K1DM3 Report

Outer Drum Fitting Alignment

Version 1.3, March 3, 2016

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I. Overview

The K1DM3 project shipped its outer drum with wheels and kinematic fixtures to WMKO on October 22-30, 2015 to test for interference with the Keck 1 tertiary tower, confirm the kinematic interfaces, and measure the alignment of the ODF relative to the existing tertiary module This report details these efforts.

Here is a brief summary of the events:

Day 1: (10/26/2015) Jim Ward and Chris Ratliff were present on Day 1 to begin the procedures. They were met by WMKO staff Sam Park and Mike Dahler who were engaged throughout the process. They did initial alignments and fitting into the tertiary tower and found that the ribs on the outside of the ODF needed to be trimmed. The modifications to K1DM3 were made the following calendar day (which was otherwise an off-day for our efforts).

Day 2: (10/28/2015) The remainder of the team arrived on the mountain. We fixed the M3 attachment to the current M3 module, found the module's center of rotation, aligned an alignment telescope to the tertiary tower cross hairs, and measured the rotation center relative to the cross-hair reference frame. We also checked whether the current module was fully contacting the tower-side defining points.

Day 3: (10/29/2015) Brought the ODF to the Nasmyth platform to fit it through the tertiary tower. Pushed the ODF to the end of the tertiary tower and coupled the ODF kinematics to the tower-side defining points. Performed measurements on the location of the K1DM3 rotation axis (front and back of the module). Struggled to disengage the kinematics.

Day 4: (10/30/2015) Passed a foam template attached to the outer drum through the tower to more precisely measure the space allowed for clearance. Repeated measurements of the ODF rotation axis.

II. M3 Measurements

On October 28, 2015 the K1DM3 team performed a series of measurements on the existing tertiary module (hereafter M3). The general procedure was as follows (note that several steps were repeated/iterated during that day):

1. Mount an M3 attachment to the ring gear of its module.
2. Rotate M3 to establish the center of rotation on the attachment, as marked on a reflective target on the M3 attachment
3. Insert cross-hairs in the wedges mounted on the Keck I tertiary tower.
4. Align our Alignment Telescope (AT) to the pair of cross-hairs.
5. Observe the "target" on the M3 attachment to measure the offset between the AT cross-hairs and the marked rotation center.
6. Tip/tilt the target mirror until it was normal to the axis of rotation of the M3 module.
7. Measure the angle of the return beam from the AT off the M3 attachment mirror.

8. Measure Z distances from the AT to several reference points with a Fluke.

We now describe the specific procedures employed and the measurements made.

A. M3 Center of Rotation

We mounted a custom attachment to the ring gear of M3 with magnetic fixtures. At first these magnets were unable to hold the fixture static, but performance was nominal after cleaning both the ring gear and magnetic surfaces. We measured the attachment bar to be at 87.8 deg where 90 deg is vertical.

Mounted at the center of this attachment was a mirror with an overlayed, transparency target grid. We shined a laser mounted on the Nasmyth deck onto the target. We marked the laser dot position (somewhat out of focus) and then continued to mark its position as the M3 module was rotated through 360 deg. An additional dot was added to mark the approximate center of rotation, i.e. the center of the ring of dots. Figure 1 shows a zoom-in image of the grid after this procedure and our best-estimate of the ring and its centroid from an eye-ball analysis. Precision in this estimate is limited by both the size of the laser spot (a higher quality laser is warranted) and human error in placing dots during the rotation. We estimate an uncertainty of ≈ 1.5 mm in the position of this centroid from the ring of ink marks.

