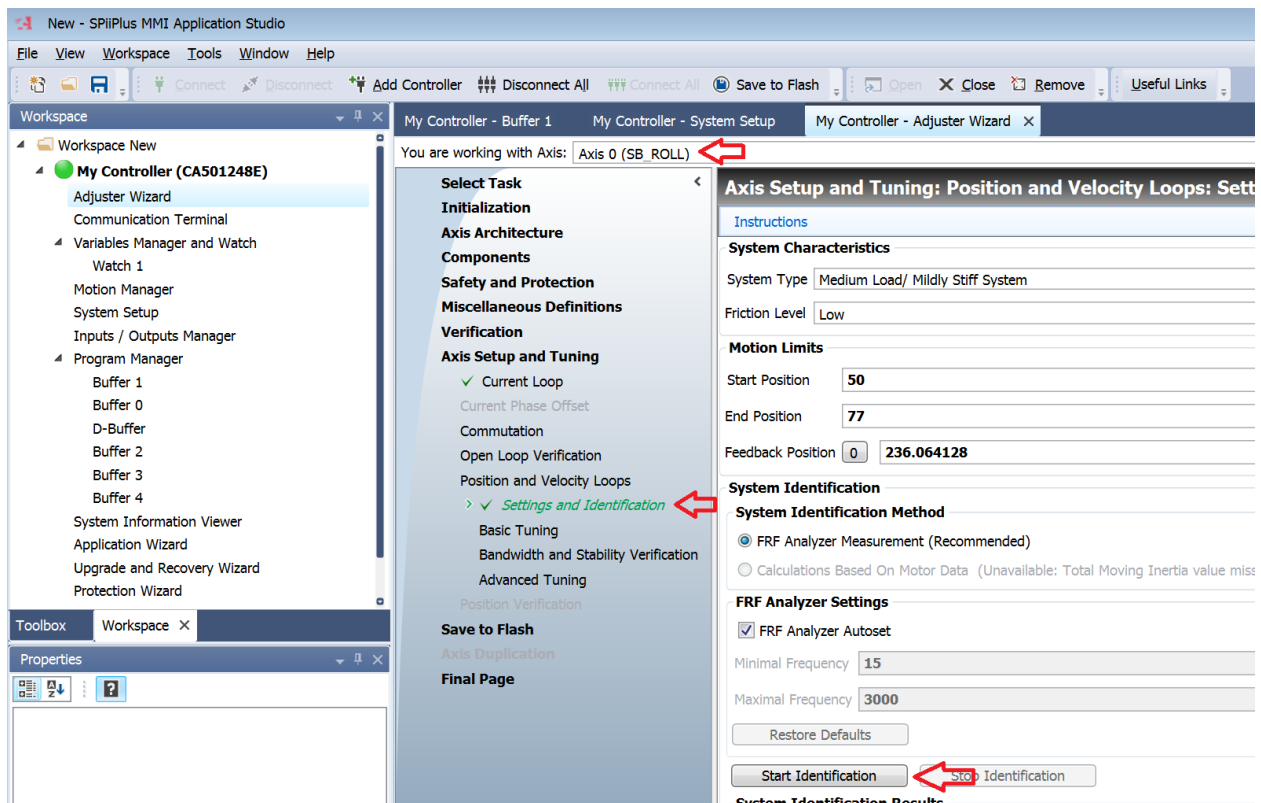


Figure 76: A screen capture showing the Axis 0 (SB_ROLL) Settings and Identification.

Once the system identification is complete, the suggested tuning parameters can be viewed from the **Basic Tuning** window. This type of tuning is referred to as **One Parameter Based Tuning**. Changing the **Bandwidth** (Hz) input value from 30 to 10 causes the five gain suggestions to be recomputed linearly, applied to the mount and re-displayed.

These suggested terms are typically good starting points though the final gains values used may be lower. The parameters that make the most difference are the **Velocity Proportional Gain**,

Position Proportional Gain, and **Integral Gain**. The relative magnitude of these should remain linear as adjustments are made. For example, if the velocity proportional gain is reduced by half, so should the position proportional gain and integral gain.

After a successful system identification, click “Enable Motor” to see if the determined (or modified) turning parameters are workable. Note, always be prepared to immediately disable the motor if the system emanates loud noises in which case, you would systematically and interactively decrease the bandwidth or tuning parameter(s) and repeat. Once the motor can be enabled, appears stable and does not emit objectional noises, you will want validate motion of system by clicking the **Motion Manager Autoset**. Setup a “back and forth” move, start out with a motion of say 5 degrees at 1 degree a second.

Click **Scope Autoset** to graph the motor’s motion and adjust turning parameters. The goal is to have the (red) velocity feedback closely follow the (yellow) reference velocity along with a reasonable (green) position error that doesn’t overshoot and dampens nicely. If you reach this goal, you may move on to turning and fine tuning within TheSky.



Figure 77: SPiiPlus Scope output giving validity to tuning parameters during a Motion Manager back and forth move. Feedback velocity follows reference velocity and a low, steady-state position error. Note the scale of the position error is 0.1 units/division.

Position and Velocity Loops: Auto Tuning

The SPiiPlus can also be used the automatically tune a system. Under **Axis Setup and Tuning** > **Select Tuning Method** choose **Automatic**. Click the **Start** button to subject the Apollo to a

range of frequencies, record the response and from that derive the corresponding turning parameters.

Autotuning has an additional advantage over manual in that beneficial digital signal filters can be automatically added, for example add a notch filter to attenuate a detected resonance.

You can validate the autotuning determined parameters using the motion manager, see above, before using TheSky for tuning the motors.

Using TheSky for System Tuning

TheSky has several unique tuning features that are tailored for astronomical use, i.e., slewing to targets and tracking them at the sidereal rate.

Tuning: Coarse and Fine

Tuning can be broken down into two steps. The first step is to simply get the tuning parameters set so that the Apollo can be successfully *slewed* between various targets. The fine-tuning concentrates on *minimizing tracking error* while tracking at the sidereal rate.

Coarse Tuning

The first step is to get the tuning parameters set so that the instrument load can be *slewed* between various coordinates without large oscillations, over-currents, critical position errors, etc. This step requires a certain amount of patience because if you set tuning parameter values too high, that is too aggressive, very loud sounds may emanate from the system, or even cause instability and produce a system fault, when negative feedback becomes positive, that will automatically disable motor(s). The controller has built-in safety features that ensure the current load is not excessive and that impossible motion requests are not executed and instead produce a corresponding error.

Fine Tuning the Motors

Once the coarse tuning parameters are set and the system can be slewed to various positions at the desired velocity and acceleration, the fine-tuning process can begin. Fine tuning is just a continuation of the initial tuning steps but focuses on minimizing position error during low, sidereal tracking velocities.



Systems that use high maximum velocities with high maximum accelerations are more challenging to tune. Initial tuning with lower maximum velocities and accelerations is strongly recommended.

When using the Apollo to track stars and other slow moving celestial bodies, the goal of *fine-tuning* is to get the position error for each axis to settle down to as low as possible, typically to a fraction of an arc second when tracking at the sidereal rate. Note, this level of precision is

usually not necessary or even possible when tracking faster moving objects since the requirements are typically not as critical as sidereal tracking.

To access TheSky's system tuning options, from the **Telescope** window, click **Tools > Bisque TCS – Direct Drive**.

The **Controller Tuning** options on the **Utilities** tab allow adjusting the five primary tuning parameters. When using TheSky with the Apollo, understanding where the variables are stored, and how they are loaded on future sessions, is important.

When an axis is selected, the five tuning parameters are read from the controller, namely **SLVKP**, **SLVKI**, **SLPKP**, **SFVSOF** and **SLAFF**. The SL prefix is short for *servo loop* and these variables are read from and saved to controller similar to all other parameters.

