NIRSPEC

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

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NIRSPEC Optics Design Note 26.00
NIRSPEC Optomechanical System ATP

Table of Contents

1 Introduction

This document describes the procedures and contains the data which verify that the NIRSPEC optical system performs as specified. Much of the verification has already been described in other documents, i.e., the Speedring ATP, the SSG ATP, etc. In those cases, a summary of the results is given, and a reference to the original document is given.

2 Optics

This section gives the requirement, test setup and procedure, and test result for each item to be verified. X is horizontal, Y is vertical, and Z is along optical axis.

2.1 Transmission

2.1.1 Requirement

The original goal for instrument (includes detector QE) transmission was 15% for the blaze peak, as stated in the NIRSPEC proposal. After changing from NLM to QLM, and updating some of the other expectations for efficiency, the goal became 30%.

2.1.2 Test description and procedures

Total system transmission has been estimated by multiplying the transmission of individual elements.

Relative transmission can be measured by dividing flux values by some reference flux. For instance, the reference flux can be the total flux using the NIRSPEC-1 filter with the cross-disperser in zero order and the LRFlat inserted into the beam. All other flux measurements can be referenced to this value. Note that the continuum lamp source energy distribution is not flat. Instead, it can be approximated as a blackbody with temperature = XX K. Flux values will have to be corrected for this.

Set up the pinhole target. Illuminate the pinhole with the lamp source. Focus the target. Obtain images in each filter with the LRFlat and cross-disperser in the beam. Keep the cross-disperser in fixed orientation, $\alpha = 35°$. Extract the spectra using IRAF APALL, for example. Divide the spectrum by the blackbody function representing the lamp. Plot the curves.

Locate the echelle in its nominal position, $\alpha = 63.5°$. Obtain an echellogram image for each NIRSPEC filter. Repeat the data reduction described above.

2.1.3 Results

The results are given in NODN2700. The maximum efficiency for the optical train (window, w/o detector) is 49% in high resolution mode, 68% in low resolution mode, and 74% for the SCAM. The efficiency with the detector is: 40%, 54%, and 44%, respectively.

2.2 Focus - Spectrometer

2.2.1 Requirement

Best focus within 50 μm depth of field.

2.2.2 Test description and procedures

This is to be performed warm, without the window inserted in the beam. Set up the pinhole target at the Keck focal plane. Use the 10 μm diameter pinhole to ensure that the beam is properly filled. Insert the Lyot stop with the NIRSPEC-1 filter. Remove the slit from the beam. Insert the LRFlat. Arrange the cross-disperser in zero order. Illuminate the pinhole with the multi-fiber light source. Obtain an image. Adjust the light intensity until it will provide adequate S/N without saturating the detector when at best focus. Adjust the pinhole until it is located within a few pixels of the center of the field. Adjust the location of the pinhole in focus and xy until the most amount of flux is seen in a single pixel. This position represents the best focus. Measure the distance between the best focus position of the pinhole and the nominal position. This distance is a measure of how far out of focus the TMA is. Divide the distance by 32. This is the defocus at the TMA. If this number is less than 50 μm, then stop, otherwise adjust the TMA detector until it is within spec. Note that we can measure the distance between the K1 flange and the pinhole no better than about 1mm (or 30 μm at the TMA focal plane).

Verify that the final position provides adequate images of the slit. Insert the slit. Obtain an image and trace the intensity profile across the short axis of the slit. Ideally, we should quantify any relative defocus between the slit and the pinhole.

The TMA MUX is now in the proper focus position. Install the InSb detector. Cool the instrument.

Using the same setup as above, position the pinhole until it is in perfect focus in the InSb detector. Make sure to account for flat fielding by using a grey card. Best focus is achieved when the target is centered within a pixel, and the pixel has the highest value possible as a function of piston at the pinhole target. From this point on, this position defines all other NIRSPEC focal plane positions. This procedure assumes that the InSb array is located at the same place as the MUX when it is inserted. Once the pinhole is properly located, then the SCAM must be forced to focus on it.

2.2.3 Results

We did extensive testing with the TMA MUX to find the final focus position. We then verified final focus with the InSb detector at cryogenic temperatures. The image performance data verify final focus.

