NIRSPEC

UCLA Astrophysics Program | **U.C. Berkeley** | **W.M. Keck Observatory**

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NIRSPEC Optics Design Note 10.00
Warm Alignment Plan

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Introduction

The NIRSPEC alignment plan was developed to provide an approach for integrating and aligning NIRSPEC components on the NIRSPEC optical plate. The plan has been generated with the goal of satisfying all positional and angular accuracies defined in the Opto-Mechanical Tolerance Analysis (OMTA) NIRSPEC Design Note 09.00.

The alignment procedure for the NIRSPEC system is based on two key concepts:

- Start with pre-aligned sub-assemblies or "modules" whose alignment is qualified and documented as part of the vendor acceptance test procedures.

- Establish an reference optical axis on the NIRSPEC baseplate and a means to maintain that reference. All modules are then aligned to this reference axis. The reference optical axis in NIRSPEC will be defined by the axis of the minibench assembly, and all subsequent modules will be integrated and positioned on the baseplate with respect to this axis. Positional accuracies of the modules are measured using either optical means or by mechanical measurements, or in some cases by using both techniques. A key principle of this approach is that the optical axis remains a reference, and that all alignment tools and modules are aligned to this common axis.

The alignment plan uses established tools and techniques which are industry standards and are commonly used in the alignment of optical instruments and precision industrial machinery. Most of these tools are positioned on an auxiliary alignment platform which is mounted next to NIRSPEC optical plate. In addition to using HeNe lasers, measurement gauges, and crosshair targets, the approach utilizes an autocollimating alignment telescope as the primary tool to achieve quantitative alignment accuracy. An autocollimating alignment telescope can typically achieve lateral positioning accuracies on the order of 0.0005" and angular accuracies of 5 arc-seconds or better. A complete parts list and excerpted catalog literature are attached to this report.

The alignment plan has evolved since the preliminary alignment report of February 1996. Modifications of the approach have been made based on the updated design of all NIRSPEC mechanical components by Speedring Systems, SSG Inc., and UCLA staff. After correspondence and meetings with UCLA personnel, the approach was altered to allow for the integration of subassemblies and a logical order of steps in the alignment plan.

It is important to realize that an alignment plan is a working document subject to changes in procedure. Almost every optical system ever built has involved real-time modifications to the alignment approach, based on realizations that there are simpler or more straightforward ways to align a component once the actual parts are in place. The alignment aids and procedures outlined should, however, provide enough accuracy to achieve the NIRSPEC alignment requirements defined in Design Note 9.00.

Alignment Plan Overview

The following summarizes the proposed order of assembly of the NIRSPEC system:

- Establish an initial line of sight (LOS) and set up alignment tools on NIRSPEC plate and auxiliary alignment platform.

- Install the minibench assembly and slit wheel assembly, and find the minibench LOS.

- Confirm that minibench alignment is maintained through image rotator positions.

- Once the minibench is established, adjust slit wheel, alignment tools, and add additional aids to match the minibench optical axis.

- Install a temporary cross-hair target to represent the nominal Keck focus location, confirm nominal location is where it should be.

- Install and align the off-axis parabolic collimator (OAPC) to the minibench LOS, confirm OAPC focus at the slit wheel.

- Install and align the echelle/LR flat mechanism, confirm aperture centering.

- Install the cross-disperser & TMA assemblies, then align the cross-disperser and confirm aperture centering.

- Confirmation of alignment of TMA assembly by checking that a HeNe beam is not clipped by any of the TMA mirrors.

- Insertion and alignment of Lyot stop and filter wheel assembly to the minibench LOS.

- After installation of the chamber, confirm that the window is nominally square to NIRSPEC optical axis.

In general, each of the components that are installed on the NIRSPEC plate have positional and angular alignment tolerances that are summarized in Table 5 of the OMTA Design Note 9.00. These alignment tolerances are governed by requirements on optical performance, image wander at the slit plane, beam displacement at component clear apertures, mechanical clearance issues, or pupil wander at the Lyot stop and filter wheel assembly. The positional and angular tolerances to meet these performance requirements need to be met and confirmed for each NIRSPEC component. **Table 1** provides a summary of the techniques outlined in this plan to confirm that each component's requirements are met.

