Southern African Large Telescope
Prime Focus Imaging Spectrograph
Optical Integration and Testing Plan

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Eric B. Burgh
University of Wisconsin

1. Scope

This document, the Optical Integration and Testing Plan, describes the procedures for the integration and alignment of the main optics onto the PFIS structure. Alignment of the lenses within their cells and the inter-cell alignment of the camera and the main collimator group will be handled by the Pilot Group, described in the Camera and Collimator Alignment and Testing Procedure (SALT-3125AM0003).

2. Optics Breakdown

The main optical system breaks down into several sections, each of which will be integrated individually:

- Field Lens
- Main Collimator Group (MCG)
- Reference Flat
- Fold Mirror
- Collimator Doublet
- Camera
- Detector Subsystem

The first four items are aligned with the alignment setup located underneath the structure. The collimator doublet and camera are aligned with the setup situated outside the structure and raised to the level of the optical axis of the camera. The detector is aligned using images taken with the calibration setup once all the optics are aligned.

3. Alignment Equipment

The alignment setup comprises the following equipment:

- Brunson 83 autocollimating alignment telescope
- Alignment telescope mount with tip/tilt adjustment
- Alignment telescope front-end LED assembly
- Tripod with vertical adjustment and Tripod head with horizontal adjustment
- Interface plate between tripod head and telescope mount
- Adjustable axis
- Round first-surface flat mirror and mirror mount

The final two items are necessary only for the alignment up to the collimator doublet. These items are not used for the alignment of the camera.

The front-end LED assembly consists of a 9V battery-powered LED light situated inside a two-axis stage. This was found to be necessary when we were unable to see the reflections from the alignment telescope's lit reticle when returned from the optical surfaces, which are coated with high-performance anti-reflection coatings[1]. The LED provided a high contrast source. The two-axis stage allows for the LED to be set on the optical axis of the telescope, a process described in the next section. It should be noted that the various reflections will produce images in the alignment telescope of varying sizes.

The telescope mount allows for adjustments in tip/tilt, the tripod head has adjustment for one axis of translation and the stage on which the fold mirror is mounted gives the other axis of translation.

Other equipment necessary for the alignment process includes:

- Inside micrometer for setting distance between field lens and main collimator group
- Cross-hair pupil target and mount pole
- High quality flat mirror for autocollimation of Brunson telescope (also used in the PFIS autocollimation described later)

[1]A different alignment telescope may have better contrast performance. If the reflections from the optics can be clearly seen then the LED front assembly need not be used in the alignment process