2.3 Focus - SCAM

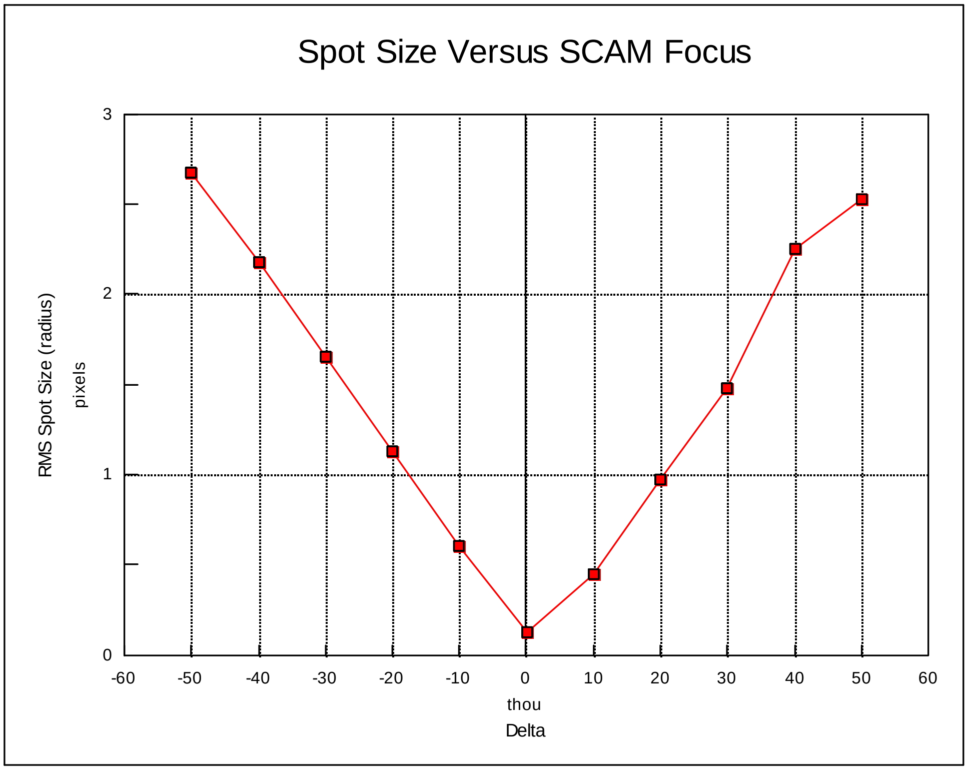
2.3.1 Requirement

2.3.2 Test description and procedures

The following is done warm with the MUX and with the window removed from the beam. Following the focus procedure for the spectrometer, position the pinhole at the location where the TMA has the best focus. Insert NIRSPEC-1 and a slit. Illuminate the pinhole with the multi-fiber light source. Obtain images with the SCAM at various SCAM focus positions bracketing the apparent best focus position. Analyze the data to determine the best focus position. Adjust the SCAM to this position. The warm Zemax model indicates that the detector should be placed 0.60 mm closer to the SCAM lenses than the position where λ = 0.98 μm light comes to a focus when warm. So, move the detector by 0.60 mm (= 0.024 inches).

Cool the instrument. Complete the spectrometer focus procedure described above.

Adjust the pinhole in xy until the greatest amount of flux is in one pixel near the center of the array. Adjust in focus until the central pixel obtains a maximum value. Record the focus position value as the best focus for the SCAM. The predicted relation between spot size and focus is given in the figure.



Using Zemax, estimate the required motion in focus at the SCAM detector so that the SCAM will be focussed for the pinhole position which satisfies the focus requirement at the spectrometer detector. The SCAM detector should be translated by this value. After this translation, repeat the procedure.

2.3.3 Results

We iterated the focus procedure with the MUX installed. Then we inserted the SCAM detector and cooled the instrument. After several iterations, we were able to adjust the SCAM focus until it was within tolerance. Final focus is verified by the SCAM image performance data.

2.4 Image Performance - Spectrometer

2.4.1 Requirement

80% enpixelled energy for λ $ 1 μm.

2.4.2 Test description and procedures

Place the pinhole at the Keck focus. Verify that it is located for best focus in the SCAM for the final SCAM focus position. Illuminate the pinhole with a white light source. Position the gratings for high-res mode. Use a short-wavelength filter. Obtain lamp on and lamp off images. Obtain a flat field image. Take the difference frame and divide by the flat. Find a location along one of the orders where the flux appears to be maximally concentrated in one pixel row. Divide the peak value (minus background level) by the sum of the peak value (minus background) and 4 times the average adjacent values (minus background); we use 4 because most of the flux which spills out of the central pixel will fall into the four immediately adjacent pixels.

2.4.3 Results

We used the following frames to get the final frame used for the enpixelled energy measurement: (21fes0004 ! 21fes0003)/(21fes0005 ! 21fes0007)*1e4. Table 2.4.3-1 gives the raw pixel data for one region of the image. Here we can see that most of the flux is located in row 537. The adjacent rows have much less flux. We can take the averaged values as representative of the flux levels. Using the formulation described above, we find EPE = 80%.

Table 2.4.3-1

row/ col	437	438	439	440	441	442	443	444	445	446	447	avg
540	502	173	-167	661	577	158	403	20	78	-129	507	253
539	87	736	58	0	586	480	106	502	250	-224	-49	230
538	226	437	218	286	643	180	284	684	796	267	551	416
537	2873	3560	3153	3390	3326	2847	3161	3376	3208	3023	3474	3217
536	578	323	517	20	236	169	484	517	753	279	158	367
535	-325	236	253	218	154	429	273	19	144	188	272	169
534	49	298	-58	346	233	176	-19	383	-10	10	99	137

2.5 Image Performance - SCAM

2.5.1 Requirement

80% enpixelled energy for λ $ 1 μm.

2.5.2 Test description and procedures

Insert a slit in the beam. Illuminate the pinhole with a white light source. Obtain an image with the SCAM detector. Adjust the light intensity until it will provide adequate S/N without saturating the detector when at best focus.

Obtain images for pinhole positions, spaced by 1 mm (equivalent to - 100 μm at the SCAM detector), bracketing the best focus position. Estimate the best focus position by finding the interpolated minimum in a plot of FWHM versus focus position. Locate the pinhole at this position. Measure the pixel values in a 5 by 5 pixel grid centered on the most intense pixel. Divide the pixel value of the brightest pixel by the sum of the pixel values; remember to subtract the background level from all pixels. Record this value as the enpixelled energy.

This test should be repeated cold. The best focus must be found again.

2.5.3 Results

Table 2.5.3-1 gives the enpixelled energy as a function of position at the SCAM detector. In all cases, the EPE is above 85%, well above the specification. The NIRSPEC-1 filter was used for these data. Figure 2.5.3-1 shows a surface plot of the region centered on pixel (38, 28). Note that the flux in neighboring pixels is very low compared to the peak value. The data are displayed in units of effective EPE. This is the enpixelled energy for each pixel if it were considered as the central pixel containing most of the flux from the pinhole image. The data have been corrected for non-linearity.