Techniques to Achieve and Confirm
NIRSPEC Component Alignments

Component	X-Y lateral centering	Z (axial) positioning	Tilt in horizontal plane (azimuth angle)	Tilt in vertical plane (elevation angle)	Z-tilt (clocking)
Minibench (Super)	Alignment scope w/ Speedring mirror target	Mechanical--measure from edge of baseplate	Autocollimation w/ Speedring mirror target	Autocollimation w/ Speedring mirror target	N/A (due to image rotator)
Filter wheel assy.	Alignment scope w/ Lyot stop	Mechanical--measure from 2 fiducials (TBD)	Autocollimation w/ filter surface	Autocollimation w/ filter surface	Insensitive to clocking
Slit wheel assy.	Alignment scope w/ installed mirror target	Mechanical--distance from f-converter	Autocollimation w/ installed mirror target	Autocollimation w/ installed mirror target	Pre-set during slit installation
Off-axis parabolic collimator (OAPC)	Reversed align. scope centered on back of slit	Shear plate collimation tester	Reversed align. scope centered on back of slit	Reversed align. scope centered on back of slit	Height gauge before/after OAPC
Echelle/LRFLA T assy.	Align.scope w/custom scribed target, & HeNe	Mechanical, & align. Scope w/ scribed target	Alignment scope w/ scribed target at CD	N/A (due to echelle rotation)	Pre-set during echelle installation
Cross disperser (CD) assy.	Align.scope w/custom scribed target, & HeNe	Mechanical, & align. Scope w/ scribed target	N/A (due to CD rotation)	Autocollimation off of grating 0th order	Pre-set during CD installation
TMA assy.	Centering using HeNe order off of gratings	Mechanical--CD to TMA distance fixed	N/A (beam steeering by grating rotation)	N/A (beam steeering by grating rotation)	Adjusted via FPA clocking

Steps in Alignment Procedure

1) Equipment Set-up: Establish a temporary line of sight (LOS) for the optical axis on the NIRSPEC optical plate.

The optical axis is temporarily established by using two crosshair targets of equal height located on the NIRSPEC optical plate. The targets should be mounted on the plate in the area between the slit wheel and the off-axis parabolic collimator (OAPC). Mounting locations for these targets, consisting of dowel pin locations and/or tapped mounting holes, are included in the optical plate hole template. By referencing the targets to the optical plate, an initial LOS will be used as a tool to help confirm that downstream components will be located close to their nominal locations and their corresponding mounting holes.

The see-through crosshair targets consist of stretched stainless steel wires mounted in a 2.25" diameter (2.2498" max., 2.2493" min.) steel ring with a centering tolerance of 0.0005" on the wires. The targets should be inserted in an adjustable mount, which can be made of custom or off-the-shelf components, and then adjusted equally to the a height of 8.250" above the optical plate. The target heights can be set using a calibrated height gauge, and both the targets and the height gauge can be viewed through an alignment telescope for comparison and confirmation.

Height of 1st target (8.25" nom.) ____________

Height of 2nd target (8.25" nom.) ____________

Required Equipment:

2 crosshair targets from Brunson or K & E
2 mounts for targets with X-Yadjustment
2 kinematic baseplates for target mounts
Tapped holes and/or dowel pin locations on the NIRSPEC plate
1 height gauge

2) Equipment Set-up: Incorporate autocollimating alignment telescope onto auxiliary alignment platform, and align to temporary LOS.

The telescope should be placed in a stand and positioned nominally at the 8.25" height. The stand should provide the lateral translations and tip/tilt adjustability to align the telescope to the two crosshair targets. In addition, the telescope should be placed sufficiently far away from the instrument to allow it to focus at the Keck focus nominal position. Currently, the Brunson Model 83 scope slated fo use has its minimum near focus at the tip of its barrel, so its focus range poses no problem. To allow for clearance for other alignment aids, the telescope and stand should be positioned 4 to 6 inches before the Keck focus.

When calibrated, the alignment telescope maintains the straightness of its line of sight while adjusted for focus from its near focus out to infinity. Factory calibration of the unit is recommended. To quickly confirm equipment calibration, it is suggested to check the infinite setting for autocollimation. With the autocollimation illumination light powered up, a flat mirror should be placed against the alignment telescope output flange. With the mirror in place, the autocollimation illumination should be reflected directly back onto the telescope reticle and should be in focus at the telescope reticle for the infinity (collimated) setting.

Confirmation of alignment telescope calibration ☐

Required Equipment:

1 breadboard as auxialiary alignment platform
1 alignment telescope w/autocollimation capability
1 alignment telescope stand with X-Y and tip/tilt adjustment

3) NIRSPEC alignment: Install minibench and make preliminary measurements.

The minibench assembly, consisting of the K1 and K2 assemblies pre-aligned on a baseplate, should be installed so that the edge of its baseplate is at its nominal distances from the edges of the NIRSPEC plate. This sets the initial axial and lateral position of the minibench (which relates to the nominal location of the Keck focus with respect to the NIRSPEC plate).

Minibench to edge of plate, Keck side (X.XXX" nom.) ________________

Minibench to edge of plate, long side (X.XXX" nom.) ________________

Note that the current plan is for the minibench to be positioned via pins to the NIRSPEC plate. Therefore, there is no capability to adjust the minibench axially, laterally, or angularly in azimuth to coincide with the appropriate distance from the edge of the plate or with the temporary LOS. The pins and holes must be in the correct position. Shimming to adjust height or elevation angle may be an option if necessary.

Using the alignment telescope, a preliminary measurement of the change in the LOS due to the minibench insertion should be made at this point. The purpose of this rough test is to confirm that the minibench will maintain the nominal "directionality" of the LOS, so that downstream components won't be significantly offset from their nominal locations.