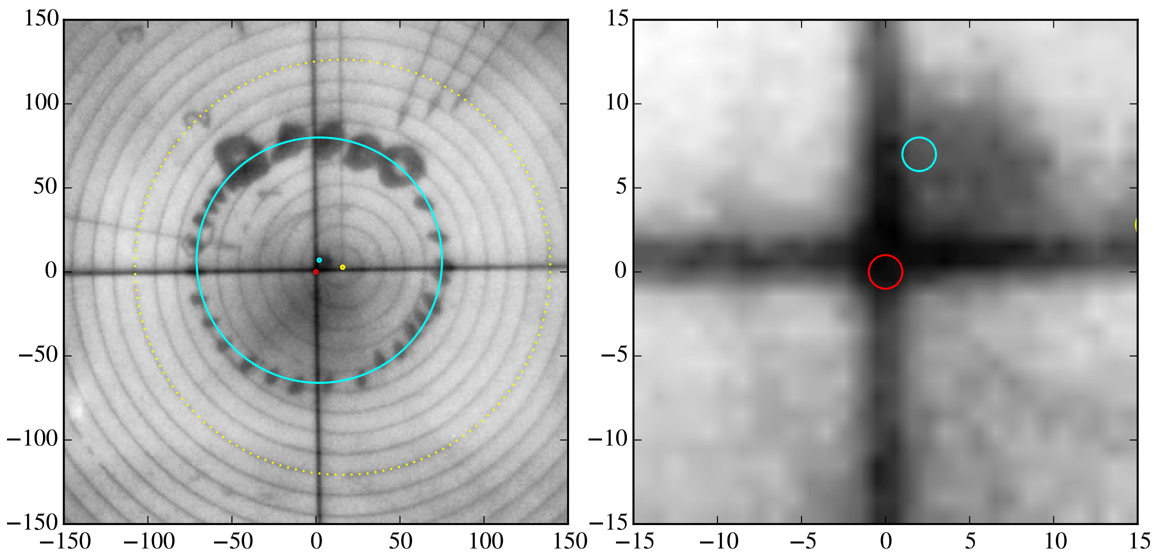

Fig. 1.— (left) Image of the M3 target as viewed by a camera mounted to our AT (it defines the cross-hairs in the image). Units are in image pixels. The ring of ink marks (circles and dots) correspond to the locations of a dot generated by a laser on the AT tripod. These were marked as the M3 module was rotated through 360 deg. The outer cyan circle shows our best estimate for the circle of marks. The inner cyan circle indicates the center. Also overlayed on the image is a circle of yellow dots used to convert the image pixels into physical units (1 pixel = 0.206 mm). (right) zoom-in on the image.

B. Establishing a Reference Frame

We established an XYZ reference frame for alignment measurements with the following procedure.

First, we installed cross-hairs in the mounting wedges on the K1 tertiary tower. We used monofilament, green, 20 pound fishing wire with 0.5 mm diameter. We found it difficult to firmly seat the wire against the front groove of each wedge (Figure 2). The next day we found we could more reliably place the wire by wrapping the excess around the entire block to force the line down to the groove. By adjusting the wire along the groove by a few mm, we found the intersection moved by approximate the wire diameter when viewed by the AT.

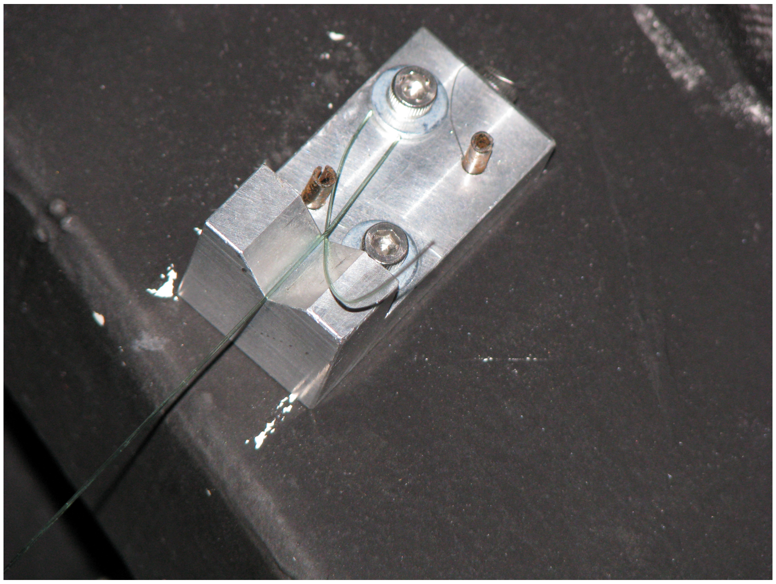

Fig. 2.— One of 8 mounts on the tertiary tower to mount our cross-hairs. In this case, the wire is well seated within the groove.

