# SUMMARY OF COLLIMATION PROCEDURES AND FLEXURE TESTS ON THE LASER GUIDE STAR LASER LAUNCH TELESCOPE. H. Petrie, 5/6/06

## I. COLLIMATION AND FOCUS CHECK.

Recent changes to the Laser Launch Telescope (LLT) were made because of severe optical problems discovered with the primary mirror. While awaiting delivery of a new 18” primary mirror, we purchased and installed a 10” primary mirror of the same focal length as the old primary. Also, because of problems keeping in synchronization the three Zaber T-HLA28 actuators used to move the primary mirror axially for focus, we redesigned the LLT secondary mirror housing to include focus motion using one of the actuators, leaving the primary fixed axially.

To collimate the new system, we proceeded as in the past to mount a laser collimator on the bottom side of the LLT primary mirror cell. This requires removing the final fold mirror and relay lens, a task made much easier with the new handling cart which allows tipping the whole cart and LLT on its side. The primary had been mechanically centered to the cell and the upward projecting laser was centered to the central hole of the primary using a reticle in the hole of the primary. We then attached a mask with crosshairs on it to the secondary and moved the secondary laterally using the LLT spider tensioning screws to line up the secondary on the laser beam projecting through the primary from below. We then removed the mask on the secondary and, using the tilt adjustment screws in the secondary housing, caused the reflection of the laser off the secondary to return on center to the reticle in the central hole of the primary. It was noted that the tilt adjustment was sensitive and that when we rechecked the centration of the secondary after doing the tilt adjustment, we had an error. This procedure of tilt and centration was repeated several times and did not seem to converge to a centration of better than about 1 mm. Because of pressure to mount the LLT on the 200”, this issue was left unresolved.

Once the secondary was centered and tilted, we could see the projected laser beam on the ceiling of the lab room. This pattern has many concentric fringes which we could center on the shadow of the secondary by tilting the primary of the LLT.

During the collimation, we also removed the laser from the bottom of the mirror cell and mounted it so it projected into the center of the top fold mirror of the LLT and down through the normal laser path, including the relay lens. The relay lens caused the collimating laser to nearly fill the secondary, which in turn nearly filled the primary. We then mounted a 15” optical flat above the LLT using a platform built by Palomar. This reflected the beam back through the LLT, and by using tilt screws on the flat, we were able to cause the laser beam to nearly return on itself. The relay lens creates a focus near the front surface of the primary, and we were able to determine that we had sufficient secondary mirror travel to cause the return beam to focus at the same place. This ensured that we would be able to achieve focus on a star and to focus the high powered sodium laser on the sky.

## II. PERFORMANCE ON THE SKY

On April 13, 2006, we attempted to use the LLT in viewing mode with a Pulnix TV cameral looking through it. We aligned the Pulnix to the LLT Primary Reticle and target on the LLT Secondary by shining a very bright flashlight on the secondary target. We were then able to see both the reticle center and the target center simultaneously. We removed the reticle and secondary target and attempted to view Saturn through the LLT when it was in the field of view of the AO system. We were unable to see Saturn in the LLT, even with the Pulnix in wide field mode. By standing above the LLT and viewing Saturn in the LLT primary, we could steer Saturn behind the LLT Secondary using the tilt screws of the kinematic mount between the LLT Pedestal and the LLT proper. At this point, with the Pulnix in wide field mode, we were able to acquire Saturn and proceed with boresighting and star test collimation tuning. Again using the tilt screws of the kinematic mount , we were able to get the LLT boresighted to the 200" and to confirm focus at about 8000 on the encoder of the Zaber actuator. We also noted that the field of view of the Pulnix seemed to be vignetted, which was corrected with a small tilt of the LLT Primary. The amount the primary was tilted was small compared to the range of detectable changes that we made in the lab when adjusting primary tilt

We then went to a star near the zenith for collimation testing and discovered we were several minutes off in boresighting, even though we had only moved a couple of hours on the sky. We reboresighted the LLT to the 200".

Translation tests of the secondary of the LLT were done to optimize the star image in the narrow field mode of the Pulnix Camera (no lens on the Pulnix, but a 150mm lens in the path between the FSM and the Relay lens). By moving the secondary about 1/2 mm North and 1 mm East, we were able to improve the star image FWHM from about 2.6 arcsec to 1.4 arcsec. PHARO seeing corrected to the visible was 1.4 arcsec at the time.

While in the narrow field mode, I pushed on components of the LLT to test for flexure while watching the star image in the monitor in Prime Focus.