Initial assessment of LOS shift:

Lateral LOS shift, 1st target, horizontal (X) ________________

Lateral LOS shift, 1st target, vertical (Y) ________________

Lateral LOS shift, 2nd target, horizontal (X) ________________

Lateral LOS shift, 2nd target, vertical (Y) ________________

Required Equipment:

Minibench assy.
1 dial caliper or other measuring tool

4) NIRSPEC component alignment: Determine minibench preliminary line of sight.

To help establish the initial minibench LOS, the following initial steps should be performed using an alignment telescope and a mirror target mounted on the image rotator:

a) Installation and adjustment of mirror target. The Speedring ATP refers to a reference mirror with a center scribe, mounted in an adjustable fixture with both tilt and lateral adjustments (Speedring ATP §4.3.1.1, p.15). This hardware should be provided to UCLA, with the fixture left in its as-aligned position from the Speedring acceptance test, if possible. To install and re-align the mirror target,

- i) Mount the mirror target & fixture on the front of the K1 housing.
- ii) Initially center the alignment telescope on the crosshairs.
- iii) Adjust alignment telescope centering and tip/tilt until:
  - autocollimation is achieved off of the target mirror, and
  - target centering is maintained.
- iv) Rotate the K1 bearing and observe the target centering and autocollimation.
- v) If necessary, adjust target centering using the Speedring-provided adjustment fixture to minimize target wobble.
- vi) If necessary, adjust target tip/tilt using the Speedring-provided adjustment fixture to minimize autocollimation drift.
- vii) Repeat steps iii) through vi) until target drift and autocollimation drift are eliminated during bearing rotation.

b) After iteration, use the alignment telescope and autocollimation to record the maximum target shift, which provides an assessment of image rotator bearing accuracy. The lateral shift is directly read using the X-Y micrometers on the alignment telescope. The angular shift is derived from the shift in the autocollimation signal and the focal length of the alignment telescope; contact the manufacturer for the specifications on the alignment telescope being used.

Motion of K1 target mirror:

Maximum detectable lateral target shift ________________

Maximum detectable angular target shift ________________

Required Equipment:

Speedring reference mirror & adjustable fixture

5) NIRSPEC component alignment: Install slit wheel mechanism and additional alignment aids.

After determining the minibench preliminary LOS based on the Speedring mirror target, the next step involves installing targets at the Lyot stop and filter wheel locations. These targets will be used to assess minibench alignment over different image rotator positions, and will be used to repeat some of Speedring's ATP steps to confirm minibench performance. If necessary, the LOS will later be adjusted from the preliminary LOS to achieve the best compromise of performance at both the filter wheel and slit wheel locations. To install the additional targets:

a) Leaving the alignment telescope orientation fixed, set the image rotator to its nominal position. Remove the K1 reference mirror and then install a cross hair target between the K1 and K2 assemblies near the nominal Lyot stop location. The target mount should have the ability to be adjusted horizontally and vertically for centering the target; axial (z) positioning is not critical for this target. Adjust the cross hair target in X and Y until it is centered in the alignment telescope.

b) Still leaving the alignment telescope orientation fixed, install the slit wheel mechanism at the nominal slit wheel location. Prior to installation, the slit wheel mechanism has been pre-calibrated with a reflective mirror target in one of the wheel positions. After installation of the slit wheel in its nominal position, the assembly should be adjusted axially (in z) using the mechanical separation of two known fiducials (TBD, most likely the distance between the f-converter and slit wheel assembly). The separation required is first set using a shim machined to the appropriate thickness. The slit wheel is then translated until it contacts the shim positioned between the two surfaces, thus establishing its axial position. Adjust the slit wheel mechanism until the target is centered in X and Y in the alignment telescope.

NOTE: This step requires the use of a reflective crosshair target temporarily installed in one of the slit wheel locations. This target is NOT tilted with respect to the NIRSPEC axis, unlike all other installed slits which are tilted for use with the slit-viewing camera.

c) Check the tip/tilt of the slit wheel assembly by achieving autocollimation with the telescope focused at infinity. If necessary, adjust the orientation of the assembly until the autocollimation signal is centered at the telescope reticle.

d) Repeat steps b) and c) until both conditions are met.

e) An option is to confirm the correct axial (z) positioning of the slit wheel using an optical rather than a mechanical technique. A temporary mirror can be installed between the K1 and K2 assemblies. The alignment telescope is then adjusted in focus until it is autocollimated off of this mirror; this confirms that the telescope is effectively collimated between the two K-mirror assemblies. Accordingly, the telescope should now be set to focus at the nominal slit plane. Remove the temporary mirror and confirm that the slit wheel target is in focus.

Centering of crosshair target at Lyot stop location	☐
Centering of mirror target at slit wheel location	☐
Autocollimation of mirror target at slit wheel location	☐

<u>Required Equipment:</u>

1 crosshair targets
1 target mount with X-Yadjustment
1 kinematic baseplate
1 mounting plate adapter, to provide mounting holes for target on minibench (if necessary ?)

Slit wheel assembly, pre-calibrated and tested as a unit prior to installation
1 reflective mirror target, sized to fit in slit wheel mechanism
An unpopulated slit wheel position for downstream alignment
Means of fine positioning of slit wheel
Shim for axial positioning of slit wheel from f-converter

6) <u>NIRSPEC component alignment:</u> Repeat some of Speedring ATP, confirm that minibench is still in alignment, determine minibench LOS.