We achieved rough alignment with a laser and then iteratively brought the AT into alignment on the pair of cross-hairs (Figure 3). This pair of points establish the Z-axis of the Reference Frame. It is defined to point from the M3 module to the AT. We then observed the M3 target and rotated the AT until its vertical cross-hair was parallel to the vertical line on the target. This established Y-axis of the Reference Frame, oriented toward the sky. The X-axis is given by the right-hand rule.

C. Measuring the Center of Rotation Position: x_3, y_3

We focused the AT on the target of the M3 attachment. This is shown in Figure 1. On that figure, we have overlayed a circle encompassing the ring at 2 inches (diameter) from the target center (yellow, dotted line). This circle has a radius of 123.5 pixels indicating that each pixel has a size of 0.206 mm.

We measure an offset in x, y of 2 and 7 pixels respectively for the Center of Rotation giving measurements of $x_3, y_3 = 0.41, 1.44$ mm. We estimate an uncertainty of less than 0.5 mm in this measurement. This implies the total uncertainty is dominated by the process of generating the ink marks (estimated to be ≈ 1.5 mm).

D. M3 Axis of Rotation

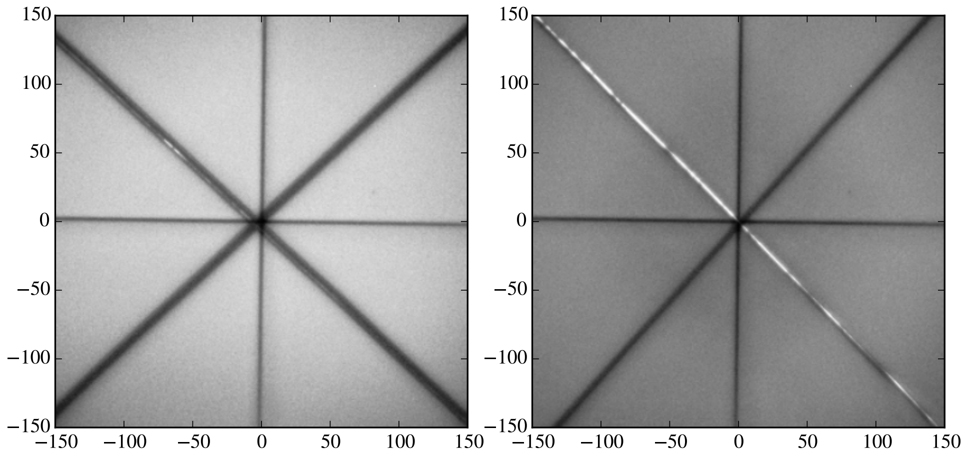

Fig. 3.— Cross-hairs as observed by the AT during the M3 alignment measurements. For reference, the wire thickness is 0.5 mm.

We have estimated the angle between the M3 axis of rotation and the Z-axis of our Reference Frame (tertiary cross-hairs) as follows.

First, we modified the tip and tilt of the mirror on the M3 attachment to define the vector parallel to the M3 rotation axis. This was roughly acheived by minimizing the circle traced out by the return laser mounted on our alignment tripod when rotating the M3 module. We found this procedure was precise to approximately 5 mm on the grid paper held fixed at the tripod. Precision was limited by both the shape of the return laser beam and (possibly) undesired motion of the mirror on the M3 attachment.

We repeated this experiment by taking images with the AT at a series of rotation angles of the M3 module. These are shown in Figure 4. With the exception of 90 deg, the patterns show a roughly circular motion. We suspect that the mirror on the M3 attachment showed additional movement in that specific position. This leads to an approximately 2 arcmin systematic error in the measurement that follows.