Table 2.5.3-1

image	Location		EPE %
	x	y	
23noi0012	136	142	86.0
23noi0016	180	17	92.5
23noi0017	38	28	92.7

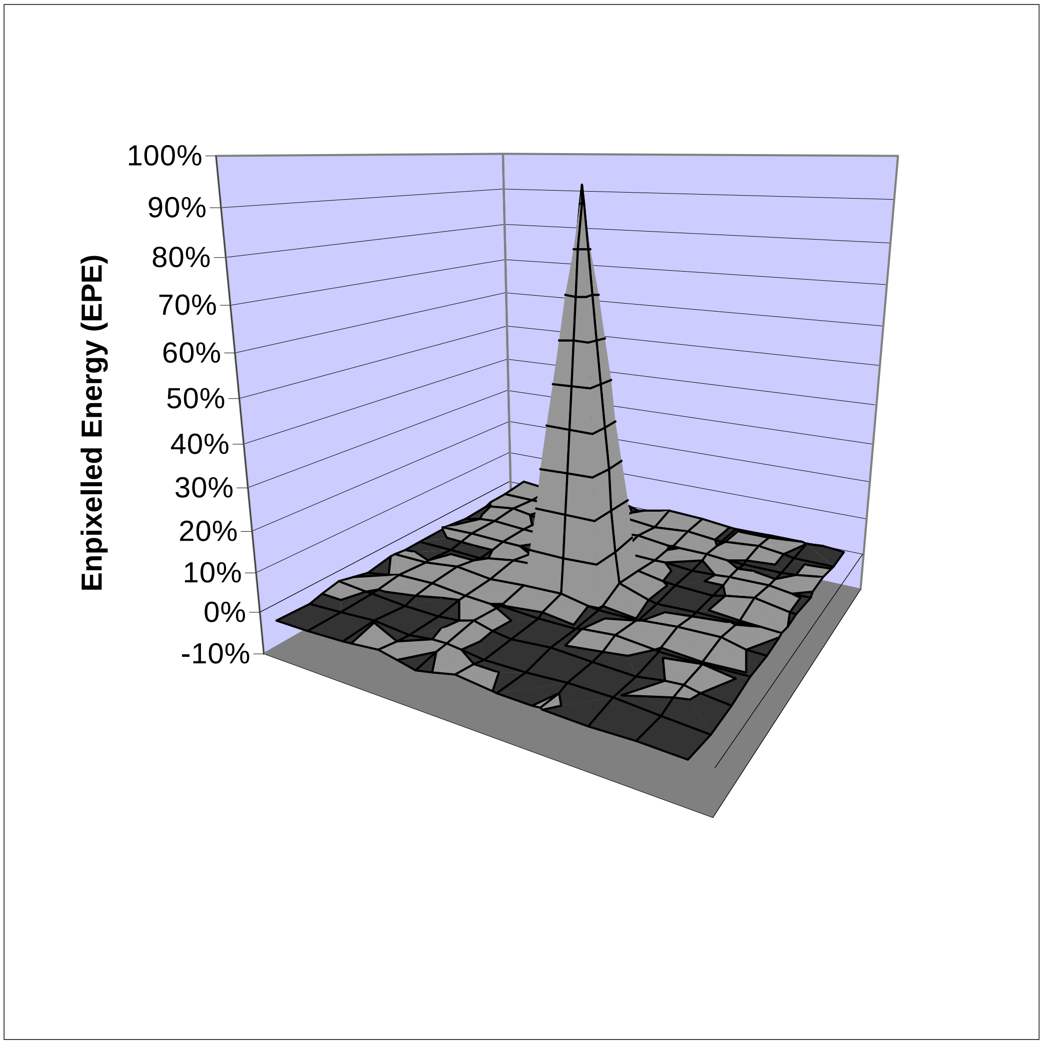


Figure 2.5.3-1

2.6 Resolution - Linear Dispersion

2.6.1 Requirement

Observationally, the ability to resolve two lines scales with $\lambda/\Delta\lambda_{\mathrm{FWHM}}$, where $\Delta\lambda_{\mathrm{FWHM}}$ is the FWHM of the profile from an emission line whose intrinsic width is much less than $\Delta\lambda_{\mathrm{FWHM}}$. Of course, $\Delta\lambda_{\mathrm{FWHM}}$ will depend upon the slit width (and other factors like image performance). A more useful number to know is the wavelength span of a pixel normalized by the wavelength, i.e., $\Delta\lambda_{1\ \mathrm{pixel}}/\lambda$; I will call this the inverse resolution. One could then multiply this number by the slit width, take the inverse, and get the slit-limited resolution. We shall attempt to measure this value in the following test. We expect a value equivalent to $\Delta\lambda_{1\ \mathrm{pixel}}/\lambda = 1.45(10^{-5})$, or $\lambda/\Delta\lambda_{2.8\ \mathrm{pixels}} = 24{,}700$.

2.6.2 Test description and procedures

The resolution will be verified by measuring the average inverse resolution across several echelle orders between 1.30 μm and 1.50 μm. To maximize the number of data points, all four arc lamps will be used (Ar, Kr, Xe, and Ne).

Insert a high-res slit into the beam. Turn on all four arc lamps. Obtain an image. (One could also obtain separate images, one per arc lamp, and then add the images together).

Locate the center of each slit image for lines from all four arc lamps and fit a gaussian across each emission line. Record the column number of the centroid of the fit. Identify the vacuum wavelengths of the various lines. Apply a separate linear fit to the wavelength centroids in each order. The slopes of the fits correspond to the wavelength coverage per pixel. Divide the slopes by the wavelength in the center of each order (pixel number 512). This is the inverse resolution.

2.6.3 Results

The following figure shows the lines which were imaged, along with the atomic species and linear fits.