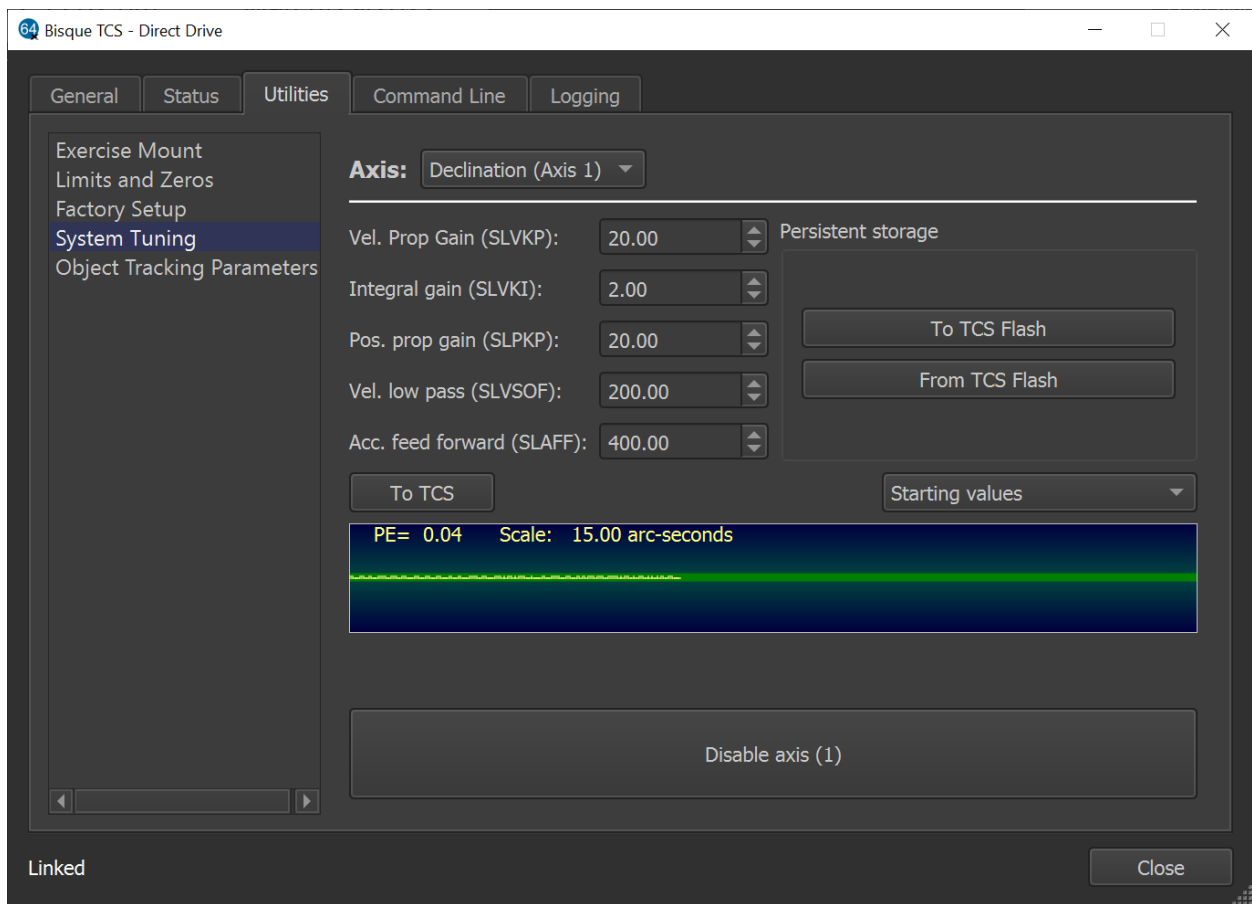


Figure 78: TheSky's Bisque TCS > System Tuning > Utilities tab.

Axis

Tuning is performed one axis at a time. Though the final tuning parameters may be similar, each axis has different loads and tuning requirements. Use this pop-up menu to select the desired axis.

To TCS Button

Click the **To TCS** button to immediately apply the values shown on the **System Tuning** window to the Apollo. Importantly, these parameters are not permanently stored in the flash memory when clicking this button. This is by design to allow easily and iteratively apply different values while watching the position error and the same time without altering the bootup behavior.

To TCS Flash Button

Once the tuning parameters are working satisfactorily or have exhibited better behavior than the parameters that were in place before the adjustment, click the **To TCS Flash** button to commit the change and permanently save them to the controller's flash memory. They values will then be loaded on startup going forward.

From TCS Flash Button

If you have modified a parameter(s), and it has not produced improvement and you haven't yet clicked **To TCS Flash**, you may click the **From To Flash** button to restore the tuning parameters to the values before modification. After this operation is performed, to have the parameters applied, press **To TCS Flash**.

In essence, this button displays the *last committed servo parameters saved to TCS flash*.

Position Error Graph

This graphic displays the position error of the system on an extremely small scale to show how the servo loop is performing while tracking at the sidereal rate. The height of green band is plus or minus one arc-second. On a well-tuned system, steady state errors will be less than ~0.2 arc seconds. When a system is not properly tuned for the slow velocities needed for sidereal tracking, noise or oscillations become apparent in the graph and further tuning will be required and aided by this information. Scroll the mouse wheel over the graph to change the scale.

Disable Axis

When tuning values are selected that cause loud noises or oscillations that are diverging in the wrong direction, otherwise known as instability, click the **Disable Axis** button to disable the motor in the currently selected axis.

General Tuning Procedure Summary Using TheSky

A general tuning procedure is to iteratively slew to a nearby star, watch the behavior of the on-screen telescope crosshair, and gradually increases the primary tuning parameters, higher and higher until short of instability, until the slew has little or no overshoot, and the axis feels rigid to the touch.

Instability occurs when you set a parameter too high and as soon as you press “To TCS” the system makes a loud vibration noise and or the control system “gives up” and motors are automatically disabled.

1. When starting out and learning to tune, lower the maximum slew rates. (General tab, choose the slow rate preset).
2. Set Axis to “Altitude”. (Start with the altitude axis as it is less dependent then say the azimuth axis that has some dependency on the altitude.)
3. Click “Starting values” and choose an appropriate selection to match your system, primarily based on weight of payload.
4. Orient the star chart so that relatively small altitude motion is obvious (mentally ignore azimuth motion since that axis is not yet being tuned).
5. Slew to a nearby star.
6. If there is overshoot/oscillation, slightly increase **SLVKP** and **SLPKP**, click **To TCS**.
7. Repeat above steps until instability and back off slightly as necessary.
8. Finally, and perhaps occasionally, increase Integral gain parameter **SLVKI** to increase the rigidity to the touch.

When you are satisfied tuning an axis, click the **To TCS Flash** button so that the tuning parameters are persistent.

Repeat the above steps for the azimuth axis.

Controlling the Apollo with TheSky

TheSky Astronomy software has a variety of tools for general astronomy, from generating and applying telescope pointing models, to performing astronomical computations, and controlling astronomical equipment. TheSky User Guide has complete information on the operation of this software. It is included in portable document format (PDF) with TheSky's installation or is available online.

Connecting to the Apollo



To enable Apollo direct drive operation, TheSky requires that the supplied security key must be plugged into one of the computer's USB ports before TheSky is launched, and *while TheSky is running*.

Also note that the security key must be plugged in in:

- During TheSky installation.
- *Before TheSky is launched*. Plugging in the security key after TheSky is launched is not supported, and the security key will not be recognized.
- While running TheSky and operating the Apollo mount. If the security key is removed after launching TheSky, Apollo direct drive operations will be restricted.

A security key is *not* required when controlling the Apollo with software other than TheSky.

The Apollo uses TCP/IP to communicate with a computer via an Ethernet cable. By default, the controller is configured with an IP address of 10.0.0.100. Please see the MMI Application Studio User Guide for information on resetting the IP address in the controller, or the ACSPL+ Commands and Variables reference guide.

The Ethernet port is located on the Apollo base in the left most Keystone port (Figure 79). The two unpopulated Keystones can be used to accommodate custom ports.

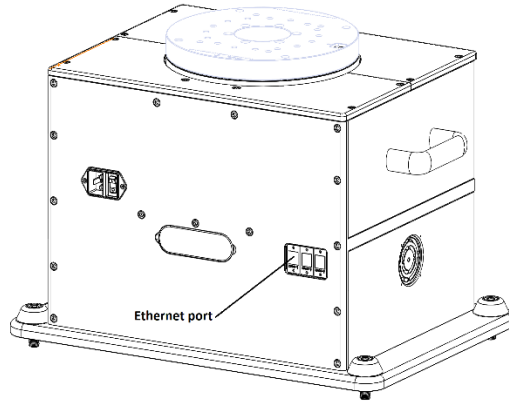


Figure 79: Location of the Ethernet communication port on the mount base.