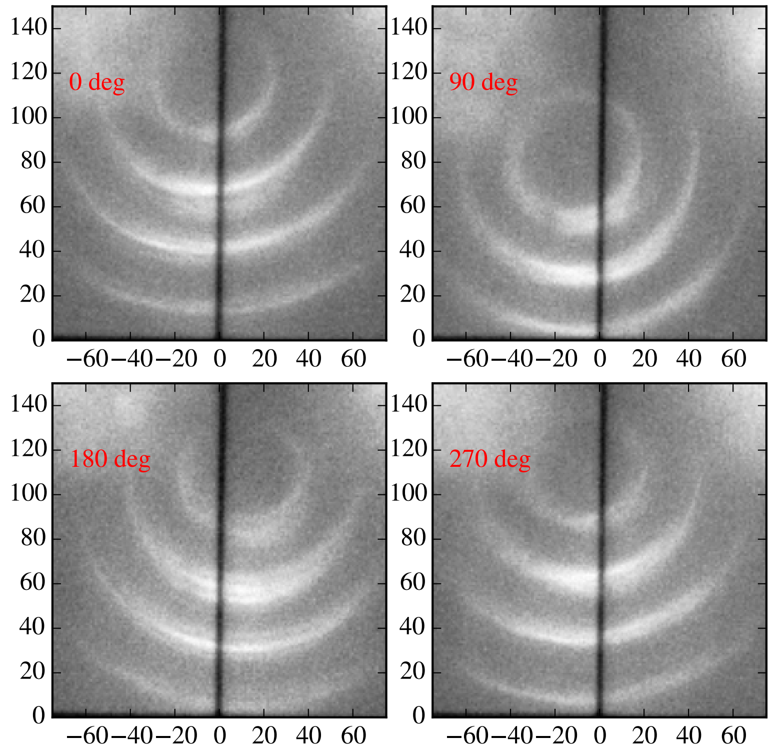

Fig. 4.— Rotation of the M3 attachment showing the concentric circles inside the alignment telescope. We repeated this process until the pattern of circles was nearly stationary as M3 rotated.

Lastly, we viewed the light rings emitted by a source in the AT and reflected off the attachment on M3. This is shown in Figure 5. We find that the origin of the AT cross-hairs very nearly intersects the second ring which has an angular size of 2 arcmin. Given that the reflected light has travelled to M3 and back, the angle between the M3 axis of rotation (given by the mirror on the M3 attachment) and Z (given by the tower cross-hairs) is just less than one-half of the measured angle. A more careful estimate, based on the yellow circle in Figure 5, is $\alpha = 0.96$ arcmin.

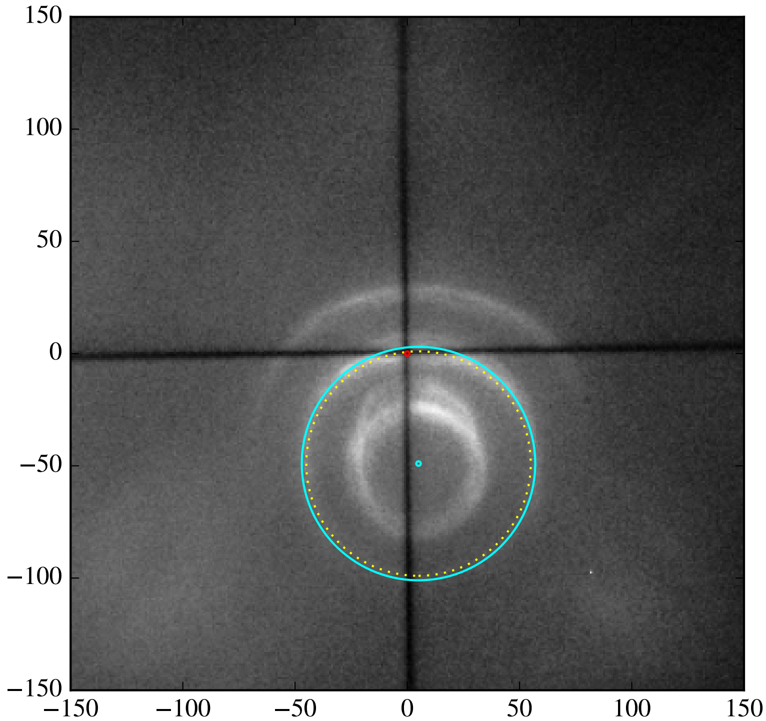

Fig. 5.— Image of the light rings emitted by a source in the AT, reflected off the attachment on M3. The cyan circle marks an estimate of the measured size of the second ring (which has a diameter of 2 arcminutes). The yellow dotted circle nearly intersects the cross-hair origin of the AT.

III. ODF Fitting and Coupling

The next day, October 29, 2015, the team removed the M3 module, fit the ODF through the tertiary tower, and coupled to the tower side defining points.

An inspection of the M3 defining points, upon its removal, indicated that they were fully engaging the tower-side kinematics. Specifically, a blue 'goop' which was placed on the tower kinematics showed across the entire kinematic surfaces on the module.