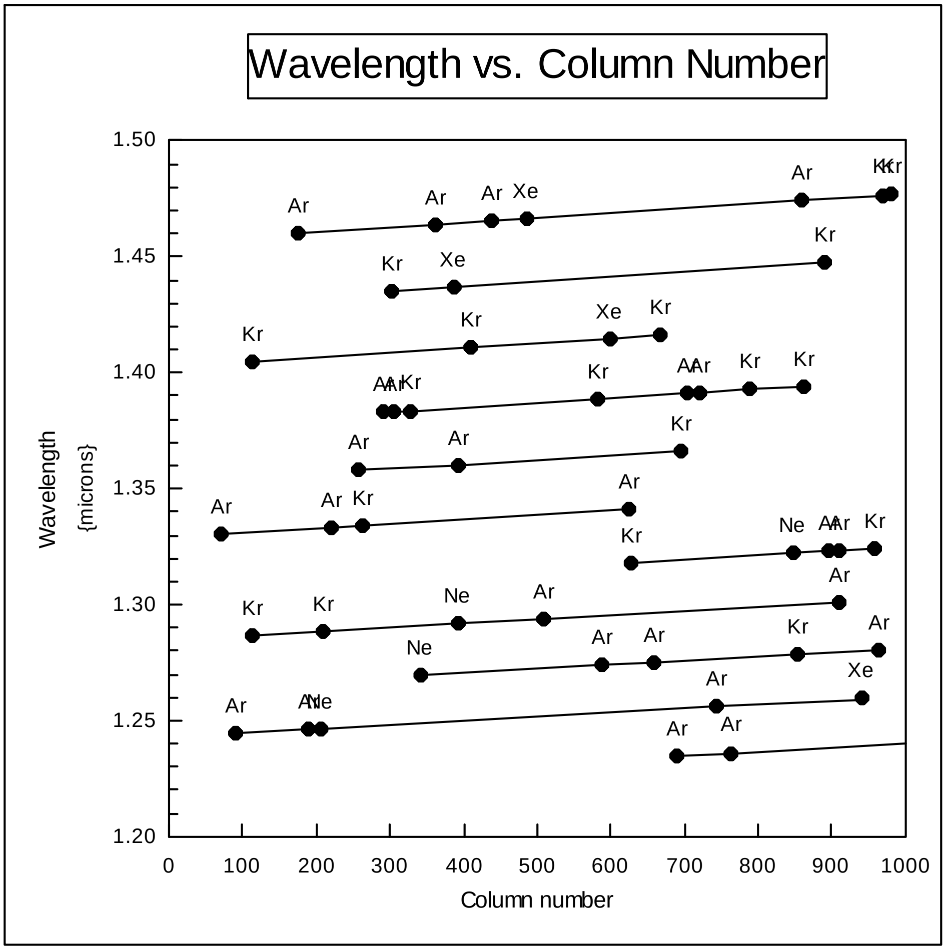


Figure 2.6.3-1

The following table gives the locations of line centers for all four lamps. Wavelengths are in microns. The inverse resolution is the wavelength span over 1 pixel (the slope of the fit) divided by the wavelength fit at column 512. The final results are as follows:

Average $\Delta\lambda_{1\ \mathrm{pixel}}/\lambda = 1.429(10^{!5})\pm1.5(10^{!7})$

DFF
Initials

Average Resolution (2.8 pix) = 24,991±250

DFF
Initials

We can use data from this experiment to judge how well we will be able to find the centroid of a target line, assuming that we can use all four arc lamps and find linear fits as we have done here. The relevant quantity is given in equation 1. This gives the mean error normalized for wavelength.

$$error = \frac{\sqrt{\frac{\sum(\lambda_{measured} - \lambda_{fit})^2}{\lambda_{fit}}}}{N-1} \qquad \textbf{(1)}$$

Equation 1 is similar to an inverse resolution. The inverse gives the "effective" resolution for measuring a centroid of a line. We should then expect to be able to measure velocity centroids to within error×c (where c is the speed of light). Given the measurements in the table, we find:

Resolution$_{\textbf{centroiding}}$ = 245,285 (or 1.22 km/s) DFF

Initials

Table 2.6.3.1-1

row number	column number	lamp	$\lambda_{measured}$	λ_{fit}	inverse res.	Res (2.8 pix)
order =	11					
930	175.23	Ar	1.46003	1.45991	1.44e-05	24828
930	361.00	Ar	1.46381	1.46383		
930	438.10	Ar	1.46540	1.46546		
930	486.76	Xe	1.46638	1.46648		
930	858.85	Ar	1.47431	1.47434		
930	968.57	Kr	1.47669	1.47665		
930	981.51	Kr	1.47697	1.47692		
order =	10					
830	302.31	Kr	1.43517	1.43515	1.44e-05	24862
830	387.86	Xe	1.43688	1.43692		
830	891.21	Kr	1.44733	1.44732		
order =	9					
735	112.45	Kr	1.40495	1.40492	1.41e-05	25308
735	410.60	Kr	1.41081	1.41087		
735	598.55	Xe	1.41460	1.41461		
735	668.21	Kr	1.41605	1.41600		
order =	8					
640	291.05	Ar	1.38298	1.38294	1.43e-05	24991

row number	column number	lamp	$\lambda_{measured}$	λ_{fit}	inverse res.	Res (2.8 pix)
640	304.89	Ar	1.38326	1.38322		
640	327.78	Kr	1.38364	1.38367		
640	581.57	Kr	1.38864	1.38870		
640	704.93	Ar	1.39112	1.39115		
640	720.49	Ar	1.39146	1.39146		
640	787.26	Kr	1.39278	1.39278		
640	861.04	Kr	1.39429	1.39424		
order =	7					
550	257.07	Ar	1.35773	1.35771	1.42e-05	25116
550	391.64	Ar	1.36029	1.36032		
550	695.31	Kr	1.36621	1.36620		
order =	6					
467	69.91	Ar	1.33060	1.33056	1.40e-05	25432
467	221.09	Ar	1.33340	1.33340		
467	262.53	Kr	1.33412	1.33418		
467	625.36	Ar	1.34102	1.34100		
order =	5					
388	628.68	Kr	1.31810	1.31810	1.46e-05	24507
388	847.95	Ne	1.32229	1.32230		
388	894.23	Ar	1.32321	1.32319		
388	908.76	Ar	1.32350	1.32347		
388	959.32	Kr	1.32441	1.32444		
order =	4					
312	113.70	Kr	1.28654	1.28649	1.42e-05	25102
312	208.38	Kr	1.28825	1.28823		
312	392.30	Ne	1.29155	1.29162		
312	508.47	Ar	1.29369	1.29375		
312	910.30	Ar	1.30120	1.30115		
order =	3					

row number	column number	lamp	$\lambda_{measured}$	λ_{fit}	inverse res.	Res (2.8 pix)
232	341.30	Ne	1.26927	1.26924	1.43e-05	24912
232	587.23	Ar	1.27371	1.27373		
232	657.50	Ar	1.27498	1.27501		
232	854.58	Kr	1.27859	1.27860		
232	963.33	Ar	1.28062	1.28059		
order =	2					
158	90.70	Ar	1.24426	1.24422	1.42e-05	25155
158	188.65	Ar	1.24595	1.24596		
158	207.44	Ne	1.24628	1.24630		
158	743.84	Ar	1.25579	1.25583		
158	939.64	Xe	1.25934	1.25931		
order =	1					
80	689.26	Ar	1.23471	1.23472	1.44e-05	24722
80	762.00	Ar	1.23602	1.23601		
80	1021.58	Ar	1.24063	1.24063		

2.7 Resolution - Instrumental Profile Width

2.7.1 Requirement

Another way to think about resolution is the minimum separation between two resolved lines. The criterion for “resolved” is somewhat arbitrary. For instance, one could use the Rayleigh criterion for diffraction-limited systems where two barely resolved lines are separated by the distance between the peak and first dark ring of the line. Another criterion would demand that the lines are separated by the FWHM of the line. There are other criteria, i.e., the Sparrow condition would say that two lines are barely resolved if their combined intensity profile has a flat peak.

