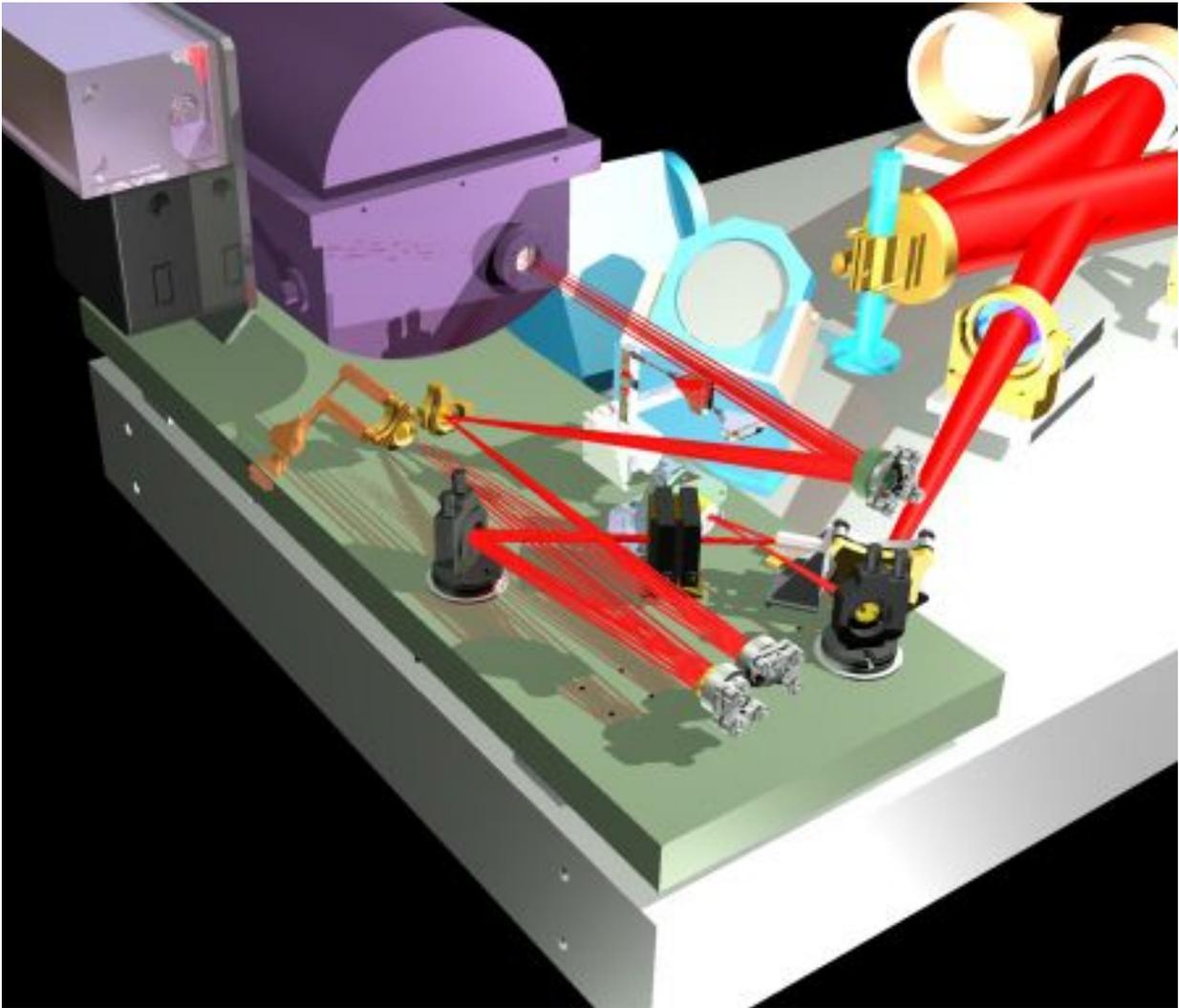


# Project 1640

## Design and Operations Documentation



Version 0.1  
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### Project 1640 Participants