To confirm that the ODF also fully engaged with the tower-side defining points, this blue goop was reapplied and the ODF kinematics were inspected after mounting. There was non-uniform contact in the couplings (e.g. Figure 6). An adjustment was made to this kinematic for Day 3, when we confirmed full coupling (i.e. goop all the way around the mating surface; Figure 7).

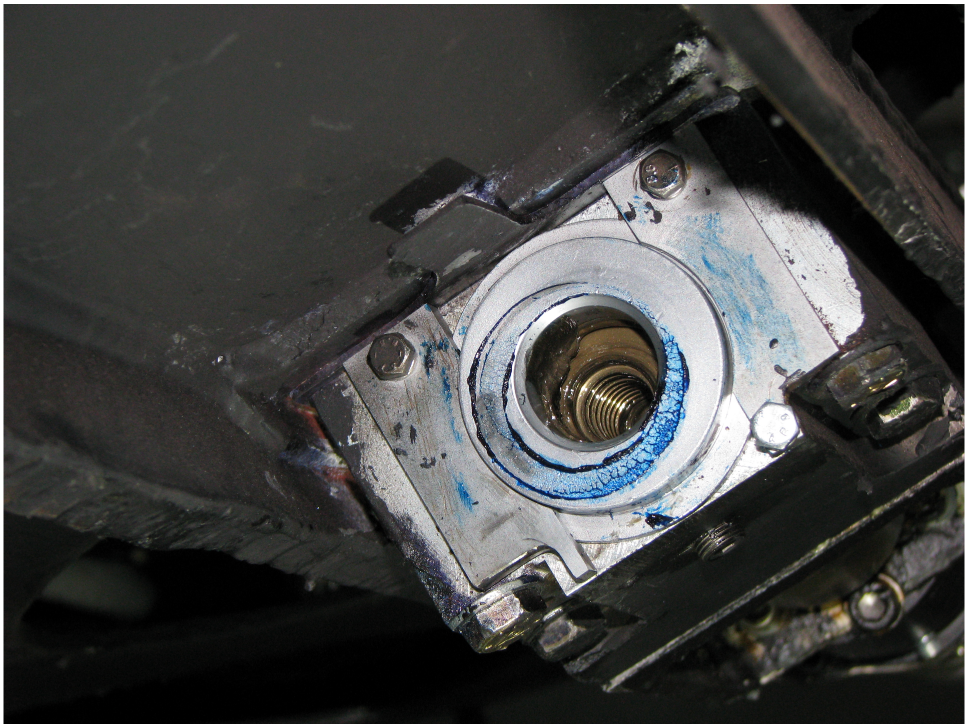

Fig. 6.— An example of incomplete coupling.

Fig. 7.— An example of complete coupling.

IV. ODF Measurements

We affixed two targets to the ODF on the upper and lower openings of the drum. We then mounted the ODF to the tower defining points. These targets were fabricated to establish the axis of rotation for the ODF, i.e. the center of each target lies on the ODF rotation axis.

We re-aligned the AT to the tower cross-hairs, using the same procedure described above for the M3 measurements. We then imaged the target located closest to the AT (farthest from M2) as seen in Figure 8. The image pixel scale were converted to physical units using the dotted circle drawn on the 2 inch diameter circle of the target (1 pixel = 0.212 mm).

The offset between the AT cross-hairs (red circle in Figure 8) and the target center is then measured to be x_1, y_1 equal to 2.2 mm, −0.1 mm. Given that this target lies close in Z-distance from the AT as the M3 target, we may estimate that the centers of rotation are approximately 1.5 mm offset in each dimension. The error in these measurements, however, are of comparable magnitude.