To confirm that the minibench is still in alignment and maintains its LOS requirements, the following steps should be performed using an alignment telescope to confirm bearing accuracy and minibench boresight:

a) Rotating the image rotator assembly, measure the motion of the cross hair target at the Lyot stop location using the alignment telescope. The lateral shift is directly read using the X-Y micrometers on the alignment telescope. A table of x and y deviations from the nominal image rotator position can be generated. This table can be used to calculate the centroid of the target motion and the maximum deviation from the centroid.

Cross-hair target between K1 and K2:

Image Rot. Position	X	Y
$\theta = 0^\circ$	0.0	0.0
$\theta = +45^\circ$		
$\theta = +90^\circ$		
$\theta = -45^\circ$		
$\theta = -90^\circ$		

Calculated

centroid:

X = __

Y = __

ΔX from centroid	ΔY from centroid

Maximum detectable lateral (radial) target shift __________________

b) Rotating the image rotator assembly, measure the motion of the mirror target at the slit wheel location using the alignment telescope. The lateral shift is read using the X-Y micrometers on the alignment telescope, and then compensating for the 1.5X magnification of the minibench assembly as it changes from f/15 to f/10. As before, a table of x and y deviations from the nominal image rotator position can be generated. In addition, the autocollimation signal may be used to measure the angular deviation of the minibench.

Mirror target in slit wheel, lateral measurements:

Image Rot. Position	X	Y
$\theta = 0^\circ$	0.0	0.0
$\theta = +45^\circ$		
$\theta = +90^\circ$		
$\theta = -45^\circ$		
$\theta = -90^\circ$		

Calculated

centroid:

X = __

Y = __

ΔX from centroid	ΔY from centroid

Maximum detectable lateral (radial) target shift __________________

Mirror target in slit wheel, angular measurements:

Image Rot. Position	X autocoll.	Y autocoll.
$\theta = 0^\circ$		
$\theta = +45^\circ$		

Calculated

ΔX from centroid	ΔY from centroid

θ =+90°			centroid:		
θ =-45°			X = __		
θ =-90°			Y = __		

Maximum detectable angular target shift ________________

From NIRSPEC Optics Design Note 9.00, the following positional and angular tolerances must be met by the minibench assembly:

Between K1 and K2 (Lyot stop location):

X-decenter	0.3mm	______________	☐
Y-decenter	0.3mm	______________	☐
Z-decenter (axial)	1.0mm	______________	☐
X-tilt (azimuth)	0.3mrad	______________	☐
Y-tilt (elevation)	0.3mrad	______________	☐
Z-tilt (clocking)	30mrad	______________	☐

After minibench (Slit wheel location):

X-decenter	0.3mm	______________	☐
Y-decenter	0.3mm	______________	☐
Z-decenter (axial)	1.0mm	______________	☐
X-tilt (azimuth)	0.8mrad	______________	☐
Y-tilt (elevation)	0.8mrad	______________	☐
Z-tilt (clocking)	30mrad	______________	☐

Required Equipment:

No additional equipment required.

7) Equipment Set-up: Adjust alignment telescope LOS to match best composite LOS (centroid) of minibench assembly.

If the beam wander at the slit plane is significant (yet still within specification), it may be desired to reset the alignment telescope LOS to match the centroid location so that all downstream components are aligned to the "best composite" LOS of all image rotator positions. Using the data taken in the previous procedure, the alignment telescope would be re-adjusted slightly in angle to the centroid location at the slit plane. A temporary target, such as the tip of the height gauge, could be set to the calculated centroid location prior to adjusting the alignment telescope to create a visual aid.

This step is optional, and it is the engineer's discretion whether this step is necessary or significant.

Required Equipment:

No additional equipment required.

8) Equipment Set-up: Confirm that minibench LOS is on-line with NIRSPEC plate, re-establish a new LOS on plate which matches the minibench optical axis.

At this time, the minibench assembly should be locked down, and the image rotator assembly reset to its nominal position.

a) Re-measure the height of the optical axis at the slit wheel location using the alignment telescope LOS and the height gauge.

Y-height at slit plane 8.250" nominal ____________

b) The target at the slit location should be removed from the LOS by rotating the slit wheel to an open position. The alignment telescope can be used once more to inspect the LOS with respect to the NIRSPEC plate. Once again, the LOS should not vary significantly from the two downstream crosshair targets which are referenced to the NIRSPEC plate.

Lateral LOS shift, 1st target, horizontal (X) _______________

Lateral LOS shift, 1st target, vertical (Y) _______________

Lateral LOS shift, 2nd target, horizontal (X) _______________

Lateral LOS shift, 2nd target, vertical (Y) _______________

c) At this point, the two downstream crosshair targets can be re-adjusted in X and in Y to bring them in line with the minibench LOS as seen through the alignment telescope.

d) Alternatively, if the minibench LOS is substantially off from the NIRSPEC optical plate, it may be necessary to shim the minibench assembly to bring minibench LOS closer to NIRSPEC plate LOS. Using the two downstream crosshair targets, iteratively shim and lock down minibench to try to bring LOS closer to the nominal plate LOS. At each iteration, the alignment telescope must be re-adjusted using the detachable cross-scribed reference mirror on the front of the K1 housing. Repeat the process until acceptable results are achieved for Steps 4 through 8.