Ben R. Oppenheimer	AMNH
Sasha Hinkley	AMNH
Douglas Brenner	AMNH
Ian Parry	IoA
Anand Sivaramakrishnan	AMNH
Remi Soummer	AMNH
Andrew Brown	AMNH
Neil Zimmerman	AMNH
Antonin Bouchez	Caltech
Jenny Roberts	Caltech
Richard Dekany	Caltech
Kent Wallace	JPL
Lynne Hillenbrand	Caltech
Charles Beichman	MSC/JPL
B. Martin Levine	JPL
Mike Shao	JPL
Dan McKenna	Caltech/Palomar

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<b>Items to add:</b>
More info on apodizer, and Remi's design document?
Tip/tilt system: rack pictures
Software inventory subsection
Procedure for on telescope fill.
ADC equations and algorithm.
SAN4 data structure
De-installation procedure
Software guide
Calibrations needed.
Pictures needed: pictures of all cabling.
Specs on Tip/tilt mirror
Ian's calculations.
Fix image orientation image.

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## 1. Introduction

Project 1640 is a complex astronomical instrument designed to produce images of the environments in close proximity to nearby stars with unprecedented contrast. This document describes the design of the system from the point of view scientific reproducibility. The driving requirements on the performance led to the following table summarizing the instrument's operational capabilities and modes of operation, in conjunction with the Palomar Adaptive Optics System.

### 1.1. System Operating Capabilities

Project 1640 is the first-ever Infrared diffraction limited Integral Field Spectrograph fed by an Apodized Pupil Lyot Coronagraph (APLC) and coupled to a high order Adaptive Optics System. The lenslet-based spectrograph covers both J and H bands (1.05 – 1.75  $\mu\text{m}$ ), and samples the 4.2 arcsec field of view with a 21mas/lenslet platescale. Our diffraction limited APLC can achieve suppression of  $10^{-5}$  at 1 arcsec as demonstrated by our results from the Lyot Project Coronagraph and the Gemini Planet Imager (GPI) testbed.

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<b>Property</b>	<b>Project 1640 IFU + Coronagraph</b>
Wavelength coverage	1.05- 1.75 $\mu\text{m}$ , $\Delta\lambda = 0.7 \mu\text{m}$
Central wavelength	1.403 $\mu\text{m}$
IFU FOV	4200 mas
Platescale	19.2 mas/lenslet
Total spectra	200 x 200 = 40,000
Pixels per spectrum	3.2768 x 32
$\Delta\lambda$ per 2 pixels	.044 (.7 $\mu\text{m}$ /32 pix)
$R = \lambda/\Delta\lambda$	32
Lenslet Pitch	75 $\mu\text{m}$ (chosen for manufacturing issues)
Input f/ratio from coronagraph for $\lambda/2D$ Spaxels at 1.0 $\mu\text{m}$	$f = 143.21$
Focal Plane Mask size	5.6 $\lambda/d$
Optimal coronagraph wavelength	1.65 $\mu\text{m}$
Apodizer throughput	51%
	<b>Palomar 3000 Actuator AO System</b>
Telescope Diameter	$D = 5.10 \text{ m}$
$\theta_{\text{AO}} = N_{\text{act}}\lambda/2D$ (1-1.8 $\mu\text{m}$ )	1010 to 1818 mas
$\lambda/2D$ at 1.05 $\mu\text{m}$	21.21 mas
Current Output f/ratio	15.4
Date Available	March 2010 1.5 m subaperture with 90% Strehl usable in August 2008?

## 1.2. Acronyms Used

The following is a list of all acronyms or abbreviations used in this document.

ADC	Atmospheric Dispersion Correction (Correction for what is sometimes
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	called “Differential Atmospheric Refraction”)
AMNH	American Museum of Natural History
AO	Adaptive Optics
APLC	Apodized-Pupil Lyot Coronagraph
Caltech	California Institute of Technology
FOV	Field of View
FPM	Focal Plane Mask
FSM	Fast Steering Mirror
GPI	Gemini Planet Imager
IFU	Integral Field Unit (spectrograph)
IWA	Inner Working Angle
JPL	The Jet Propulsion Laboratory
LN2	Liquid Nitrogen (N <sub>2</sub> )
P1640	Project 1640 (including IFU, Coronagraph and control/acquisition system)
P3k	The Palomar 3000 actuator AO system
PCB	Printed Circuit Board
TCS	Telescope Control Software
TT	Tip-Tilt system
ZIF	Zero-Insertion Force