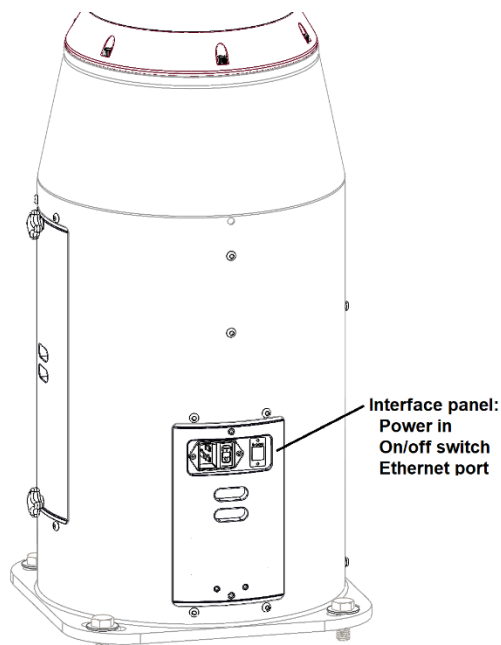


Figure 80: Paramount Duo Interface Panel.

The Apollo's IP address must be set within TheSky software by clicking **Telescope > Telescope Setup > Imaging System Setup > Mount Setup pop-up > Direct Drive Settings**. The **Find IP Address** button searches for the controller on all networks connected to your computer and will find the TCS networks with a mask of 255.255.255.0. If the Apollo is plugged into a network with a different subnet mask, you will have to enter the IP address directly.

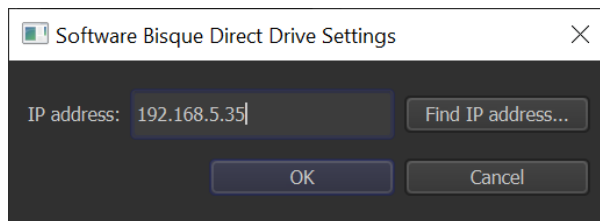


Figure 81: Enter the Apollo's IP address.

Once the IP address specified, connect to the controller by clicking **Mount Setup > Connect** on the **Imaging System Setup** window, **Telescope > Connect**, or, from the **Telescope** window, **Startup** pop-up menu, click **Connect**. Upon successful connection, the telescope status changes to **Tracking Off** and the telescope bull's eye appears on the Sky Chart.

MMI Studio

The ACS controller comes with the MMI Application Studio that has options for setting up and controlling the Apollo. In most circumstances, the reasons to use this software are to configure the IP address and to help tune the system.

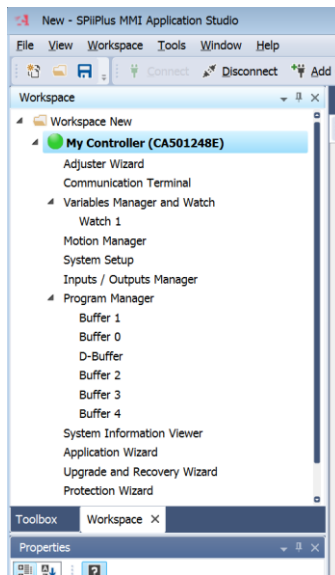


Figure 82: The MMI Studio software's workspace.

To connect to the Apollo, right click on the **My Controller** in the workspace tree and click **Connect**. On the first connect, you can also choose **Change Controller** to view a list of IP addresses, including the default address 10.0.0.100.

The IP address can be changed by selecting **Communication Properties**. After changing the IP address, when the Apollo is restarted, the connection may be lost because the IP address of your computer changes.

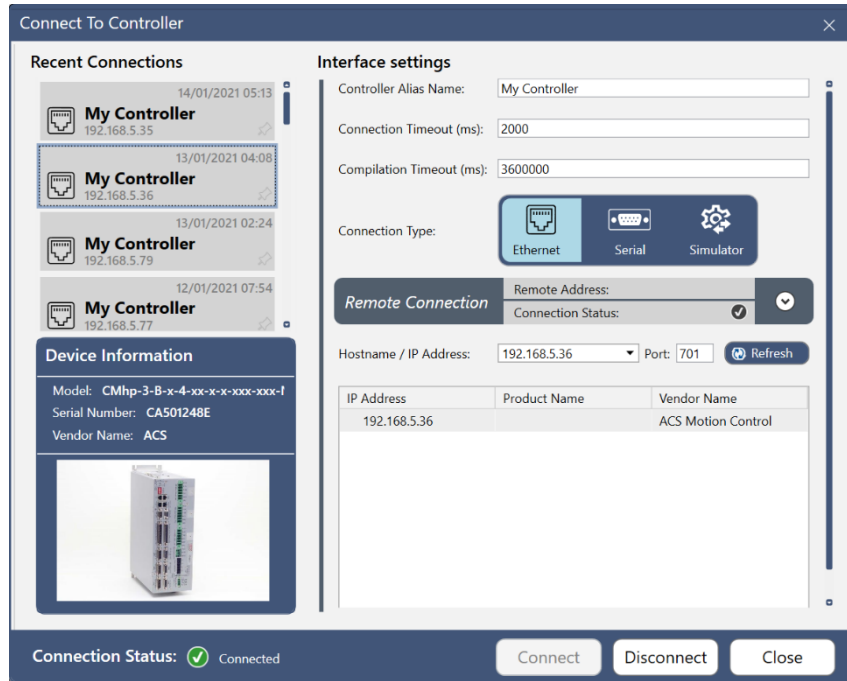


Figure 83: MMI Studio's Connection window.

To achieve exceptional performance, direct-drive motor systems must be tuned. The following sections offer tips that have been used to successfully tune Apollo mounts with instrument packages from less than 50 kg up to 300 kg.

Bisque TCS Direct Drive Window

The *Bisque TCS/DD window* shows information about the mount, controller and other settings related to operating the Apollo mount. From the *Telescope* window, click the **Tools > Bisque TCS Direct Drive** command.

Overview

The bottom left of the window shows the status of the connection and/or state of the direct drive motors. During normal operation, the status shows *Linked*. If one or more of the motors is disabled for some reason, the status shows the motor state.



Most options are enabled after a connection to the Apollo is established.

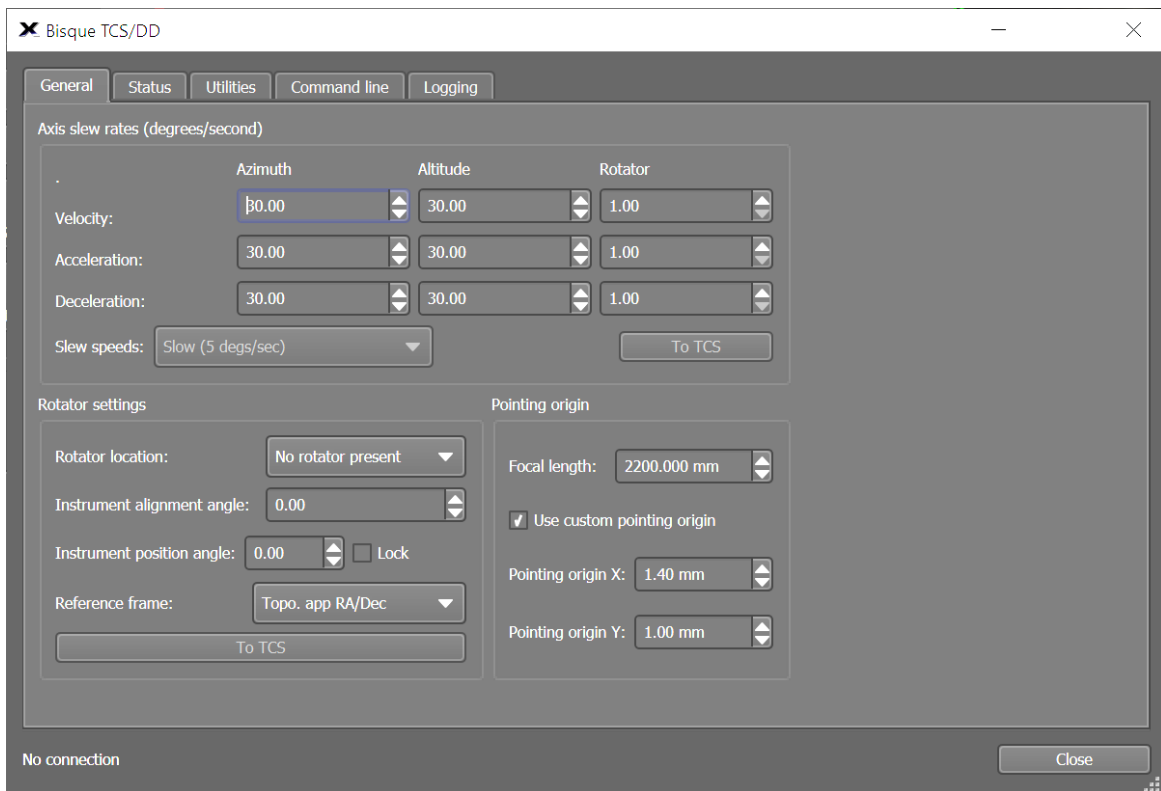


Figure 84: TheSky's Bisque TCS/DD General tab.