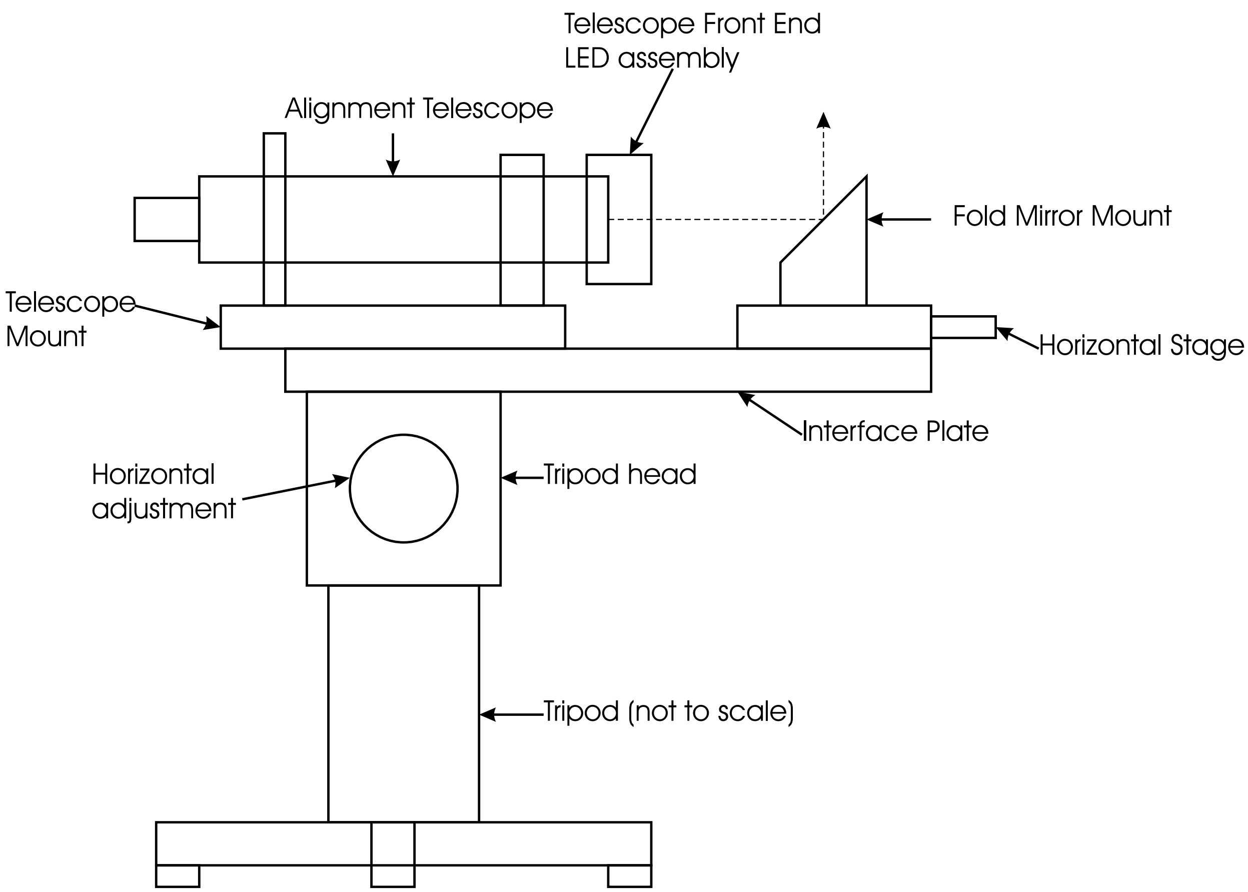

Fig. 1.— Schematic layout (not to scale) of alignment setup, shown for collimator alignment

4. Integration and Alignment Procedure

The integration and alignment plan for each of the above optics group will be descried in more detail in this section in the order in which they will be integrated. First, however, the method used to align the LED front assembly with the alignment telescope is described.

1. Set up the high quality flat mirror (that will later be used for autocollimation) a fair distance away from the telescope.
2. Autocollimate the alignment telescope by centering the reflection of the reticle in the telescope field-of-view. This requires a light source to illuminate the reticle.
3. Adjust the focus of the telescope until the reflection of the LED light appears.
4. Using the 2-axis stage on the LED front assembly, adjust the light until the reflection is centered in the telescope field-of-view.
5. Adjust the focus to verify that the reticle reflection is still centered.

The LED is now properly centered and the lit reticle need not be used in the rest of the alignment process.

4.1. Main Collimator Group

The main collimator group barrel will be inserted first into the structure. This group will define the optical axis relative to the instrument axis.

1. Bolt the main collimator group to the bottom flange connected to the invar collimator barrel. We assume that machine tolerances are acceptable for this interface. The interface has been pinned so that the placement of the collimator should be highly repeatable.
2. Align the alignment telescope to the collimator by alternately focusing on the first and last surfaces of the main collimator group. Adjust the alignment telescope until the reflected images of the LED light from the first and last surfaces are coincident. This is best achieved by picking one reflection to adjust tip/tilt only and the other for x-y only. When each reflection is found, mark the position on the focus nob with a marker. Adjust the telescope in two axes until the spot is near the center, then find the other reflection and adjust in the other two axes. One reflection will be more sensitive to tip/tilt and the other to x-y and if these are chosen correctly this process will converge quickly. Once the telescope is aligned with the optical axis of the main collimator group, care must be taken not to bump the alignment setup.