## 2. Design

### 2.1. Coronagraph

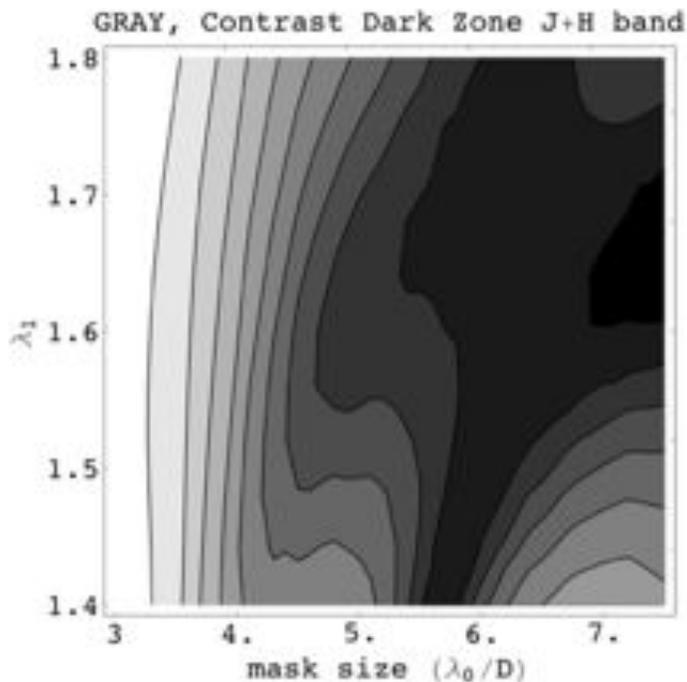
To suppress the starlight of our target stars, we have built an apodized-pupil Lyot coronagraph (APLC) based on the designs of Sivaramakrishnan (2001) and Soummer (2003, 2005). We achieve our suppression with the combination of an apodizing mask, a Focal Plane Mask, and a pupil plane Lyot mask. This section describes in detail the design and optimization of our APLC which can theoretically achieve a suppression of  $10^{-6}$  at  $5\lambda/D$ . Our design is further constrained by the  $f/15.4$  Palomar Input beam, space constraints on the PALAO bench and the  $75\ \mu\text{m}$  lenslets pitch. Our focal plane mask (FPM) is reflective, with a  $1322\ \mu\text{m}$  diameter hole. We use the hole as an opaque mask and let the unocculted portion of the image around the hole be reflected on to the rest of the optical train. The light that has passed through the hole is used to drive our tip-tilt system using a set of four infrared Hamamatsu photodiode sensors. The center of the stellar image is maintained on the sensors using a centroiding algorithm in conjunction with a control loop working with our fast-steering mirror (FSM). Our fast steering mirror is updated at a  $\sim 1$  kHz frequency to maintain the position of the star on the center of the spot.

To determine the best combination of mask parameters for the APLC, we have optimized our mask characteristics by calculating the expected contrast and PSFs for the system. Considering just the H-band along, ignoring the J-band, we identified a very good solution for the H-band which is also acceptable at J. We have found, however, that optimum solutions for the combination of J and H bands exist, but they require masks that are much larger, impacting the inner working angle (IWA) too much. In addition, the AO system will not