General Tab

Axis Slew Rates (degrees/second)

The **Velocity**, **Acceleration** and **Deceleration** can be set separately for each axis, in degrees per second and degrees per second per second. The maximum achievable velocity is dependent on several factors including your comfort level and the mass of the system.

During the initialization of the system, slower slew speeds (less than 10 degrees per second) are strongly recommended. Once a system is balanced and tuned higher speeds and accelerations can be tested.

The **Slew Speeds** pop-up sets the speeds for all three axes to the selected value. When the rates have all been entered as desired, click the **To TCS** button to send the rates into the controller.

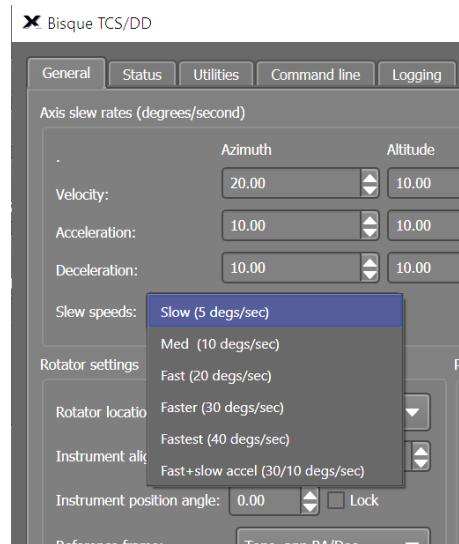


Figure 85: Default slew rate options.

Instrument Rotator Settings

If an optional instrument rotator is being connected as a third axis, several settings are needed to ensure correct operation.

Instrument Rotator Location

There are six options for the location of the instrument rotator, depending upon where it is located on the system:

- **OTA:** the instrument mount is fixed to the telescope tube. This option embraces Cassegrainian, Gregorian, prime focus, Newtonian, Cassegrain-Newtonian, Gregory Newtonian, and others. (OTA stands for **Optical Telescope Assembly**. The term is used here in a completely generic sense: it could equally well be the dish of a radio telescope.)
- **Nasmyth:** the instrument mount moves with roll but not pitch.
- **Coud'e:** the instrument mount is fixed to the ground.
- **Generalized:** rather than nominating a physical location for the instrument mount, the respective influences of roll and pitch on the field orientation are specified explicitly.

Instrument Alignment Angle

The Instrument Alignment Angle (IAA) is the orientation of the instrument on the rotator. IAA is measured as part of calibrating the instrument on the telescope and will remain constant until the instrument is removed.

Instrument Position Angle

IPA is the user-specified **Instrument Position Angle**. It can be with respect to any of the supported sky coordinate systems—J2000.0 [α , δ], topocentric [Az, El] etc. As a rule, it will remain constant during one observation.

Reference Frame

The reference frame specifies how the rotator will behave as the mount is slewing or tracking across the sky. The altitude/azimuth reference frame will keep the rotation relative to the azimuth coordinate, while the equatorial options will maintain relative to hour angle.

The **To TCS** button sends the rotator settings to the virtual telescope.

Pointing Origin

The pointing origin feature permits adjusting the pointing center, as in the case of an off-axis instrument, without changing the current target. The units are in millimeters. The amount of offset is computed based on the entered focal length of the system. For example, if the pointing origin X is set to 5 mm, when the **Use Custom Pointing Origin** checkbox is turned on, the center of the pointing will move 5 mm on the focal plane.

Status Tab

The **Status** tab shows information about the Apollo's position (RA/Dec, Alt/Az), demand, velocity, and other parameters.

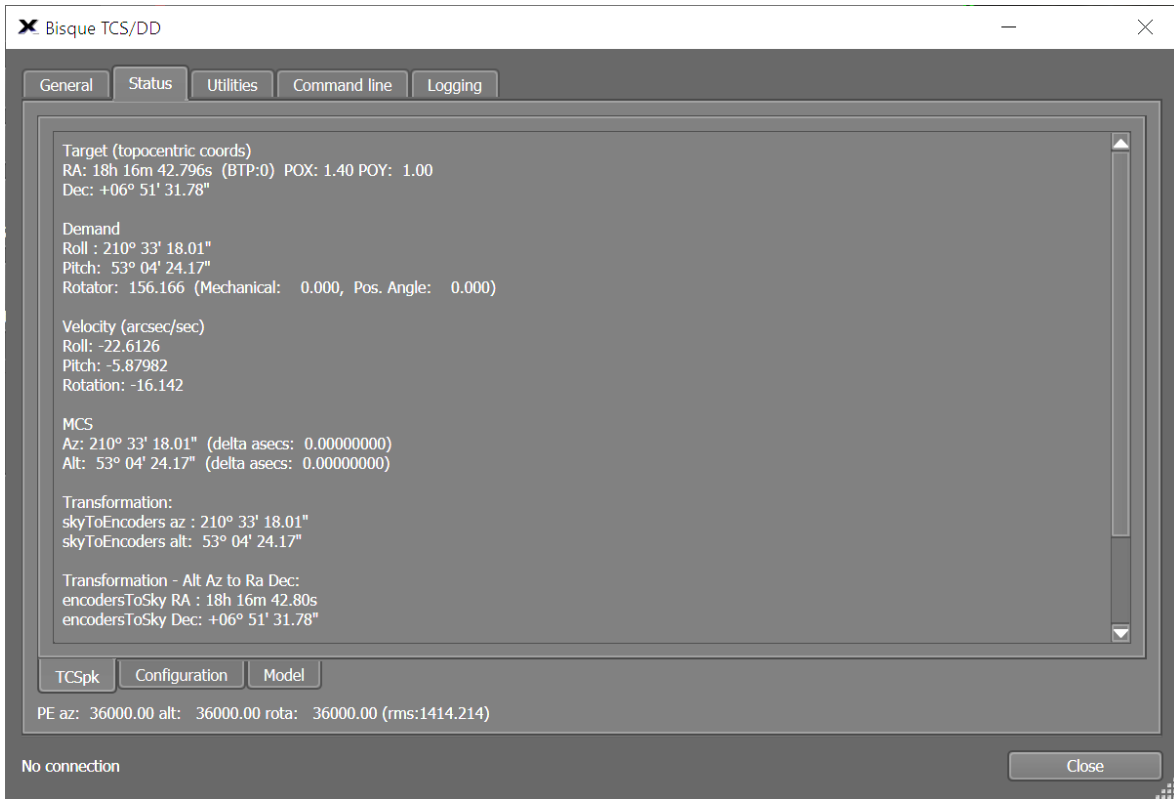


Figure 86: The Bisque TCS Direct Drive **Status** tab.