Required Equipment:

No additional equipment required.

9) Equipment Set-up: Install cross-hair target on removable kinematic baseplate at nominal Keck focus location.

A crosshair target should be positioned at this time on the auxiliary alignment breadboard. The target should be located approximately the appropriate distance from the edge of the NIRSPEC plate. Lateral centering of the target should be accomplished by adjusting the target X and Y heights so that it is centered in the alignment telescope. Axial positioning of the target can be established by inserting a flat mirror between the K1 and K2 assemblies and adjusting its tip/tilt until an autocollimation signal can be detected in the alignment telescope. When the telescope is focused at the nominal Keck focus position, the autocollimation signal will be reflected by the mirror in collimated space and should come back to a focus in the alignment telescope. This location should be measured mechanically to ensure that the Keck focus is the appropriate distance from the NIRSPEC plate.

Keck focus to edge of plate (X.XXX" nom.) ________________

Note that this distance will be shortened (by approx. 3mm) in the final NIRSPEC system due to the incorporation of the CaFl window. The mechanical distance from the NIRSPEC plate should be compensated by this factor.

Calculated Keck focus, compensating for window (X.XXX" nom.) ____________

Required Equipment:

1 crosshair targets
1 target mount with X-Yadjustment
1 kinematic baseplate

10) Equipment Set-up: Co-align a HeNe laser with the alignment telescope, with HeNe focus at Keck focus location.

This test equipment is important since adding a laser gives a second, highly visual aid in the alignment of the NIRSPEC. In addition, the HeNe laser, when used with a shear plate, is used as a sensitive test of focus and collimation setting of the OAPC. Finally, the HeNe also allows for the lateral positioning of downstream components and a visual confirmation that the components are centered on the illuminated aperture. The following steps are envisioned:

a) Mount a HeNe with integral focusing optics attached to its front flange on a X-Y stage. The entire assembly should be mounted on a small aluminum baseplate which can be aligned separately and positioned on the auxiliary alignment platform. The focusing optics should be adjusted so that an approximately f/15 focus is created.

b) Install a 3" pellicle beamsplitter tilted at 45° on a beamsplitter gimbal mount in the space between alignment telescope and the Keck focus crosshair.

c) Adjust HeNe positioning and pellicle tip/tilt to align the HeNe to the optical axis. This is accomplished when the HeNe focuses at both the Keck focus crosshair and the slit wheel reflective target.

d) If room permits, a possible step would be the insertion of a shear plate tester in the space between the K1 and K2 assemblies to test for HeNe collimation.

This alignment is an iterative process between X-Y HeNe translation and pellicle tip/tilt adjustment. Ideally, the HeNe should be adjusted in X-Y to hit the pellicle exactly where the NIRSPEC LOS intercepts the pellicle. (Note: If the slit wheel reflective target is blocked and all back-reflections are minimized, it may be possible to <u>CAREFULLY</u> look through the alignment telescope and see that the HeNe footprint on the pellicle is centered in the alignment telescope. Caution is strongly recommended here; confirm that there is no significant HeNe light entering the alignment telescope aperture before looking into the eyepiece !!!).

<u>Required Equipment:</u>

1 HeNe laser
1 HeNe laser beam expander and focusing optics assembly
1 laser mount w/X-Y adjustment
1 small baseplate for HeNe assy.
1 pellicle beamsplitter, 3" dia. or larger
1 beamsplitter mount w/ tip&tilt adjustment
1 kinematic baseplate

11) <u>NIRSPEC alignment:</u> Install/align off-axis parabolic collimator (OAPC) in rear half of system.

The approach first utilizes the alignment telescope and the auxiliary reference flat on the OAPC assembly, using a technique similar to the alignment approach outlined in SORL mirror literature (see attached). A shear plate tester is then used to fine adjust OAPC focus with respect to the slit location, so that the light off the OAPC mirror is accurately collimated. The OAPC installation is done at this point in the procedure since previous steps have established the diverging HeNe beam needed for the shear plate tester, thus creating the necessary conditions for fine focusing this mirror. The installation procedure is as follows:

a) Prepare for moving the alignment telescope by establishing positional aids for relocating the telescope when returned to its current position. This may include marking its position, epoxy-held blocks to help re-establish positions, and/or using the downstream cross-hair targets to confirm re-alignment.

b) With the HeNe laser off, remove the alignment telescope from its stand and locate it on a second alignment stand, looking towards the OAPC and its collimated output from a position near the echelle location. Ideally, the alignment telescope could be aligned looking predominantly at the OAPC, with a small portion of its aperture overlaying the auxiliary reference flat.