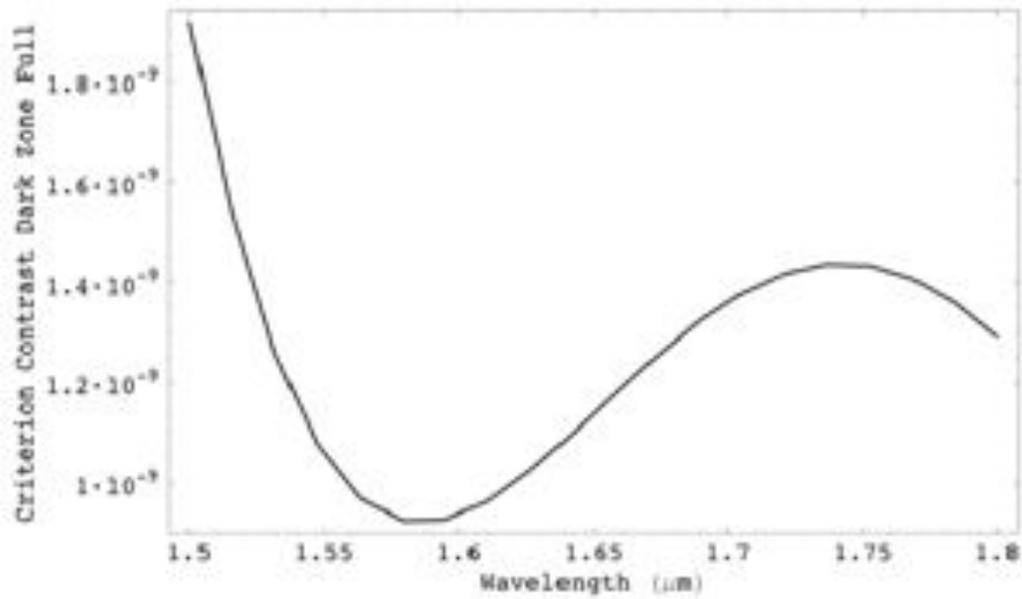
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deliver the same performance at J band, so it is not necessary to have the same theoretical contrast at J band. However, we find that we can improve the performance at J band by oversizing the Lyot stop central obstruction to eliminate most of the J-band leakage in the Lyot plane. Putting these two issues together, we re-optimize the H-band solution at the same time and find a new solution with the Lyot mask slightly larger. The parameters of the optimized H-band solution are not affected by the Lyot stop oversizing, so that the J-band performance can be improved by a factor of a few by oversizing the Lyot stop.

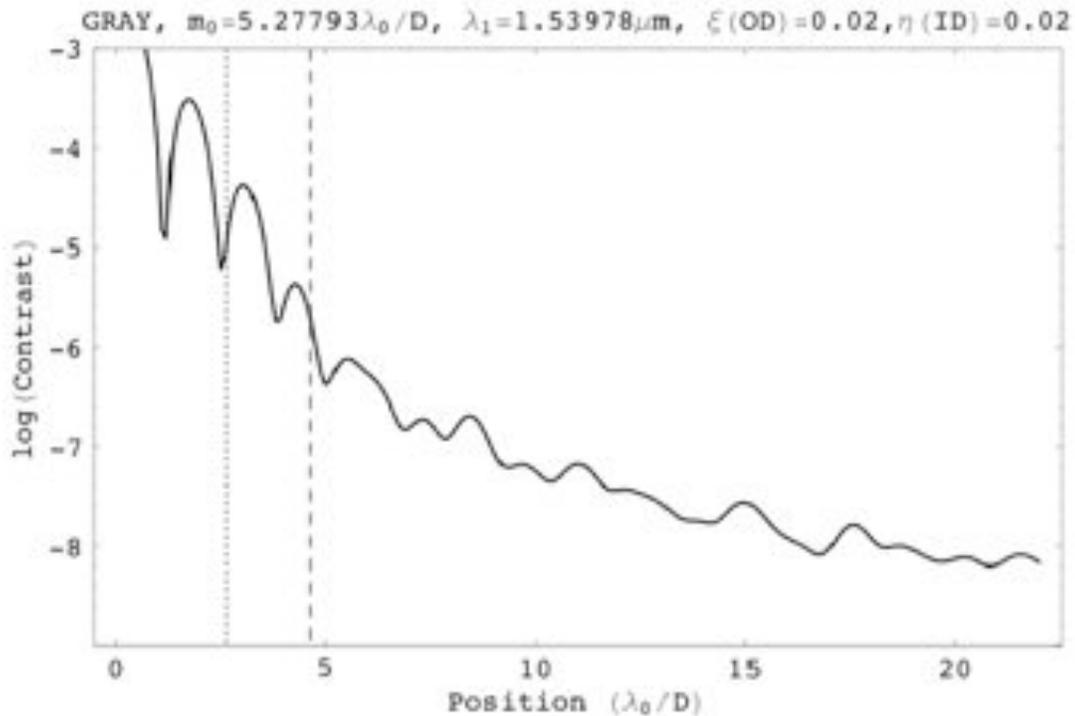
The following figure shows the expected contrast as a function of central wavelength and mask size.