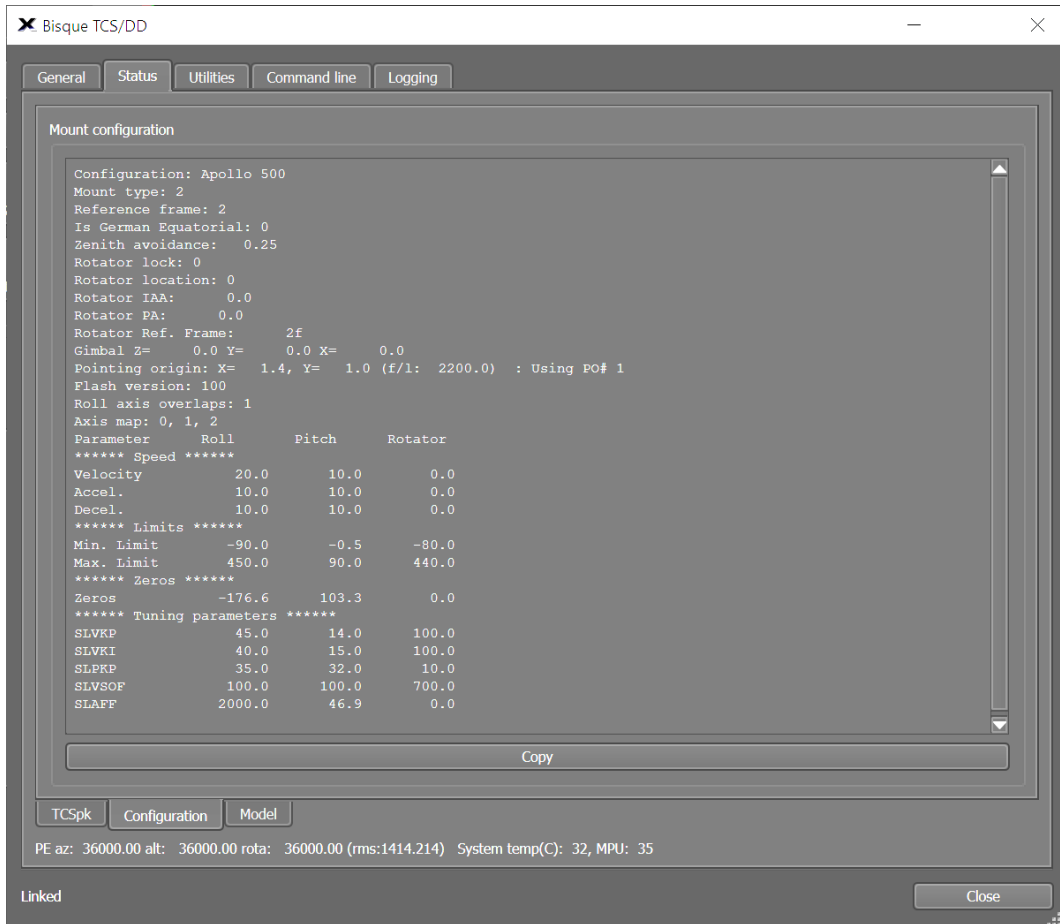


Figure 87: The **Configuration** tab on the **Status** tab.

Utilities Tab

While the **Utilities** tab contains many optional functions, the **Tuning** options are required during mount setup and initialization.

Exercise Mount

The options on the **Exercise Mount** pane allow moving a single axis of the mount to absolute coordinates or in relative “jogs.” Several inputs are supplied making it easy to slew to different targets for testing purposes. The units are in degrees, and the current coordinate of the selected axis is displayed near the top of the window. Clicking the **Abort Motion** button immediately stops the motor rotation.

Sidereal tracking must be turned off before exercising the motors. To do so, from the **Telescope** window, click **Tools > Turn Tracking Off**. Note that when sidereal tracking is turned off, it is turned back on when the mount is slewed to a target.

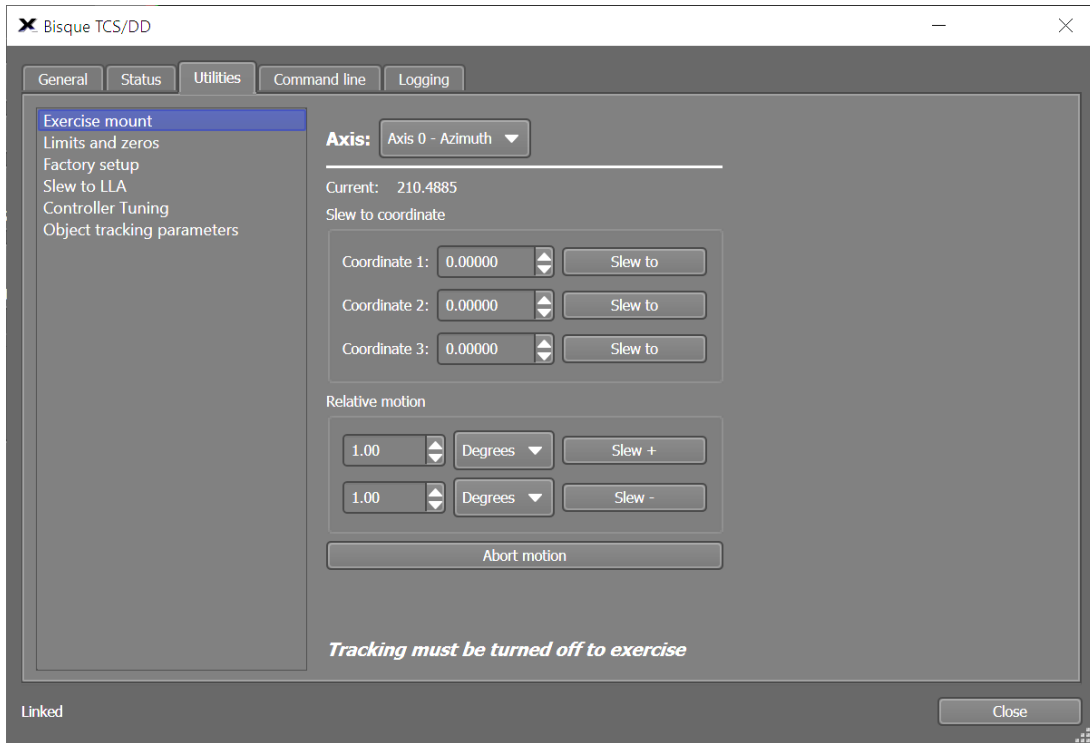


Figure 88: The Exercise Mount option on the Utilities tab.

Limits and Zeros

Use these options with caution, as entering incorrect values can make the system inoperative. The factory settings should work for most circumstances. Because the azimuth axis has 90 degrees of overlap in each direction, resetting the azimuth zero position may be necessary when the mount base cannot be physically attached to the ground in the expected orientation. For example, if the mounting plate in the observatory is rotated 90 degrees from the expected orientation, reset the zero point to account for this offset.

Factory Setup

These options are available for setting the low-level kernel settings and are rarely changed. The **Zenith Avoidance** input and the reference frame choice are the exceptions.

System Tuning

Please refer to “Tuning Direct-Drive Systems” on page 69 for details on using TheSky to help tune the TCS.

Object Tracking Parameters

These options allow changing the PID loop that is used to track at sidereal rates, with separate inputs for satellite rates. The default values should work in most circumstances.

TheSky's Command Line Tab

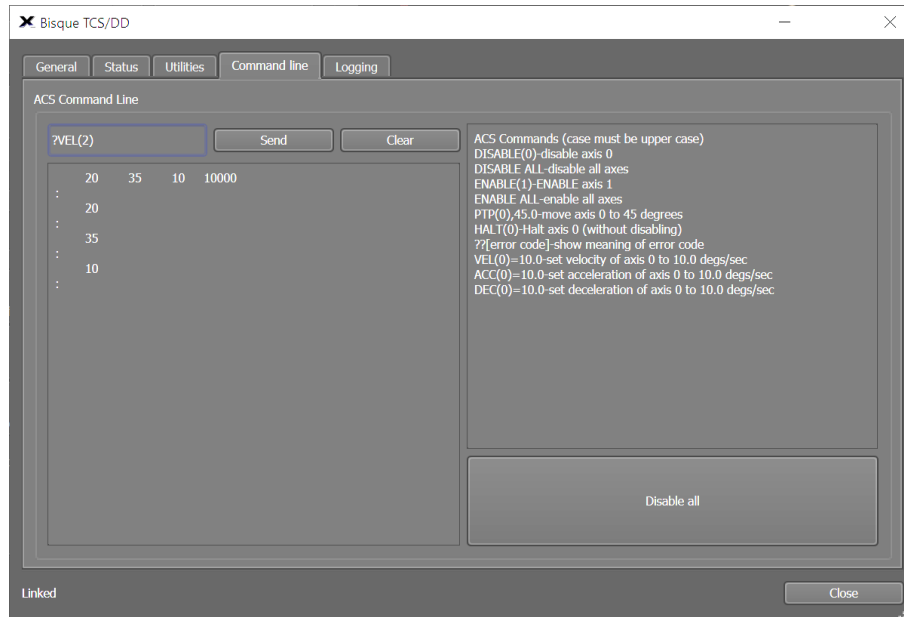


Figure 89: TheSky allows command-line control of the Apollo's position.

The **Command Line** tab is used to issue configuration or motion commands to the TCS.