In any case, such definitions are all dependent on line width. Therefore, we will measure the individual line widths as a function of slit width in this experiment.

2.7.2 Test description and procedures

Obtain spectral images with various slits inserted into the beam and various arc lamps illuminating the slit. It doesn’t really matter which lamps are used, but it is best to have as many arc lines in the final images.

Measure and record the FWHM of the arc lines.

2.7.3 Results

The final data are given in section 2.10.

2.8 Plate Scales and Distortion - Spectrometer

2.8.1 Requirement

None.

2.8.2 Test description and procedures

Before writing this section, we need to see if a target at the slit focal plane can be sufficiently illuminated so that its image is well-defined at the TMA MUX.

Place a target with an evenly spaced grid of pinholes at the slit focal plane, making sure that it is roughly square to the gut ray and at the true slit focus. Set the echelle mechanism such that the LRFlat is in the beam. Direct laser light into the A/T via a multifiber bundle, or by directly illuminating the reticle input port. Focus the A/T at infinity. Insert AF3 with the alignment mirror affixed. Set the cross disperser mechanism such that $\alpha=25°$ (See A.4).

Take images at the TMA MUX with the surface of the cross disperser covered by kim wipes. Note that one need not strictly use laser light because we are using all mirrors in this setup.

2.8.3 Results

2.9 Plate Scales and Distortion - SCAM

2.9.1 Requirement

None.

2.9.2 Test description and procedures

Set up the SCAM distortion target at the Keck focal plane, making sure that it is square to the optical axis and that the central hole is on the rotation axis of the IROT. Image the target with the SCAM. Adjust the backlighting as necessary in order to obtain reasonable contrast without saturating.

Measure and record the centroids of each pinhole image, for instance using IRAF. The plate scale at each point can be calculated by dividing the known angular distance between neighboring pinholes by the corresponding distance in pixels. This calculation should be done for each axis according to equation 2, where x is the pixel number of the centroid and Δ is the angular separation of the pinholes at the distortion target.

$$P_{i,j}=\left[\frac{1}{2}\left(\frac{x_{i,j}-x_{i-1,j}}{\Delta}+\frac{x_{i+1,j}-x_{i,j}}{\Delta}\right)\right]^{-1}. \qquad \textbf{(2)}$$

The distortion is the deviation in position of the pinhole image from what is expected. The distortion can be expressed by equation 3, where x is the location of the centroid along one axis in pixels, $P_{central}$ is the plate scale at the center of the array, and θ is the angular separation at the Keck focal plane between pinhole i,j and the center of the field.

$$D_{i,j}=(x_{i,j}-x_{central})\frac{P_{central}}{\theta_{i,j}}. \qquad \textbf{(3)}$$

Calculate and record the plate scales and distortion values.

2.9.3 Results

2.10 Slit Sizes

2.10.1 Requirement

Verify slit dimensions for purposes of documentation. Should be done in spectrometer detector and the SCAM detector pixel units.

2.10.2 Test description and procedures

Obtain an image for each slit. Use the arc lamps to measure the slits in high-res mode. Make sure that $\alpha = \beta$, so that there will be no anamorphic magnification from the echelle. Image each high-res slit. Measure and record the FWHM. Note that this test measures the net slit width along the wavelength axis without compensating for any apparent tilt of the slit. Repeat the same experiment for the low-res slits, but this time, insert the low-res flat and move the cross-disperser so that $\alpha_{CD} = 35°$. Measure and record the FWHM.

Refer the measurements to arcseconds using the focal lengths given in NODN2100, i.e., 1 pixel corresponds to 0.145 arcseconds along the slit width direction in high-res and 0.191 arcseconds along the slit width direction in low-res. For the SCAM measurements, it will be easiest to measure the width along columns and then multiply the values by cos(15°) to get the true slit width along the shortest axis. The conversions to arcseconds assumes a plate scale of 0.18 arcseconds per pixel (NODN0301).

2.10.3 Results

Table 2.10.3-1 lists the measured FWHM for all slits. Data from February 5th were used for the spectrometer measurements in high-res mode. Data from February 4th were used for the SCAM measurements; these values reflect multiplying by cos(15°) for the high-res slits.

Table 2.10.3-1

Slit Name	SCAM		Spectrometer	
	pixels	arcseconds	pixels	arcseconds
12X0.144*	2.3	0.41	1.7	0.24
12X0.288	2.0	0.36	2.0	0.30
12X0.432	2.6	0.47	2.7	0.40
12X0.576	3.2	0.57	3.5	0.52
12X0.720	3.7	0.66	4.5	0.65
24X0.432	2.6	0.47	2.7	0.39
24X0.576	3.1	0.56	3.6	0.52
24X0.720	3.8	0.68	4.5	0.66
42X0.380	2.5	0.44		
42X0.570	3.2	0.58		
42X0.760	4.0	0.72		
*Note that the error on the FWHM for this slit is on the order of the slit width because the sampling is so sparse.				

2.11 Gratings - Groove Densities

2.11.1 Requirement

The groove densities were selected from the list in the Spectronic, Inc., catalog. There is no formal requirement.