c) Using the reflected beam and autocollimation off the auxiliary flat, tip/tilt the alignment telescope until perfect autocollimation is achieved. The alignment telescope is now perpendicular to the auxiliary flat and is parallel to the parent axis of the OAPC.

d) Examining the reticle in the alignment telescope, adjust the tip/tilt of the OAPC mount to center the back of the slit target in the telescope. The alignment telescope set to infinity should be focused by the OAPC at the slit location. Note, however, that the substantial depth of focus associated with the alignment telescope-OAPC combination does not allow for precision focus adjustment of the OAPC.

e) Repeat steps c) and d) to re-adjust the alignment telescope to the OAPC axis and re-adjust the OAPC focus to the slit plane. The process will be iterative until the conditions of both c) and d) are met.

f) Check the OAPC centerline height using a height gauge near the mirror edge. Also check the alignment telescope height using a height gauge near the edge of its entrance aperture. If either the OAPC height or the alignment telescope height are substantially different from the slit height measured in step 7a), then this is an indication of OAPC clocking error in its mount. If necessary, adjust OAPC clocking to try and clock its focus to the same height as the OAPC mirror and repeat steps c) through e).

g) Turn on the HeNe laser. Block the eyepiece of the alignment telescope to prevent accidental viewing. Examine the diverging light from the HeNe laser and its footprint on the OAPC. The HeNe footprint may be emphasized by carefully laying a sheet of lens paper on top of the OAPC, so that the footprint as well as the mirror edge can be seen. If the HeNe footprint is not perfectly centered on the OAPC aperture, it is likely the fault of the HeNe alignment rather than OAPC mis-centering (because steps c) through e) above are more accurate than the HeNe alignment using crosshair targets). If necessary, adjust the pellicle tip/tilt to center the HeNe footprint on the mirror. Remove lens paper and blow any lint off of the mirror surface.

h) Position a shear plate collimation tester in front of the alignment telescope in the pseudo-collimated HeNe beam. Confirm that the shear plate is relatively horizontal by placing a bubble level on top of the cube. Adjust shear plate height and level as necessary. If the light off the OAPC is collimated, the fringe lines displayed on the shear plate viewing screen should be horizontal. Fringe lines should be straight and oriented horizontally; deviations from horizontal lines indicate divergence or convergence of the beam. Adjust OAPC axial (z) positioning to create horizontal fringe lines at the shear plate. Once again, return to step b) and repeat steps c) through e), f) through h) until all conditions are met. Whereas OAPC boresighting is best measured with the alignment telescope, achieving horizontal fringe lines with the shear plate tester is a more accurate measurement of OAPC focus and beam collimation.

Slit centered on alignment telescope reticle			☐
Autocollimation off of auxiliary reference flat			☐
	Y-height at OAPC	8.250" nominal	____________
	Y-height at align. scope	8.250" nominal	____________
Straight & horizontal fringes at shear plate tester			☐

<u>Required Equipment:</u>

OAPC assembly w/ auxiliary reference flat
Means of fine positioning of OAPC
1 shear plate tester, can be purchased from Melles Griot

12) <u>NIRSPEC alignment:</u> Install and align the echelle/LR flat mechanism.

Since the echelle, cross disperser, and TMA all sit in collimated space, the positioning of these downstream components are driven by aperture centering and beam steering considerations more than by wavefront sensitivity to misalignment. Accordingly, the important goals are to center the apertures of the components, and to orient their tip/tilt to steer the beam to the next component.

a) Turn the HeNe off and return the alignment telescope to its original stand. Confirm that the alignment telescope is still aligned to the LOS by using the various crosshair and mirror targets.

b) Install the echelle/LR flat assembly in its nominal position. Also temporarily install the cross-disperser (CD) in its nominal location. The cross disperser will serve as a "target" for aiming the LR flat in azimuth angle.

c) Rotate the mechanism to the LR flat position and turn the HeNe on. Adjust the azimuth and elevation angle of the assembly to "steer" the HeNe beam onto the CD grating.

d) Turn the HeNe off and examine the height of the LOS using the alignment telescope and the height gauge set to 8.25 inches. With the height gauge positioned in front of the CD grating, fine adjust the elevation angle of the LR flat to bring the LOS onto the height gauge tip.

e) Install a custom-made fixture on the LR flat mount to provide an alignment target for fine adjustment of LR flat centering. The custom fixture should mount to the tapped holes on the LR flat mount and should be scribed at the appropriate offset from the LR flat center for the incident LOS. This offset is due to the fact that the LR flat and the fixture surface are not coincident with the echelle grating pivot axis. Adjust the assembly laterally until the scribe is centered in the alignment telescope.

f) Turn the HeNe on and confirm that the LR flat aperture does not clip the beam. Again, lens paper can be used here with care.

g) Repeat steps c) through f) until all conditions are met.

h) If these conditions cannot be met, it may be necessary for the assembly to be re-machined or shimmed in height in order to obtain the appropriate optical axis height.

<u>Required Equipment:</u>

Echelle/LR flat assembly, pre-calibrated and tested as a unit prior to installation
Custom fixture w/ scribed targets

13) <u>NIRSPEC alignment:</u> Install cross-disperser & TMA, align cross-disperser assembly.