Sending commands directly to the mount control system is typically unnecessary when the Apollo is used for astronomy. However, direct access can occasionally be helpful, or even necessary when troubleshooting if things go wrong.

The **Command Line** tab allows text-based commands to be entered and sent directly to the TCS. This can happen even when pointing kernel running in TheSky has control of motion. Of course, typing in commands that conflict with the tracking functions will yield unpredictable results and should be avoided. (*With power comes responsibility.*)

Several common commands are listed on the right side of the window. **All commands must be typed in upper case.** When reading a variable, the **?** is used in front of the variable name. For example, issuing the command **?VEL (0)** returns the current velocity setting for axis 0.

The **Disable All** button can be used to quickly turn off all axes. When clicked, it issues the **DISABLE ALL** command to the controller and all axes will be disabled.

Logging

The **Logging** tab is available for troubleshooting and displaying messages (which are sometimes errors) sent by the TCS. The default output shows errors only, but several other choices are available depending on the type of output desired.

Apollo Mount Control System

Apollo direct-drive mounts use an ultramodern industrial three-axis TCS and is one of the most versatile and high-performance controllers available on the market today. With all three axes housed in a single unit, there is no need for requirement for a separate power and communications source for each axis.

Important note: With any gimbal system, precise pointing throughout the sky can only be achieved by calibrating the mount using stars and applying a mount model. The mount model corrects for zero offsets, non-perpendicularities, flexures, harmonics, atmospheric refraction, and other systematic errors. TheSky, with integrated TPoint modeling, along with tools for automatic pointing calibration, performs these tasks well.

Direct Apollo Control

While TheSky performs the necessary communications and control of the mount for most astronomy-based purposes (including initialization, creating mount models, slewing, and tracking etc.), you may wish to communicate directly with the mount using the protocol of the TCS.

The Apollo TCS has a complete set of commands and settings for direct control that are well documented in the manufacturer's documentation.

Coordinate Convention

The coordinates for the Apollo mounts were chosen to follow the commonly used astronomical altitude/azimuth convention, that is, the units are degrees, and the azimuth increases north through east, and the altitude is zero at the horizon, increasing to 90 degrees at zenith.

Axis	Minimum Limit	Maximum Limit
Azimuth	-90.0	450.0
Altitude	-1.0	90.0
Rotator	-45.0	360.0

MMI Studio

To support their line of controllers, ACS Motion Control offers a comprehensive application for programming, tuning, and exercising the controller and associated drives. The Windows software package is available at www.acsmotioncontrol.com under **Products > Software > SPiiPlus MMI Application Studio**. Version 3.11 is available as of early-2022, though future versions should be compatible.

Please refer you to the extensive documentation and user guides that are available supporting the controller. In particular, the ACSPL+ Commands and Variables Reference guide and the SPiiPlus Low Level Host Communication Guide.

After installing the MMI Studio Software, the documentation can be found here:

C:\Program Files (x86)\ACS Motion Control\SPiiPlus ADK Suite v3.02\Documentation\Software Guides

Name	Date modified	Type	Size
ACSPL+ Commands & Variables Reference Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	5,622 KB
ACSPL+ Programmer's Guide.pdf	10/1/2020 10:59 AM	Microsoft Edge PDF Document	7,152 KB
EtherCAT DS402 Drives User Guide.pdf	10/1/2020 10:59 AM	Microsoft Edge PDF Document	1,665 KB
GSP Reference Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	2,367 KB
SPiiPlus .NET Library Programmer's Guide.pdf	10/1/2020 11:12 AM	Microsoft Edge PDF Document	2,080 KB
SPiiPlus ADK Suite 3.02 Release Notes.pdf	10/1/2020 10:56 AM	Microsoft Edge PDF Document	2,342 KB
SPiiPlus C Library Reference Programmer's Guide.pdf	10/1/2020 11:01 AM	Microsoft Edge PDF Document	3,027 KB
SPiiPlus COM Library Programmer's Guide.pdf	10/1/2020 11:02 AM	Microsoft Edge PDF Document	2,473 KB
SPiiPlus EthernetIP User Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	1,167 KB
SPiiPlus Low Level Host Communication User Guide.pdf	10/1/2020 11:06 AM	Microsoft Edge PDF Document	935 KB
SPiiPlus MATLAB Library Programmer's Guide.pdf	10/1/2020 11:07 AM	Microsoft Edge PDF Document	2,180 KB
SPiiPlus MMI Application Studio User Guide.pdf	10/1/2020 11:10 AM	Microsoft Edge PDF Document	12,549 KB
SPiiPlus Modbus Setup Guide.pdf	10/1/2020 11:11 AM	Microsoft Edge PDF Document	1,070 KB
SPiiPlus Setup Guide.pdf	10/1/2020 11:13 AM	Microsoft Edge PDF Document	11,771 KB
SPiiPlus Utilities User Guide.pdf	10/1/2020 11:14 AM	Microsoft Edge PDF Document	1,261 KB

Figure 90: Control system PDF documentation.

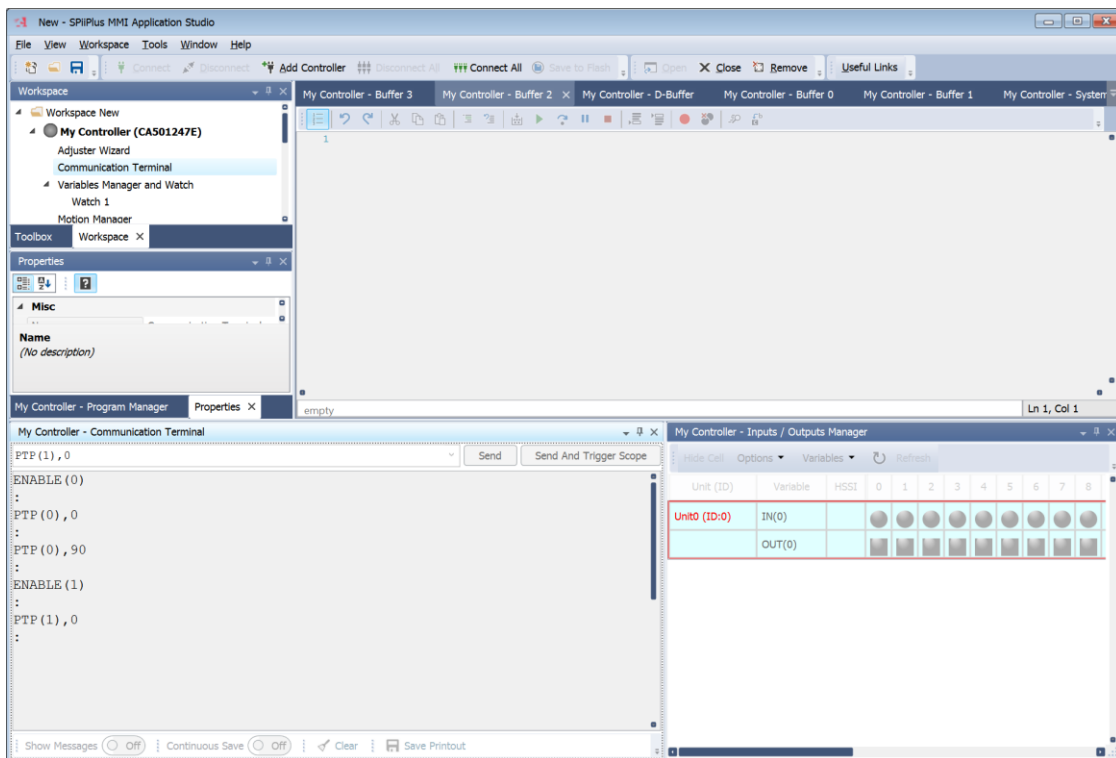


Figure 91: Screen capture of the MMI Studio software.

Overview of ACS Commands

The following table lists commonly used motion commands for directing the Apollo mount. Note that when typing in commands in the MMI studio application or from the Command Line window within TheSky, all commands are upper case.

The axes are numbered 0, 1, 2 where the roll axis (azimuth or HA) is axis 0, the pitch axis (altitude or declination) is axis 1, and the rotator is axis 2.

The table below shows some of the common ACS motion commands.