2.11.2 Test description and procedures

2.11.2.1 Echelle

Position the filter wheel so that the laser beam can be transmitted through the system. Remove the slit. Adjust the laser so that it is roughly along the axis. Insert the LRFlat. Locate a cross-hair target between the slit and the OAPC, nearer to the latter. Adjust the target, in height, so that the laser beam strikes the center of the target. Now, move the target to a location near the entrance of the TMA. Adjust the LRFLAT, in azimuth, until the laser beam strikes the center of the target. This procedure ensures that the laser beam is normal to the y-axis of the LRFLAT. It assumes that the target can be rested on a surface which does not change height between position 1 and position 2. This assumption has little impact on measurement error.

Flip the echelle/LRFLAT mechanism by 180°. The laser spot nearest the center of the cross-hair should correspond to zero order. Tweak the position of the echelle until the spot is on the center of the cross-hair. This position corresponds to α=0°. Record the step number of the mechanism. Rotate the echelle to α=63°. Tweak the echelle until the brightest laser spot strikes the center of the target. This condition should happen for α=63.08°, assuming that the groove density (T) is 23.2 l/mm. Note that this assumes order = 121. It might be difficult to find the right spot, because the spot for order = 122 is equally separated from the nominal blaze peak. It resides at α=64.03°. So, those two spots will be equally bright. Hopefully, the groove density will be close enough to specification so that it will be obvious which spot is aligned.

Find the difference in the new step number and the recorded step number. The angle moved is (delta steps)/300 in degrees. Using the grating equation, calculate the groove density:

$$T = \frac{2\sin(\theta)\cos(\gamma)}{m\lambda}. \tag{4}$$

This assumes that γ = 5°. Recall that λ_{HeNe} = 632.8 nm in air. This is the warm groove density, and it should be close to the specified value of 23.2 l/mm. To get the cold value, divide T by 0.9963, the contraction rate of aluminum. Record this as the cold groove density.

2.11.2.2 Cross-disperser

For the cross-disperser, $\gamma = 0°$, so the beam can be returned on itself without using a downstream target. This simplifies the procedure greatly. Using the appendix, adjust the cross-disperser until it provides autocollimation for orders 0 through 8, starting with order 8. As an aid, insert an acetate sheet into the reflected beam located at one of the primary baffles. This will make it easier to see when the reflected beam is truly retro-reflected. Record the mechanism position, in step number, for each order. Record the angular separation between each position assuming that the angle is (delta steps)/200 in degrees. We now have 8 similar equations, each of the following form:

$$\theta_i - \theta_j = asin(m_i \lambda T/2) - asin(m_j \lambda T/2). \tag{5}$$

Find the solution for T which produces the minimum deviation from our measured deltas. Record this as the warm groove density. Again, multiply by 0.9963, and record the result as the cold groove density.

2.11.3 Results

2.11.3.1 Echelle

Table 2.11.3.1-1 gives the recorded step numbers corresponding to the echelle position which locates the m=0 and m=121 orders of the HeNe light onto the cross-hair of the target. The "mechanism angle" gives the software angle on the mechanism corresponding to the two positions. There appears to be a small offset between the "mechanism angle" and true α.

Table 2.11.3.1-1

step number	mechanism angle	$\alpha_{echelle}$	$m_{echelle}$
! 10	0°.033	0°.000	0
! 18940	63°.133	63°.100	121

We estimate an error of 10 steps (or 0°.033 in α), primarily due to the difficulty in determining whether the laser spot is truly on the cross-hair target. Equation 5 gives:

$T_{echelle, warm}$ = 23.205±0.007 l/mm

DFF
Initials

$T_{echelle, cold}$ = 23.291±0.007 l/mm

DFF
Initials

2.11.3.2 Cross-disperser

Table 2.11.3.2-1 gives the difference in steps between adjacent orders, where we started with order 8 and proceeded to smaller order numbers. This ensured that the anti-backlash algorithm would not be used in making moves, i.e., all moves where in the same direction. So, we moved !273 steps in order to go from light in order 8 being retro-reflected to light in order 7 being retro-reflected. The mechanism angles were not recorded.

Table 2.11.3.2-1

order	step number
1	!280
2	!280
3	!273
4	!270
5	!280
6	!274
7	!273
8	0

Equation 5 gives 28 independent equations, each representing the spacing, in steps, between the 8 positions in the table. We can simultaneously solve these equations to get the best fit for T, weighting the residual for each equation according to the difference in order number. The error is taken as the square root of the sum of the squares of the measured minus predicted (equation 5) delta angles, divided by the number of independent equations.

We find a best fit for:

$T_{CD, warm}$ = 75.465±0.00036 l/mm

DFF
Initials

$T_{CD, cold}$ = 75.745±0.00036 l/mm

DFF
Initials

2.12 Etalon Spacing

2.12.1 Requirement

No requirement. Measure the etalon spacing by using data from NIRSPEC.

2.12.2 Test description and procedures

With NIRSPEC fully operational, obtain spectrometer images with all arc lamps turned on. Without changing the instrument setup, obtain a similar image with the calibration unit configured to transmit the continuum source light through the etalon system. Choose two arc lamp lines in the first image which are separated by roughly the number of pixels between two adjacent etalon lines in the second image. Identify the arc lines in our line lists. Calculate the linear dispersion based upon these two lines. Find the wavelength of the etalon line nearest to the first arc line by measuring the distance between the two in pixels and using the estimated linear dispersion. Using the etalon equation, calculate the likely order number for this etalon line. Increment this order number by 1 for each subsequent etalon line. Now simultaneously solve the etalon equation while allowing the etalon thickness to vary. Make sure that the order numbers are fixed. Notice that this procedure assumes that we already know the etalon spacing fairly well so that we can get the order numbers in the first place. Also, note that the linear dispersion we calculate from the arc lines is not constant due to the various distortions in the pixel-wavelength relation. In any case, the relation should give a good fit over a small region surrounding the arc lines.