Alignment of the cross-disperser (CD) assembly is similar to that of the echelle/LR flat. However, since one mounting foot of the CD assembly actually sits on the TMA baseplate, it is necessary to install the TMA prior to CD fine alignment.

a) Install the TMA assembly in its nominal position. Install the CD assembly in its nominal location with its mounting foot in the TMA structure. Initially orient the grating in its 0th order, normal to the NIRSPEC optical axis.

b) Install a custom-made fixture on the CD mount to provide an alignment target for fine adjustment of CD centering. The custom fixture should mount to the tapped holes on the CD mount and should be scribed with a centered target. Adjust the assembly laterally until the scribe is centered in the alignment telescope.

c) Confirm the tip/tilt of the CD assembly assembly by achieving autocollimation off of the grating in its 0th order with the alignment telescope. If necessary, adjust the orientation of the assembly until the autocollimation signal is centered at the telescope reticle. This also confirms that the CD is oriented with its elevation angle correctly set, i.e. the CD assembly is truly vertical. Check that the scribe is still centered and remove the custom fixture.

d) Adjust the CD azimuth angle to approximately 35 degrees angle-of-incidence using mechanical measurements at the edges of the CD mount and calculating the trigonometric angle. With the HeNe on, it is now possible to use the diffracted HeNe orders to perform visual alignment off of the cross-disperser. With a tip angle on the grating of 35.561°, the 7th diffracted HeNe order will come off the grating at an angle of 14.439° and will be aimed into the entrance port of the TMA assembly. Fine adjust the cross disperser angle to steer the HeNe into the TMA and roughly center the footprint in the entrance aperture. This will set the nominal angle for the cross-disperser for the next steps.

e) Install a custom-made fixture on the CD mount to provide an alignment target for fine adjustment of CD centering. The custom fixture should mount to the tapped holes on the CD mount and should be scribed at the appropriate offset from the CD center for the incident LOS. This offset is due to the fact that the fixture surface stands in front and is therefore not coincident with the CD grating pivot axis. Adjust the assembly laterally until the scribe is centered in the alignment telescope.

f) Turn the HeNe on and confirm that the CD aperture does not clip the beam. Again, lens paper can be used here with care.

g) Repeat steps d) through f) until all conditions are met.

h) If these conditions cannot be met, it may be necessary for the assembly to be re-machined, shimmed in height, or shimmed to introduce vertical tilt in order to obtain the appropriate optical axis height or elevation angle.

Required Equipment:

Cross disperser assembly, pre-calibrated and tested as a unit prior to installation
Custom fixture w/ scribed target

14) NIRSPEC alignment: Confirmation of alignment of TMA assembly.

As mentioned before, the TMA is located in collimated space and its wavefront performance is not driven by TMA package misalignment but by mirror-to-mirror misalignments within the assembly. Since the TMA is delivered as a pre-aligned assembly with no user adjustments, there are no provisions in this alignment report for TMA fine adjustment.

As before, however, the important goal for TMA positioning is the centering of the input beam on the apertures of the components, and the orientation of the tip/tilt of the assembly to avoid clipping at internal mirror surfaces. Fortunately, the echelle and the CD can be though of as a pair of adjustable beam steering mirrors, so beam steering can be achieved in operation by adjusting the grating angles.

However, to confirm that the TMA mirror and baffle apertures do not clip the NIRSPEC beam, the following steps can be performed:

a) As in the previous step, confirm that the LR flat is adjusted to its nominal position and that the CD azimuth angle is such that the 7th diffracted HeNe order will come off the grating and will be aimed into the entrance port of the TMA assembly. This beam should effectively represent the center of the field for the TMA camera, and the HeNe light should come to a focus at roughly the center of the FPA format. Without the FPA installed, use a power meter to measure the HeNe power at the FPA location.

b) Fine adjust the LR flat and cross disperser angles to steer the HeNe into the corners of the FPA format and again measure the HeNe power at the FPA location. If there is no substantial clipping of the beam, then the power measured at the corners of the format should be approximately equal to the previous measurement for the center grating positions. Record the power measurements and their deviation:

HeNe power at center of format _______________

HeNe power at upper left corner of format ____________ Percent Δ from center _____________

HeNe power at upper right corner of format ____________ Percent Δ from center _____________

HeNe power at lower left corner of format ____________ Percent Δ from center _____________

HeNe power at lower right corner of format ____________ Percent Δ from center _____________

c) Significant power variation imply a clipping of the HeNe beam internal to the TMA assembly. Carefully assess if clipping is occurring by examining the internal surfaces of the TMA, looking for scattering off of the edges of HeNe-illuminated surfaces. If necessary, the TMA assembly may need to be re-oriented in azimuth angle, shimmed in height, or shimmed to introduce vertical tilt in order to obtain the appropriate orientation for vignetting-free transmission.

NOTE: This procedure does not account for vignetting due to the change in the beam footprints when using the echelle grating instead of the LR flat mirror. In addition, this test assumes that the diffracted efficiency of the HeNe beam does not vary significantly as the CD grating is adjusted. However, although the test is not perfect, it is a means to check that the TMA mirror and baffle apertures are not clipping the NIRSPEC beam.