Command	Description
ENABLE(0)	Enable the motor for the altitude axis.
ENABLE ALL	Enable all motors.
DISABLE(0)	Disable axis 0.
DISABLE ALL	Disable all motors.
JOG/V (0),5.4458	Start motion for axis 0 at 5.4458 degrees per second using the current acceleration and deceleration values.
VEL(0)=10.0	For motion commands like point-to-point, use this as the maximum velocity.
ACC(0)=10.0	For motion commands like point-to-point, use this as the maximum acceleration.
DEC(0)=10.0	For motion commands like point-to-point, use this as the maximum deceleration.
TRACK(0)	Turn on track mode for axis 0, followed by TPOS points.
TPOS(0)=90.0	Set a destination position for the TRACK command. These can be updated during the motion.

Operating Temperatures

The operating range for the Apollo TCS is 0–40° C. The TCS generates sufficient heat so that the mount can still operate below the control system’s minimum temperature specification. If the TCS is not heated by the built-in heater, the mount’s minimum operating temperature is near –10° C, provided the unit is turned on for about 30 minutes or more before use so that it warms up.

Control System Heater

The Apollo’s built-in heater regulates the minimum temperature of the TCS. The thermostat turns the heater on when the ambient temperature is 5° C or lower, and turns it off when the temperature is above 10° C.

If the ambient temperature is too cold, the TCS will issue a temperature fault and not operate. In this case, make sure the built-in heater is connected (see “Apollo Fork Cable Connections” on page 27) so that the TCS can warm up before use.

The temperature of the TCS CPU and the MPU are displayed near the bottom of the **Status** tab in the **Bisque TCS/DD** window. *Note: There is a known issue with the most recently tested TCS firmware versions. When the temperature falls below 0° C, the TCS incorrectly reports temperature values that decrease from 255.*

Cooling Fans

The two cooling fans located on the sides of the Apollo pedestal provide airflow to cool the TCS if necessary. From the factory, only one of these fans is connected, as a one fan normally provides sufficient airflow to keep the TCS below the maximum operating temperature. If the mount is operated when the ambient temperature is above about 30° C, the second fan can be connected to the cable distribution PCB to increase air flow when necessary.

Appendix A: Apollo Internal Cabling Details

The following graphics and table list the cables and connections that are found inside the Apollo mount, including the cables that depart from the drive components, such as the encoder and motor cables.

This information is supplied primarily for reference and troubleshooting purposes, or if any electronic cabling needs to be disassembled. The table is cross referenced to the graphics below and shows the connections on the Distribution board and the ACS controller.

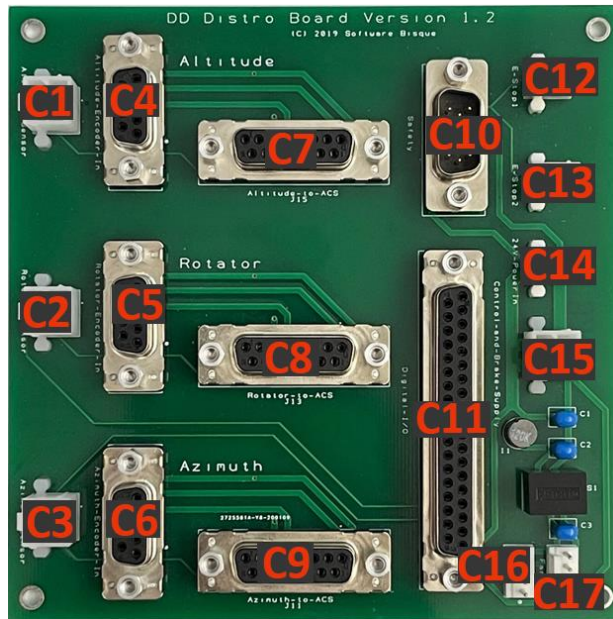


Figure 92: Apollo direct drive distribution printed circuit board (PCB).

Note: Some of the connectors on the above PCB are optional. For example, connectors labeled C12 and C13 can be used to add one or two emergency stop buttons on the outside of the mount. Likewise, a given system may use one or both of the cooling fans (C16, C17).

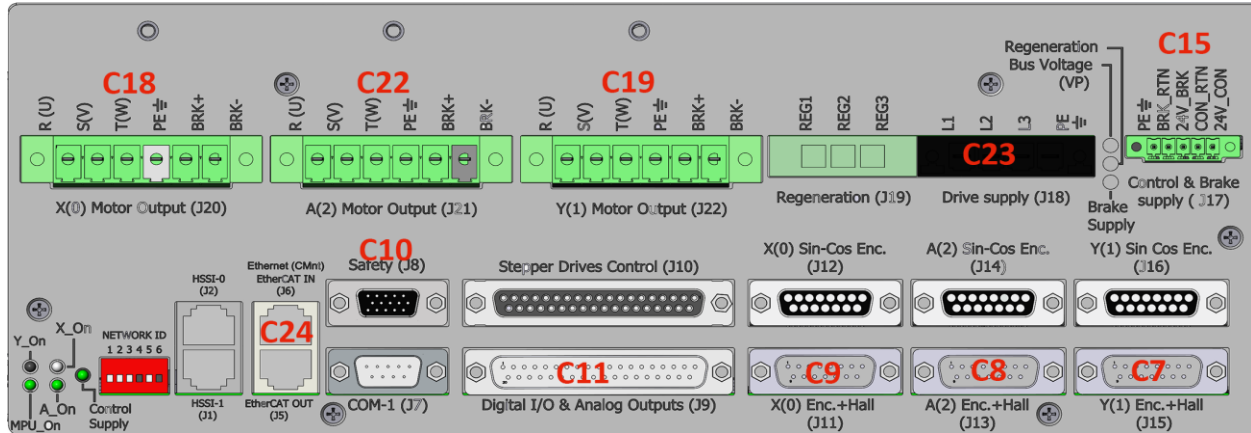


Figure 93: Control system cable connection points.

The following table lists Apollo’s internal cables and connectors.

Cable	Description	Connector	From	Connects to
C1	Alt/Dec sensor	4-conductor Molex	Distro PCB	Alt/Dec drive
C2	Sensor part of harness	4-conductor Molex+(3x motor)	Distro PCB + (ACS J21)	Rotator panel
C3	Az/HA sensor	4-conductor Molex	Distro PCB	Az/HA drive
C4	Alt/Dec encoder	9-conductor DB-9	Distro PCB	Alt/Dec encoder
C5	Rotator encoder extension	9-conductor DB-9 MF, 10 feet	Distro PCB	Rotator panel
C6	Az/HA encoder	9-conductor DB-9	Distro PCB	Az/HA encoder
C7	Alt/Dec encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J15
C8	Rotator encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J13
C9	Az/HA encoder	15-conductor MF DB-15 2-row	Distro PCB	ACS J11
C10	Safety	15-conductor MF DB-15 3-row	Distro PCB	ACS J8
C11	Digital IO	37-conductor MF	Distro PCB	ACS J9
C12	E-stop 1	2-conductor Molex	Distro PCB	Optional switch
C13	E-stop 2	2-conductor Molex	Distro PCB	Optional switch
C14	24V power-in	2-conductor Molex	Distro PCB	24V power supply
C15	Control and brake supply	4-conductor Molex	Distro PCB	ACS J17
C16	Fan1	3-conductor header	Distro PCB	Fan 1 cable
C17	Fan2 (optional)	3-conductor header	Distro PCB	Fan 2 cable
C18	Az/HA motor + (brake)	6-conductor Phoenix	Az/HA drive	ACS J20
C19	Alt/Dec motor + (brake)	6-conductor Phoenix	Alt/Dec drive	ACS J22
C20	Rotator encoder	9-conductor DB-9	Rotator	Rotator panel
C21	Rotator motor/sensor	Turck female 7-conductor	Rotator	Rotator panel
C22	Motor part of rotator harness	6-conductor Phoenix	Rotator panel	ACS J21
C23	Drive supply	4-conductor	Terminal block	ACS J18
C24	Ethernet in	Ethernet	External panel	ACS J6
C25	Alt/Dec brake	2-conductor combined with C19	Brake on Alt/Dec axis	ACS J22 (with motor leads)

Cable	Description	Connector	From	Connects to
C26	Enclosure heater power (AC)	2-conductor 18-gauge	Stego 50W heater	Terminal block
C27	Azim/HA brake	2-conductor combined with C18	Brake on Azim/HA axis	ACS J20 (with motor leads)
C28	AC in to 24V supply	3-conductor	Terminal block	24V power supply