4.2. Reference flat

The double-sided reference flat mirror will be used in the alignment of PFIS on the SALT payload. One side will be spotted through the collimator during this alignment process and the other side will be spotted from the CCAS tower. The mirror has a parallelism of less than 30 arcseconds and the specification for the alignment of PFIS on SALT is 4 arcminutes.

1. The fold flat structure is bolted to the top of the collimator tube and the double-sided flat assembly is attached to the structure.

2. The alignment telescope is used to adjust the angle between the optical axis and the normal of the double-sided flat. The flat should be adjusted until the reflection is coincident with those of the surfaces of the main collimator group.

4.3. Fold Flat

1. Attach the fold flat to its mount.

2. Attach the pupil target to the structure. The mount pole screws into the hole in the articulation hub. Note that the grating rotation mechanism needs to be removed for this. The pole has been fabricated so that the target lies at the desired height for the collimated beam axis.

3. Spot the target through the main collimator group with the alignment telescope. Adjust the fold mirror until the pupil target is centered.

4.4. Field Lens

1. The field lens is set in place in the field lens/guider mount structure. The field lens has adjustments in 5 degrees of freedom. The tip, tilt, and piston adjustments are accomplished with three screws that bear kinematically in the axial direction. The centering adjustments are accomplished with two screws that bear in the radial direction and cells that are flexured for motion in the radial direction.

2. The field lens in its structure is attached to the bottom of the collimator tube.

3. Center and tilt the field lens until the images of the reflection target from the first and last surfaces of the field lens are coincident.

4. Adjust the piston of the field lens until the spacing between the field lens and the main collimator group is correct.

4.5. Collimator Doublet

The collimator doublet, like the field lens, has adjustability in 5 degrees of freedom.

1. The reflections from the doublet are too low contrast to be seen through the field lens and main collimator group so the alignment telescope has to be set up outside the structure such that it can view the main collimator group via the fold flat. The telescope should be positioned as close as possible to the doublet because one of the reflections can be shifted to a focus position beyond infinity and not seen in the telescope. We found that we had to position the tripod such that the neck of the tripod passed up through one of the spaces between beams in the structure.

2. Align the alignment telescope to the collimator by alternately focusing on the first and last surfaces of the main collimator group. Adjust the telescope until the images off the two surfaces are coincident. The alignment telescope is now aligned with the optical axis of the main collimator group.

3. The collimator doublet assembly is attached to the structure with the focus travel near the center position.

4. Center and tilt the collimator doublet until the images of the reflection target from the first and last surfaces are coincident.

   See section **??** for the autocollimation procedure.

4.6. Camera Barrel

The camera optics are integrated inside the camera barrel by the Pilot Group. With the articulation mechanism in place on the structure, the camera barrel can be placed onto the articulating cradle.

1. The camera on its cradle is integrated onto the structure

2. The camera is articulated away from the zero position so that a line of sight through the collimator is visible.

3. A target pinhole is placed in the focal plane via a slitmask and the alignment telescope is set up to spot the pinhole backwards through the collimator. This ensures the alignment of the telescope with the collimator axis.

4. The telescope is translated 7mm in the direction of the articulation in order to place the camera in its offset position.

5. The camera is adjusted until the images of the reflection target from the first and the last surfaces of the camera are coincident.

4.7. Detector

Once the detector has been attached, its alignment is measured and adjusted.

1. Affix the calibration setup to the spectrograph
2. Insert the slitmask with the array of foil pinholes
3. Insert an interference filter to limit wavelength regime
4. Take images of the pinholes through focus.

Analysis of the images will provide the information to determine the tip, tilt, piston, x-y shifts and rotation of the detector with respect to the slitmask plane. The x-y shifts and rotation can be taken out by adjusting the detector at its interface mounts. To adjust for tip, tilt and piston, use the adjustment screws of the detector kinematic mount – see Figure 2 for a schematic layout of these screws.