<u>Required Equipment:</u>

TMA assembly, pre-aligned as a unit
1 HeNe power meter

15) <u>NIRSPEC alignment:</u> Insertion/alignment of Lyot stop and filter wheel assy.

The filter wheel and Lyot stop assembly is one of the last components to be installed on the NIRSPEC plate due to the obscurations of the Lyot stop and the lack of visible transmission through the IR filters. Lateral positioning of the filter wheel assembly is accomplished using the alignment telescope to center the Lyot stop on the NIRSPEC LOS. Z-axis (axial) positioning of the filter wheel will be accomplished mechanically since axial positioning cannot be accomplished conveniently with any of the proposed alignment aids.

The filter wheel assembly should be positioned as follows:

a) Install filter wheel assembly on the minibench baseplate. The wheels should be oriented in their "open" positions to aid alignment, i.e. Wheel 1 in Lyot-stop-only position, Wheel 2 in open position.

b) After installation of the filter wheel in its nominal position, the assembly should be adjusted axially (in z) using the mechanical separation of two known fiducials (TBD). The separation required is first set using a shim machined to the appropriate thickness. The filter wheel is then translated until it contacts the shim positioned between the two surfaces, thus establishing its axial position.

c) The filter wheel is centered laterally using the alignment telescope. Using the filter wheel with the Lyot stop visible, the wheel should be centered so that the Lyot stop obscuration is centered in the alignment telescope crosshairs.

d) To confirm filter wheel angular alignment, autocollimate off of one of the highly-reflective filters installed in the wheel assembly. After any necessary tips and tilts of the wheel assembly, the autocollimation return should be roughly centered.

Steps b) though d) should be repeated until all conditions are met.

<u>Filter wheel alignment measurements:</u>

Lateral alignment, obscuration centered in alignment telescope ☐

Angular alignment (max. runout XXXmrad) ____________ ☐

<u>Required Equipment:</u>

Filter wheel assembly, pre-calibrated and tested as a unit prior to installation
Means of fine positioning of filter wheel

16) <u>NIRSPEC alignment:</u> Installation of chamber, confirm that window is nominally square to NIRSPEC baseplate and LOS.

After Keck-to-FPA alignment has been achieved, the final optical component in the NIRSPEC alignment is the optical window in the vacuum chamber wall. This is done late in the NIRSPEC integration process, and requires adjusting the baseplate inclination with respect to the chamber. Although this adjustment may be difficult to perform, the system's insensitivity to window misalignment may mean that alignment can be achieved via mechanical tolerances only. To check the window alignment, the testing steps would include:

a) Position the alignment telescope outside of the chamber location and aligning it to NIRSPEC LOS using the available alignment targets. If the chamber can be positioned without disturbing the original alignment platform, then this step should already be completed.

b) Position chamber walls with window installed. After installing the chamber and affixing it to the NIRSPEC plate, confirm that the window is approximately centered in the alignment telescope LOS. The window's clear aperture is oversized so that window centering is non-critical.

c) Using autocollimation, measure the deviation in the retroreflection from window surface. All surfaces, even AR coated surfaces, have a small but detectable retro-reflection. The autocollimation retroreflection should not be significantly off-center from the alignment telescope reticle.

Window tilt error (XXX mrad max.) ____________

d) If the window tilt is greater than the allowable budget, the baseplate-to-chamber isolation mounts must be adjusted in pairs to reset the tip/tilt of the chamber walls with respect to the NIRSPEC baseplate. Repeat steps a) through c) until an acceptable window orientation is achieved.

Required Equipment:

NIRSPEC chamber w/ installed window

Alignment Hardware List

Needed off-the-shelf hardware and recommended optional hardware for NIRSPEC alignment includes the following:

1 alignment telescope with autocollimation capability
2 alignment telescope stands
1 HeNe laser
1 HeNe laser beam expander and focusing optics assembly
1 laser mount w/X-Y adjustment
1 HeNe power meter
4 cross-hair targets
4 cross-hair target stands w/ X-Y adjustment
5 kinematic mounting baseplates (Thorlabs or Newport)
1 reflective mirror target, sized to fit in slit wheel mechanism
1 pellicle beamsplitter, 3" dia. or larger
1 beamsplitter mount w/ tip&tilt adjustment
1 shear plate tester, can be purchased from Melles Griot
Height gauge
Dial caliper and other measuring tools
Telescoping gauges
Two or three bright lamps, such as a halogen gooseneck lamp, for illuminating targets (makes them easier to see in alignment telescope).
Lens paper
Clean air source for blowing dust off of optics

Optional: 2nd alignment telescope
Optional: 1 large mirror (6"-8") in adjustable mount
Optional: 1 or 2 additional cross-hair targets
Optional: 1 additional reflective mirror target
Optional: 2 or 3 additional target stands
Optional: 1 or 2 additional kinematic mounting baseplates
Optional: 2-4 additional smaller mirrors and mounts