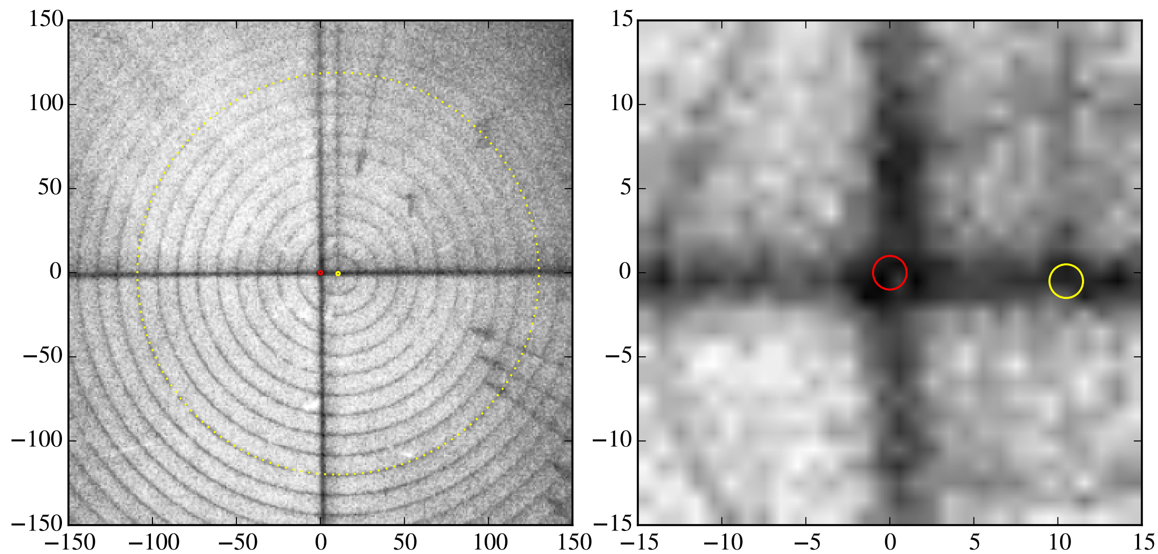

Fig. 8.— (left) Image of target 1 on the ODF as viewed by the AT. The yellow dotted circle is centered on the target center and encompasses its 2 inch diameter circle. (right) Zoom-in showing the offset in image pixels between the AT cross-hairs and the target center.

We repeated the exercise for target 2 on the ODF, as seen in Figure 9. We recognized after taking the measurements that the target was mounted backwards. But we have confirmed at UCO that the offset in the target center was much less than 1 mm. Again, a conversion from the image pixels to physical units was determined from a circle co-aligned to the 2 inch diameter mark on the target (Figure 9, yellow dotted ring). We measure 1 pixel is 0.229 mm.

There is a greater offset between the target center and the AT cross-hairs for target 2. We estimate x_2, y_2 equal to 4.8 mm, −0.9 mm.

Lastly, we may estimate the angular offset between the ODF axis of rotation and the cross-hair reference frame. This is simply the arctan of the displacement between the two targets relative to their separation: $\alpha_{\rm ODF} = \tan^{-1}(2.7\,{\rm mm}/775.2\,{\rm mm}) = 12\,{\rm arcmin}$.

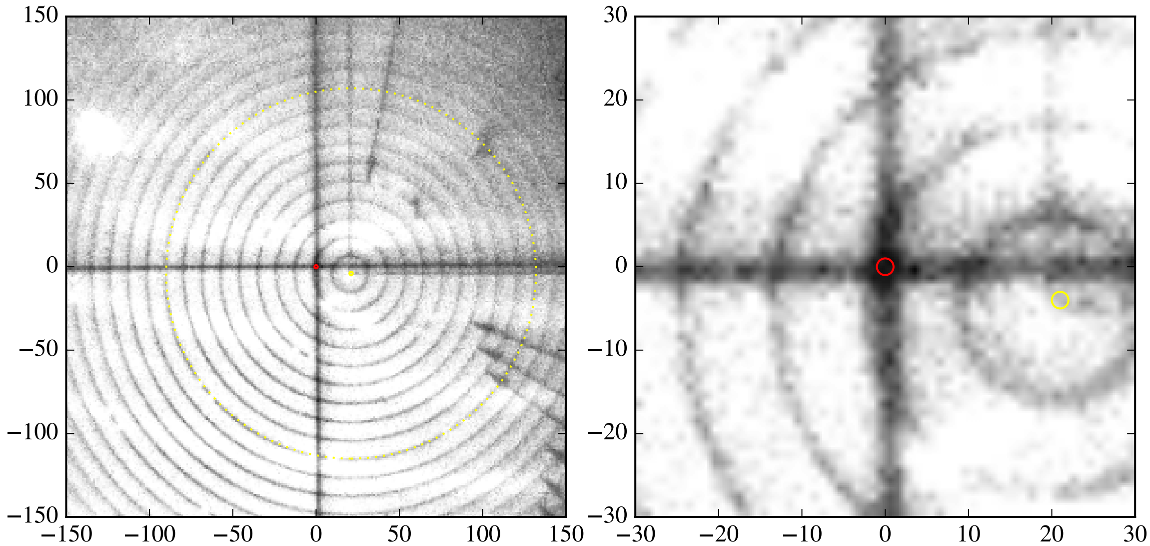

Fig. 9.— (left) Image of target 2 on the ODF as viewed by the AT. The yellow dotted circle is centered on the target center and encompasses its 2 inch diameter circle. (right) Zoom-in showing the offset in image pixels between the AT cross-hairs and the target center.