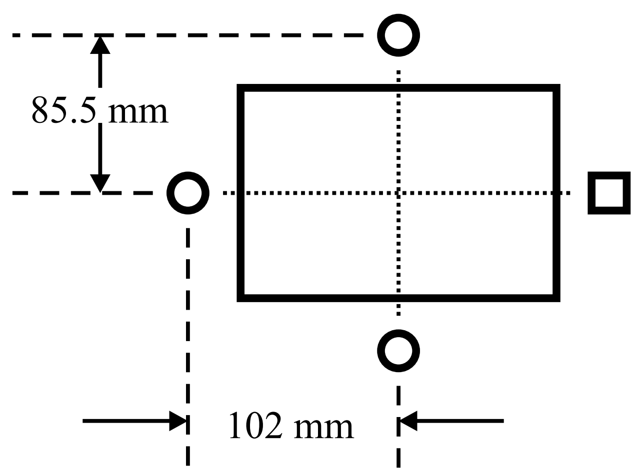

Fig. 2.— Schematic layout for detector interface. There are three screws that allow tip/tilt adjustments. Relevant distances are indicated.

To make an adjustment in tip, one should push one of the vertically aligned screws in and pull out the other by equal amounts. The screws are pitched at **200 microns/turn**. To adjust tilt, only the left-hand adjustment screw need be changed. For piston, adjust all three screws.

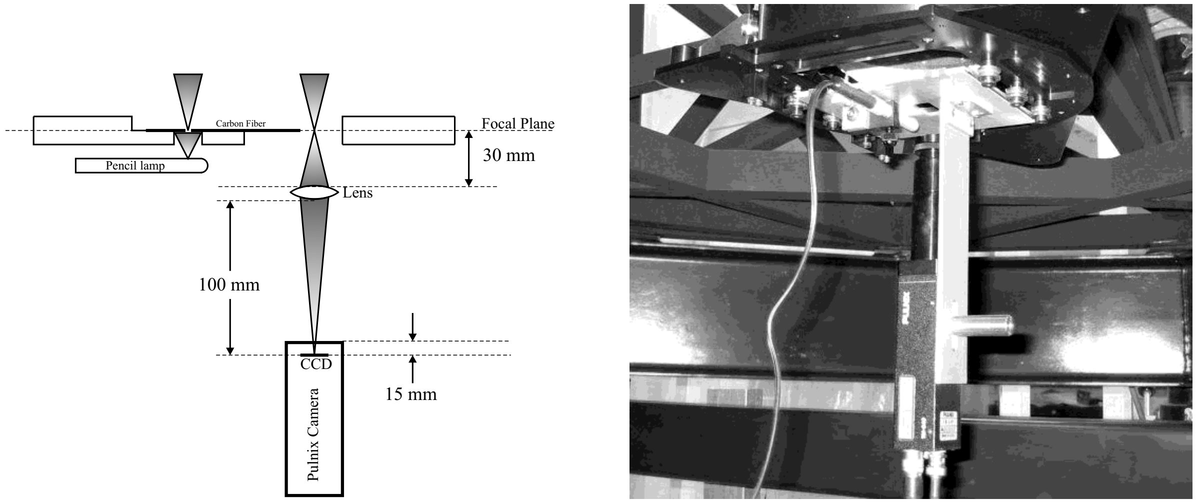

Fig. 3.— Left: Schematic drawing (not to scale) of the autocollimation setup. The pencil lamp illumintes a pinhole cut in a small carbon fiber sheet placed at the center of a modified slitmask holder. The light bounces from the mirror in the collimated beam space returns to the focal plane where the return spot is imaged onto the CCD camera by an intervening lens. Right: Photo of the setup as attached to PFIS.