1. Axial force on the edge of the Primary Mirror support base: movement of star,
2. Radial force on the edge of the Primary Mirror support base: no star movement.
3. Axial and Radial force on the LLT Mirror Cell: no star movement.
4. Radial force on the LLT Spiders: no star movement.
5. Radial force on the LLT Secondary Housing: no star movement.
6. Radial force on the LLT Secondary Zaber Actuator: no star movement.
7. Radial force on the LLT Secondary Focus Ram: movement of star.

(**NOTE**: "star movement" means a deflection on the monitor of one to two star diameters in the narrow field mode, about 2 to 5 arcsec.)

Qualitative conclusion:

1. Primary mirror mount seems soft axially, probably the flexures in the wiffletrees.
2. Secondary mount soft radially, probably the linear stage for focus motion.

**On a subsequent night, it was found that the laser spot projected through the LLT was not boresighted to the 200" and corrections of several minutes were required. This, plus the earlier boresighting problems in the star viewing mode, is disturbing and requires attention.**

## III. LAB TESTS FOR FLEXURE

On April 26, 2006, tests were performed in the lab at Palomar to determine the flexure characteristics of the LLT. The LLT was on its handling cart. The laser collimator was mounted near the Top Fold Mirror and a beam was projected through the optical system. This required changing the angle of the Top Fold Mirror and the Final Fold Mirror and powering up the FSM. A mark was made on the LLT where the laser beam was initially shining before moving the Top Fold Mirror so that it can be returned to its correct position. The Final Fold Mirror required turning the top adjusting screw 1 ¼ turns CCW. This setting will have to be restored before the LLT is installed at Prime Focus of the 200”.

With this setup, the laser was projected onto the LLT Primary and could be observed by putting a piece of paper on the primary with a small hole in it to let the laser shine through from the Final Fold Mirror.

**Qualitative Evaluation of Flexure**:

A. Trouble Spots – movement of laser evident when pressure applied to component.
  1. Secondary.
  2. Top Fold Mirror.
  3. Truss Assembly.
  4. FSM Plate.

B. OK Spots – laser stable.
  1. Primary.
  2. Secondary housing and Zaber Actuator.

C. Truss Assembly observations.

1. Truss stable to side loads, but weak to torsional loads. Torsion can occur due to offset weight of Top Fold Mirror. Movement here causes laser to project differently but does not affect Pulnix TV viewing of stars. Laser motion due to East-West forces on the Fold Mirror are due to transferring the force into the truss assembly. North-South forces on the Final Fold Mirror also cause deflections in the mount itself. This mount, could be stiffened.

2. The truss is assembled with shoulder bolts that serve as pins in the clevis joints at the ends of the struts. The shoulder bolts are slightly longer than the width of the clevis which means that the nut on the shoulder bolt bottoms out before clamping the clevis joint. The nuts mainly kept the shoulder bolts from falling out. One was particularly loose and I made a spacer washer for under the head of the bolt so that the joint could be clamped tightly. Qualitatively, this did not change the torsional stiffness of the truss, but there were many more loose bolts that could affect the system. I believe that putting appropriate washers under each shoulder bolt head would allow all joints to tighten up under clamping forces and this would improve the torsional stiffness.

3. The FSM plate showed elastic movement with loads in the East-West plane, but it caused less laser deflection than twisting the truss assembly did. At some point when the optical design is stable, this area could be rebuilt with a stiffer design.

**Deflection Tests with Dial Indicator**:

1. A dial indicator holder was clamped to a spider and the indicator tip placed against the side of the secondary holder. With a few ounces of force (the assembly weighs about 4 ounces), deflections of .001 to .002 inch were noted. When we did star testing collimation, we moved the secondary sideways in minimum ¼ turn steps on a 32 pitch thread, which is .008 inch. Generally, movement at the .008 inch level is hard to detect in the quality of the star images. A move of .008 inch of the secondary would move the star image over more than half the field of view which was on the order of 60 arcsec. This suggests that star movement from .001 inch of secondary deflection would be on the order of 8 arcsec, of the same order of magnitude noted when the LLT was in Prime Focus.

2. With the indicator in the same position, the tilt screws were adjusted to see if lateral movement occurred. With the indicator near the SW screw the motions measured were: SW - .003/.004 inch per screw rotation; E – less than .001 inch; NW – less than .001 inch. Again, these are small deflections and no tilt moves were made with the LLT mounted at Prime Focus of the 200". However, the source of these motions should be investigated.