2.12.3 Results

Table 2.12.3-1 gives results using 05fes0013.fits (all arc lamps on) and 05fes0014.fits (etalon). NIRSPEC-4 was inserted into the beam. Two Krypton lines were used to estimate the linear dispersion: 1.440651 μm and 1.443087 μm in vacuum. They are located at pixel column number 469.502, and 589.874, respectively and pixel row number 695. The estimated linear dispersion and resolution is 2.023448E-05 μm/pixel and 71,197.8 (per pixel). Wavelength1 is in air and is given by the pixel position and linear dispersion, whereas Wavelength2 is in air and is given by the etalon equation assuming a best fit etalon thickness. Note that the fit seems to get progressively worse as the distance from the line at pixel 482.797 increases. This is probably due to the slowly varying linear dispersion as described in the section above. I tested the inferred etalon thickness

The final best etalon thickness is given below.

$$\Delta T_{\mathbf{etalon}} = \mathbf{1.091199\ mm}$$

DFF

Initials

Table 2.12.3-1

Etalon Order	Pixel #	Wavelength 1	Wavelength 2	Error
		μm	μm	μm
1516	435.968	1.439580	1.439577	2.9143E-06
1515	482.797	1.440527	1.440527	4.9885E-10
1514	529.678	1.441475	1.441478	3.1167E-06
1513	576.231	1.442409	1.442431	2.2585E-05
1512	622.473	1.443373	1.443385	1.2478E-05
1511	668.907	1.444341	1.444340	3.6802E-07

3 Optomechanics

This section gives the requirement, test setup and procedure, and test result for each item to be verified.

3.1 Static boresight

3.1.1 Requirement

The beam shall not deviate by more than 1 mm for the full field on any element in the system.

3.1.2 Test description and procedures

Square the A/T to the IROT boresight. Insert acetate cross-hair target at the front-end pupil location. Verify that the target is centered by sighting through the A/T. Insert a “large” pinhole at the Keck focus. “Large” means that diffraction effects are minimal (anything larger than 10 μm would do). Align the laser so that the laser light passes through the pinhole and strikes the cross-hair. The laser now defines the boresight for NIRSPEC.

Measure the offset between the laser spot at the OAPC and the center of the aperture. This can be done with calipers or a height gauge.

Insert AF1 onto the front of the LRFLAT. Sight through the A/T to make sure that the LRFLAT is properly positioned, i.e., AF1 is centered on the A/T cross-hair. Simultaneously, adjust the LRFLAT mechanism in altitude and azimuth until AF2 can be sighted by eye through the system, and the reflection of AF1 through AF2 is properly centered. Now, the LRFLAT is aligned in x, y, α, and β. The cross-disperser is only rough aligned because we have used AF2 instead of the surface of the CD. To fine tune the CD alignment, remove the alignment fixtures, and re-install the laser. Adjust the CD in azimuth until the seventh order light is retro-reflected back into the system. Adjust the CD in altitude until the reflection of the laser spot falls on itself at the back of the slit. Now, the CD is adjusted in x, y, α, and β.

Record the offsets and angles for each element using the alignment fixtures.

Install the TMA. Insert AF3. Adjust the TMA in x, y, until AF3 is properly centered along the line of sight. The line-of-sight can be directly visualized by the unaided eye. Align the eye to the cross-hair acetate target at the pupil plane and to the cross-hair of AF1.

Insert the pinhole target at the Keck focal plane. The pinhole must be small enough to induce diffraction effects to populate the pupil. Center the pinhole in the A/T. Insert the laser and illuminate the pinhole. Adjust the CD so that it is retro-reflecting the beam back onto itself in 7th order. Now rotate the CD in azimuth by X° (+5200 steps) so tha the 7th order light is falling on the MUX. Obtain an image. Adjust the tilt of the CD until the spot is within 1 mm of the central pixel.

Install the primary back-end baffles using the baffle alignment fixture. With the laser in the system, install baffle #1 such that the cross-hair on the fixture is aligned to the laser beam. In this experiment, the pinhole should be large enough so that diffraction is minimal. Adjust the baffle in clocking motion (γ) until the horizontal cross-wire is coincident with the laser beam after it has reflected off the LRFLAT. The final alignment can be examined by inserting a small pinhole at the focus, limiting the pupil beam diamater with the Lyot stop, and then illuminating the pupil. The room must be very dark in order to see the laser beam throughout the system. A piece of paper can be taped to the baffle aperture to verify beam position. A hand-held CCD camera can be used to obtain verification data.

3.1.3 Results

The laser was inserted into the beam according to the procedures above. Offsets were measured at each alignment fixture. The x-axis is orthogonal to the beam and lies in the plane of the optical plate and the y-axis is orthogonal to the beam and is perpendicular to the optical plate. Positive for x means toward the left when standing and facing the instrument, i.e., the echelle lies at positive x. Positive for y is up. Note that these measurements are with respect to a local coordinate system defined by the center of the optic in question. Also, the offset coordinates describe the location of the beam with respect to the center of the optic.

Table 3.1.3-1

	X	Y
OAPC	+1.0 mm	!1.0 mm
echelle	!1.0 mm	!1.0 mm
CD	+1.0 mm	+1.5 mm
TMA	!0.5 mm	+2.0 mm
Detector	< ±1.0 mm	< ±1.0 mm

DFF
Initials

The primary baffles were inserted by affixing the baffle alignment mask to each baffle in turn.

DFF
Initials

3.2 Image Wander

3.2.1 Requirement

The image should not wander by more than 1 spectrometer pixel (75 μm) at the slit plane.

3.2.2 Test description and procedures

Insert the pinhole at the nominal Keck focal plane (55.515 mm in front of the K1 front flange). Translate the pinhole until its image is located off-center in the SCAM detector. Take a long exposure while the IROT is rotating. Measure the center of rotation in the SCAM image. This location corresponds to the rotation axis of the IROT.

Locate the pinhole on the IROT axis, as obtained by the above experiment. Take another long exposure while rotating the IROT. Measure the FWHM of the resultant image. This blur size represents image wander at the slit plane.

3.2.3 Results

Record the pixel coordinates of the rotation axis at the SCAM. 133 131
X Y

Note that the pixel numbers are based on a system which starts at 1, not zero.