5. Autocollimation

To set the proper collimator doublet z-position and ensure good collimation, an autocollimation setup is used. This setup comprises a high quality flat mirror that is placed on the same mount pole as the pupil target used in the fold flat alignment and a modified slitmask holder placed at the entrance of the spectrograph (shown in Figure 3). Attached to this slitmask are the following items:

- a pencil lamp for illumination
- the Pulnix CCD camera with a c-mount extender barrel, adjustable barrel and lens holder, with lens installed
- a small carbon fiber sheet with a pinhole in it

The carbon fiber sheet is attached so that the pinhole is situated above a larger circular hole in the modified slitmask and the edge of the sheet is over the large rectangular open space in the slitmask. The CCD camera is adjusted so that the edge of the carbon fiber sheet is in focus.

The image of the return spot on the CCD camera can be viewed on a TV display and measured as a function of the collimator doublet piston position. However, the combination of the thickness of the carbon fiber sheet (200 microns) and the limited size of the mirror in the collimated beam cause the beam speed of this setup to be large, resulting in a shallow focus curve.

Collimation can be checked later by using the Fabry-Perot etalons. A slitmask with pinholes can be viewed through the etalons and the focus curve of a direct spot can be compared to that of one of the ghosts naturally produced by having a flat reflective surface in the collimated beam space. Lack of collimation produces an offset between the position of best focus for the direct spot and the ghost spot.

6. Calibration Setup

The calibration (cal) setup consists of the following parts:

- Three support rods
- Three triangular plates with central hole cutout
- One triangular plate with circular bolt pattern in center
- Fresnel lens assembly: holder, lens, & cover
- Fiber-optic backlight
- Pencil lamp holding block assembly: block, end-plate, lamp holder with thumb screw, o-ring and cover for filters
- QTH lamp holding block assembly: block, o-ring and cover for filters
- Pillow block to hold end of fiber
- Three cross-beams for added support when testing at angle

The cal setup is assembled by placing the three support rods through the holes in the corners of the triangular plates. The plate with the circular bolt pattern in the center is the bottom plate. Only the placements of the bottom two plates are critical (see Figure 4): The plate with the Fresnel lens on it is set so that the lens is at the position of the PFIS entrance pupil; the plate beneath it is set so that the lamp is at the proper focal distance behind the lens. The other two triangular plates should be placed at regular intervals along the length of the rods for support; these may need to be adjusted if the cross-beams are used.

The lamp blocks attach to the bottom plate by screws placed through the plate from below. Filters may be placed above the lamp by placing it in the block on top of an o-ring and then screwing down the cover to hold it in place. If operating with PFIS horizontal, it's not really necessary to screw down the filter, just placing it there is fine.

The Fresnel lens assembly attaches to the second-to-bottom plate, first by screwing down through the holder, then placing the lens on top, and finally screwing the cover down to the holder.