V. Measuring the Maximum Tower Clearance

Another goal for this trip was to accurately determine the available clearance in the tertiary tower for the K1DM3 profile.

For this assessment, we fixed a foam core to the outside of the ODF, as seen in Figure10. As we ran the ODF down the tower, we trimmed away the foam with razor blades at points of interference. In this process we were conservative by a few mm.

The foam core was then shipped back to UCO. We then had it precisely scanned by Tapemation to convert its profile into CAD (Figure 11).

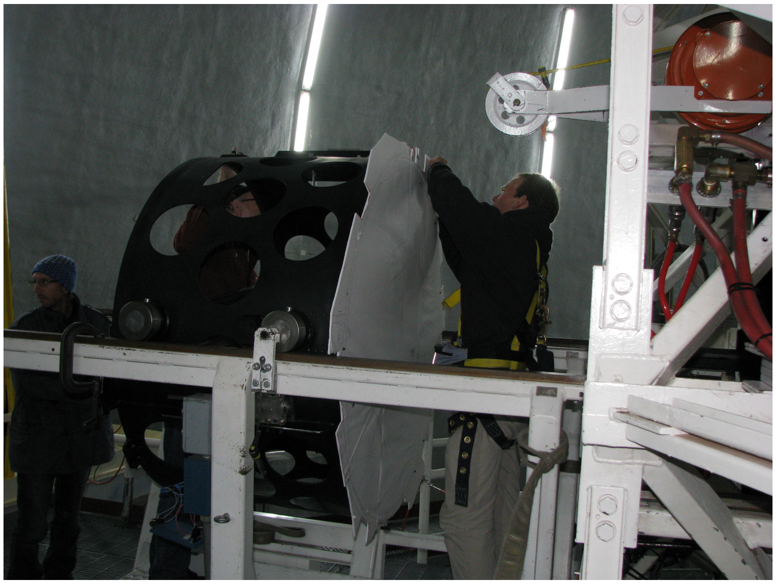

Fig. 10.— ODF fitted with the foam core.

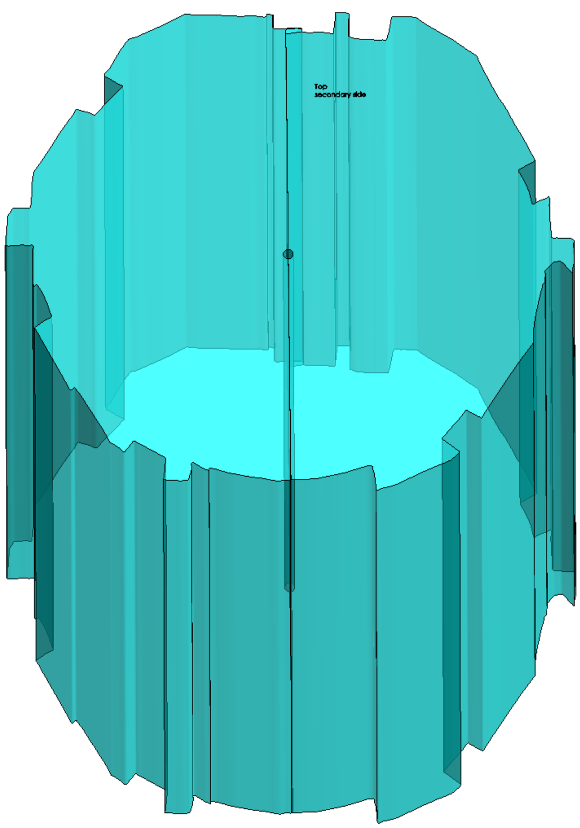

Fig. 11.— CAD model of the foam core.