Electronics Schematic

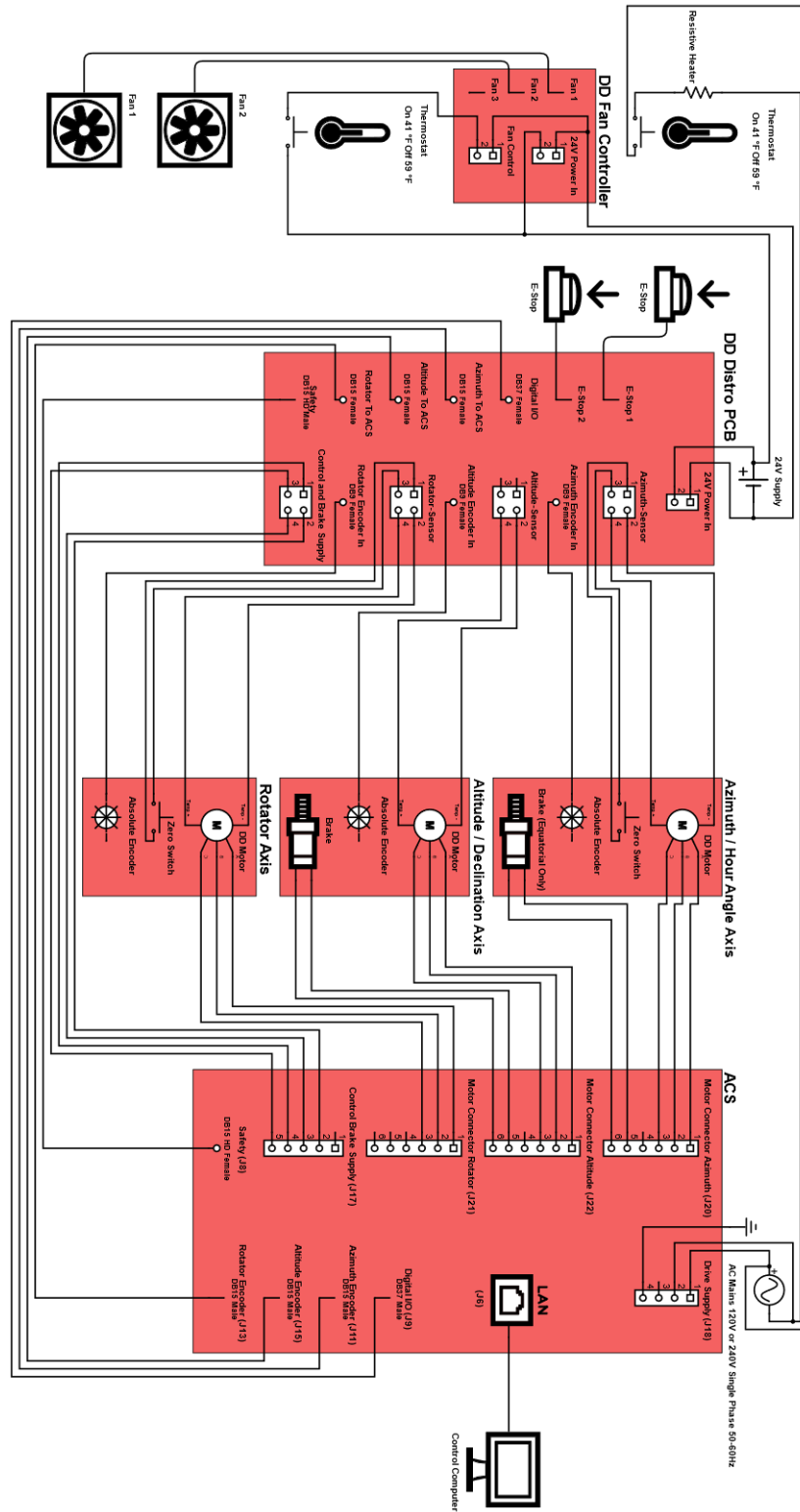


Figure 94: Apollo electronics schematic.

Appendix B: Apollo OTA Mounting System

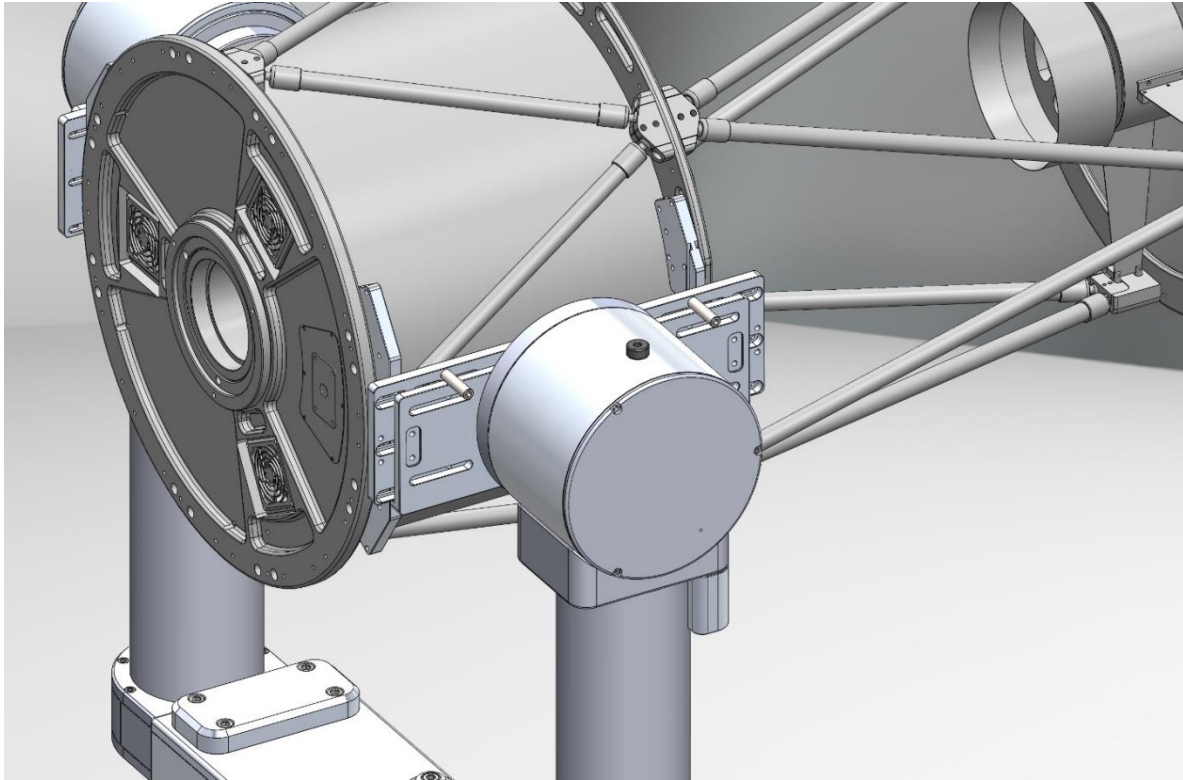


Figure 95: OTA mounting system carrying a 0.5 m OTA.

Apollo Fork Telescope Mounting System Introduction

Refer to the *Scope Rail System User Guide* for details about attaching common commercial optical telescope assemblies to the Paramount Apollo altazimuth mount. A printed copy is included with your mount, and this document can be downloaded from the Software Bisque website's Downloads. Search Downloads for *Scope Rail System User Guide*.

The URL to this page is: <https://www.bisque.com/downloads/scope-rail-system-user-guide/> (log in required).

Appendix C: Revision History

The table below describes the changes in each revision of this user guide.

Revision Number	Changes
1.8	<ul style="list-style-type: none">• Minor formatting changes and corrections.
1.7	<ul style="list-style-type: none">• Reorganized content.• Added Paramount Duo wedge documentation.• Updated Duo's packing list.
1.6	<ul style="list-style-type: none">• Clarified mount tuning.• Added Paramount Duo setup.• Clarified operating temperature specifications.
1.5	<ul style="list-style-type: none">• Clarified USB security key requirements.• Added missing photos to packing list items.
1.4	<ul style="list-style-type: none">• Miscellaneous corrections and clarifications.
1.3	<ul style="list-style-type: none">• Clarified product dimensions.• Updated dates.• Miscellaneous corrections and clarifications.
1.2	<ul style="list-style-type: none">• Corrected typographical errors related to the TCS operating temperatures.
1.1	<ul style="list-style-type: none">• Initial release.