Record the FWHM of the blur spot. < 1 pixel
FWHM

DFF
Initials

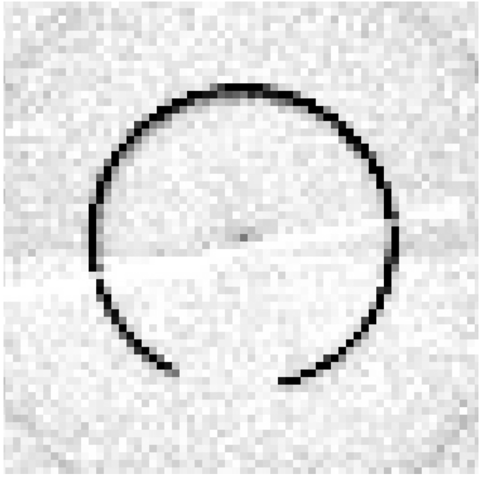


Figure 3.2.3-1. A SCAM image of the arc pattern produced by taking a long exposure while illuminating a pinhole at the Keck focus, while rotating the image rotator. The dot in the center coincides with the rotation axis. Notice the image of the slit.

3.3 Guider Camera Alignment

3.3.1 Requirement

none

3.3.2 Test description and procedures

See NODN2801.

3.3.3 Results

Measure & record the pixel coordinates of the Nikon lens axis.

________	________
X	Y

______
Initials

A. Common Setup Procedures and Alignment Aids

A.1. Alignment telescope (A/T)

The A/T line-of-sight must be aligned along the NIRSPEC optical axis. See NODN10.00, section 4a.

A.2. Pinhole at Keck focus

There are three pinholes which are used in the test plan.

The first is part of the Keck focal plane target. It is really used as an alignment aid, i.e., it does not induce appreciable diffraction because its holes are too large (diameter = 0.011 inches). It is usually aligned with the optical axis at the Keck focal plane, providing a reference point for the laser. The laser beam can then be pointed at the pinhole and another downstream reference point to ensure that the beam is along the NIRSPEC axis. Once this is done, the pinhole target can be removed, and a smaller pinhole can be inserted.

The second pinhole, the 10 μm pinhole, is used because it does significantly diffract the beam. This pinhole is also situated at the Keck focal plane and along the optical axis. The focal plane is located at 55.515 mm from the front surface of K1 when the dewar window is not in the beam. The laser beam is aimed so that the light is along the optical axis. It is important that the pinhole be orthogonal to the beam to produce an even illumination of the beam (if that is important). The altitude/azimuth and x/y micrometers can be adjusted to establish this condition.

The third pinhole is used at the front of the laser to attenuate the beam intensity. We have found that the 50 μm pinhole, positioned at the laser front face, is ideal for producing a beam which is faint enough (after having gone through pinhole #2) so that the SCAM MUX does not saturate. The final intensity is a function of the distance between the output from pinhole #3 and the input of pinhole #2, as the beam is diverging out of pinhole #3. We have found that a separation of 6 inches is ideal (any closer and the MUX will become saturated for even short exposure times). Normally, the A/T will prevent the laser from being positioned so far back from the Keck focal plane target, so a fold mirror has to be inserted. This way, the laser light reflects off the fold mirror at 45° and is directed into pinhole #1.

A.3. Alignment fixtures

There are three alignment fixtures. AF1 is a scribed T-bracket which bolts to the flange of the LRFLAT. AF2 is a scribed L-bracket which bolts to the cross-disperser mounting plate. AF3 is a rectangular bracket which bolts to the side input port of the TMA. The brackets were designed such that the instrument line-of-sight passes through the center of the scribes for operation with the LRFLAT in the beam. The cross-disperser must be arranged so that $\alpha=\beta=0°$ for the scribe target to be in proper position.

A.4. Targets

The TMA focal plane target is a polished aluminum mirror with an evenly spaced grid of scribe lines. Each scribed box is numbered, and the center and corner boxes have cross hairs scribed within them. More detail can be found in the SSG ATP.

The pinhole target has 10 small holes (diameter = 0.011 inches) drilled into it. A drawing is given below.

The SCAM distortion target has a grid of 11 by 11 pinholes (diameter = 1 mm) drilled into it.

A.5. Cross-disperser settings

To set up the cross-disperser for auto-collimation mode, set the cross-disperser angle according to the following table for HeNe light ($\lambda_{\text{HeNe, air}}$ = 632.82 nm). For near-autocollimation, the 8th order produces the last bright spot upon diffraction. The 9th order light is very faint. This table can be used to determine a fiducial position in azimuth for the cross-disperser.

Table A.5.-1

order	α=β=
1	1°.3598
2	2°.7204
3	4°.0825
4	5°.4469
5	6°.8144
6	8°.1859
7	9°.5620
8	10°.9438

To move to another setting of the cross-disperser, use the values in the following table. Note that the cross-disperser mechanism moves 200 steps/°. For example, in moving from 7th order autocollimation to 7th order operational position, the cross-disperser should be rotated by (35°.5613 − 9°.5620)*200 = +5200 steps.

Table A.5.-2

order	α	β
1	26°.5004	−23°.4996
2	28°.0018	−21°.9982
3	29°.5053	−20°.4947
4	31°.0120	−18°.9880
5	32°.5228	−17°.4772
6	34°.0388	−15°.9612
7	35°.5613	−14°.4387
8	37°.0914	−12°.9086

B. Summary Table

Table 1: ATP Test Summary

Section	Item	Spec.	Goal	Measured	Referring Documents
2.1	Transmission - Spec	19%	30%	40%	NODN2700
2.1	Transmission - Scam	N/A	N/A	44%	NODN2700
	Scattering	negligible	N/A	low surface roughness	BRO report, SSG ATP, & SR ATP
	Plate scales/distortion				
	Spectrometer	N/A	$0^0.2$ X $0^0.2$/pix	$0^0.15$ X $0^0.19$/pix	NODN2100
	SCAM	$0^0.2$/pix	N/A	$0^0.2$/pix	
	Boresight	< 1 mm	N/A	< 1 mm	
	Image performance				
	Spectrometer	> 70% EPE	> 80% EPE	> 80% EPE	
	SCAM	N/A	> 80% EPE	> 80% EPE	
	Image wander	r < 1 pixel	N/A	r < 1 pixel	NODN0700