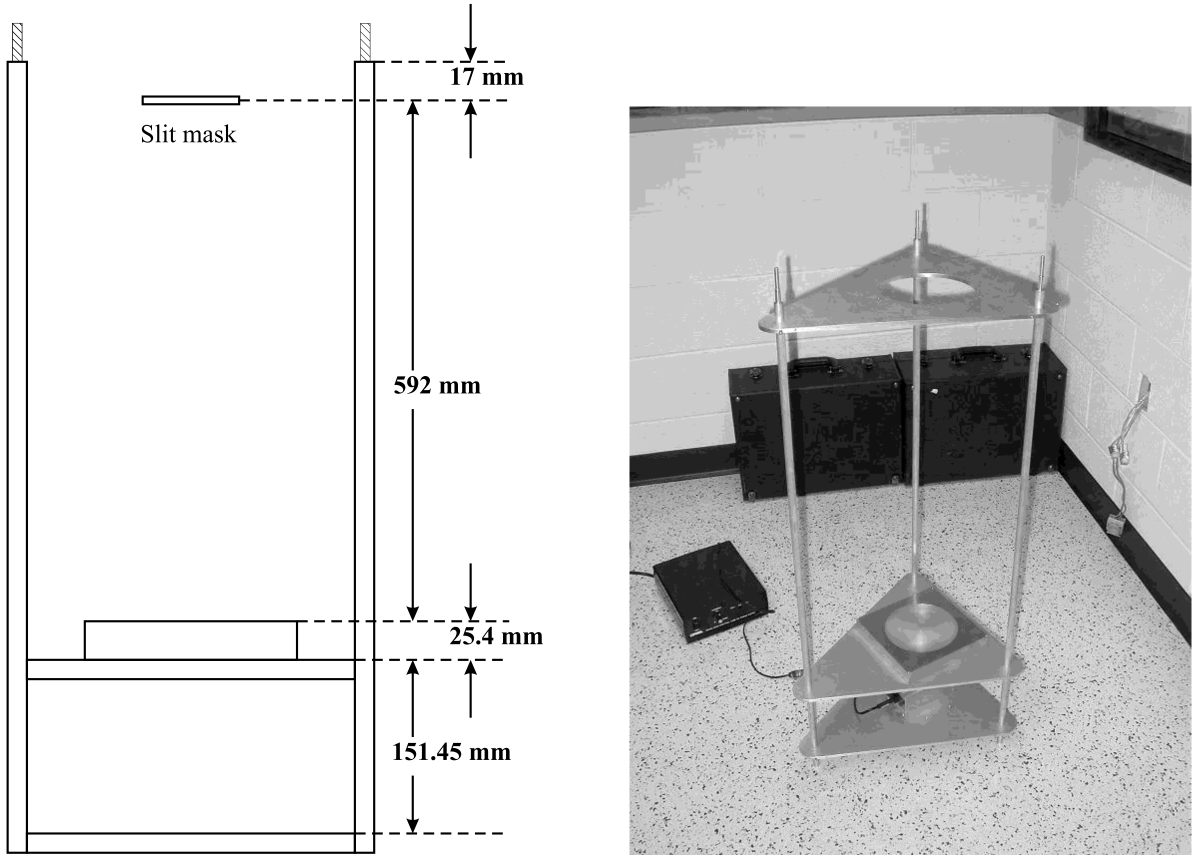

Fig. 4.— Left: Layout of calibration setup with important dimensions labeled. Note: not to scale. Right: Photo of assembled calibration setup with pencil lamp and Fresnel lens. More photos are available at http://www.sal.wisc.edu/ ebb/pfis/pics/assembly/calib/index.html

All of the major testing was done with the Fresnel lens rather than the fiber-optic backlight. However, if you want to use the backlight, it can bolted to the same plate without the need of repositioning the plate. The lamp block, either one, can be rotated by 90 degrees so that the light is emitted sideways and into the end of the fiber held by the pillow block, which is itself bolted to the bottom plate (see Figure 5).

Once the whole cal system is assembled it can be lifted up underneath PFIS so that the threaded sections of the support rods fit into the holes of the field lens mount (where the guider attaches) and held down by bolts from above.

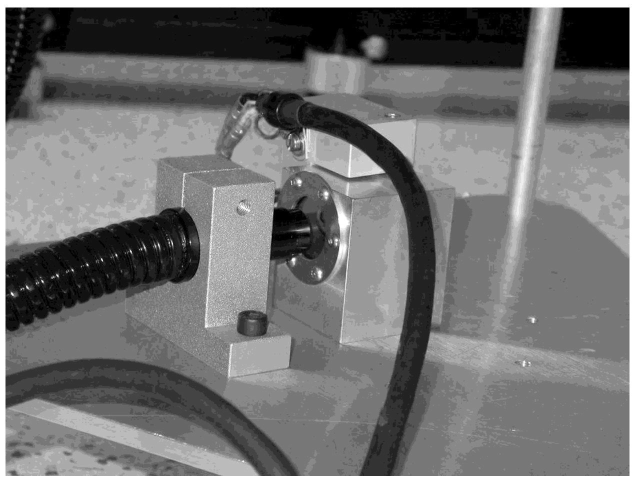

Fig. 5.— QTH lamp block set up for use with the fiber-optic backlight.