3. Using a dial indicator, the motion of the adapter plate for the 10" LLT Primary Mirror with respect to the Mirror Cell was measured. A 10 lb downward force at the edge of the 18" diameter plate created .001 inch of deflection. This was the type of force applied in Prime Focus to create star movement on the Pulnix monitor. A similar force applied on-axis through the earthquake clips of the 10" mount created no measurable deflection. This suggests that if changing gravity loads due to tilting the LLT do not cause a moment on the support wiffletrees, no misalignment will occur. This condition should be met if the radial support of the primary is through its center of gravity, which is essentially the case. Close attention to this will be paid in the design of the mount for the new 18" mirror. Confirmation of the specifications for the wiffltree flexures with the design engineer from the University of Chicago confirm that they should have more than adequate stiffness for good axial support.

4. Using a dial indicator to measure radial motion of the adapter plate for the 10" primary showed .0003 inch of movement for a 10 lb force. The same force applied to the 10" primary itself from two directions 180 degrees apart showed a total movement of about .016 inch due to compression of the felt pads that define and support the mirror radially and flexure of the posts that carry the pads.. So, from a neutral position, about .008 inch of movement is possible since the mirror weighs a little over 10 lbs. This effect of this movement is related to the plate scale of the primary. The focal length of 37.5 inches gives a plate scale of 216 arcsec/mm. Therefore, a movement of .008 inch (.2 mm) corresponds to about 43 arcsec on the sky. This would be the maximum amount when going from the zenith to the horizon and would actually not be linear with zenith angle since it would take a certain angle before the mirror could slip sideways on the felt pads that define it axially. This feature of the 10" primary mount could be moderated by replacing the radial felt pads with nylon pads on the ends of set screws, which would also make centration of the 10" mirror easier to adjust.

## IV. MODIFICATIONS TO THE SECONDARY FOCUS RAM

1. The Secondary Focus Ram, including the linear stage and tilt system, was removed from the LLT and taken to campus for further evaluation and modification if needed.

2. Examination under a microscope revealed that the ball bearing ended set screws used for secondary tilt adjustment differed in profile from the simplified model used in the Solidworks design of the parts. In particular, a shoulder envelops the ball farther than had been modeled and this shoulder was rubbing on a flat surface of the focus ram. This kept the balls from fully entering the V-grooves on the focus ram that make up the kinematic mount. When the screws were rotated, they would wobble on the shoulder, causing lateral movement of the secondary holder. This problem was fixed by machining the flat surface .005/.007 inches deeper to make the V-grooves shallower. Also, 2 of the 3 screws had balls that were stuck. They were replaced with screws that have rotating balls. The cell for the secondary mirror is now well located, will not move in the focus stage under a forces of several times its own weight, and does not move laterally at the plane of its vertex during tilt adjustments.

3. The play in the linear ball bearing focus stage was remeasured in the inspection area of Central Engineering Services (CES). It was found to have about .0001/.0002 inch side play at the location of the secondary and about .0005 inch elastic deformation under a few ounces of side load. This was less than measured in the lab at Palomar, but that measurement may have included some of the inadequacy of the kinematic mount. The stage had extremely low friction, indicating very little preload. We entered into a dialogue with the manufacturer about specifications and procedures for changing the preload. After exploring options for sending the unit back or ordering a new one, we settled on the option that had us readjust the stage following instructions from their Engineering Department. Under the microscope, the stage was adjusted to have enough preload to just restrict movement of its own weight in the vertical plane. This was between .1 and .2 ounce of axial force. Motion was still smooth. The system was remeasured at CES with essentially the same deflections measured as before - .0001 inch of play and .0005 inch deflection with several ounces of side force. The readings were the same normal to and sideways to the slide.. This seems to rule out the linear stage as a cause of pointing errors.

## V. SUMMARY

1. The LLT was measured and some small flexures were found. The focus stage and secondary support have been modified to fix the deflections found. Shims will be added to the Truss Assembly which should improve torsional stiffness, but will not change the star viewing mode pointing errors observed in the last run. The radial support and definition of the 10” Primary Mirror will be stiffened, but the existing system should not have caused the magnitude of pointing errors observed.

2. **The tests conducted so far have failed to show why large (several arc minutes) pointing errors were observed with the LLT during the April 13, 2006 run**.

3. Pointing errors of the laser with respect to the star viewing Boresight setting are probably due to the interaction between the boresighting procedure and the alignment of the Pulnix TV cameral to the LLT optical axis. This will be checked when the LLT is

reassembled in the Palomar lab.  If the interaction is determined to cause problems, we will have to iterate between boresighting and Pulnix alignment at the start of the next run.