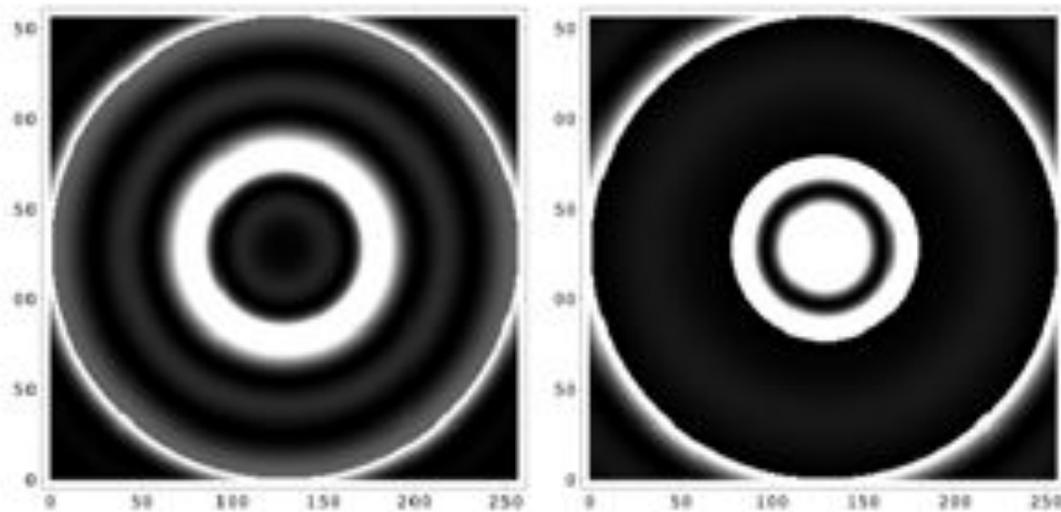
**Figure 1. Parameter space for the two main parameters (mask size at band center  $\lambda = 1.65$  microns. The vertical axis corresponds to the wavelength at which the prolate apodizer is applied)**



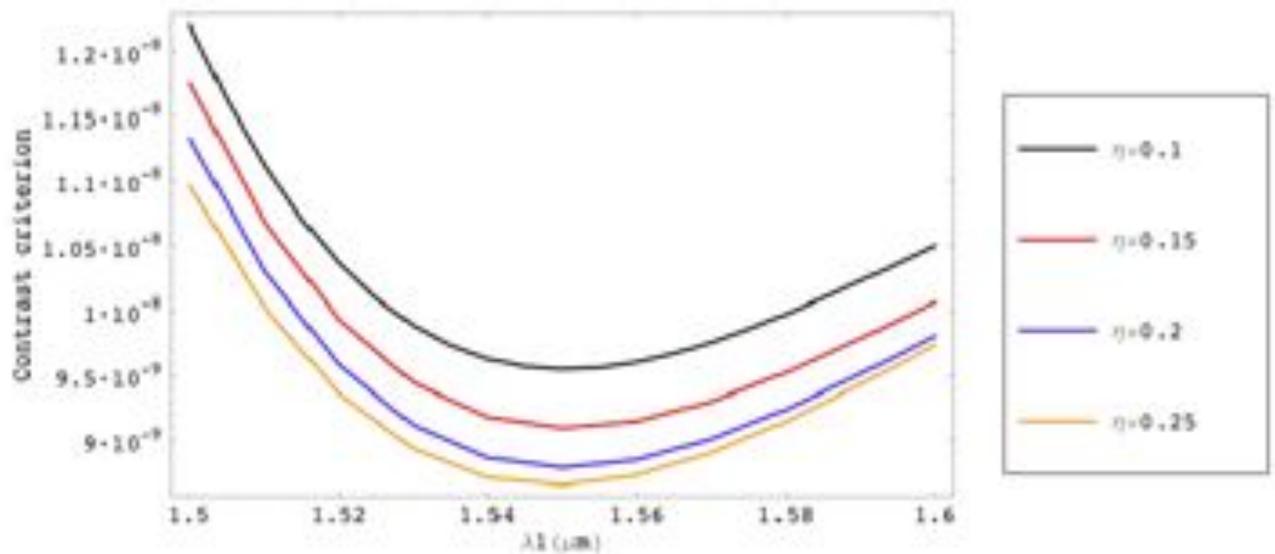
**Figure 2. Sensitivity of the contrast criterion as a function of wavelength in the H-band.**



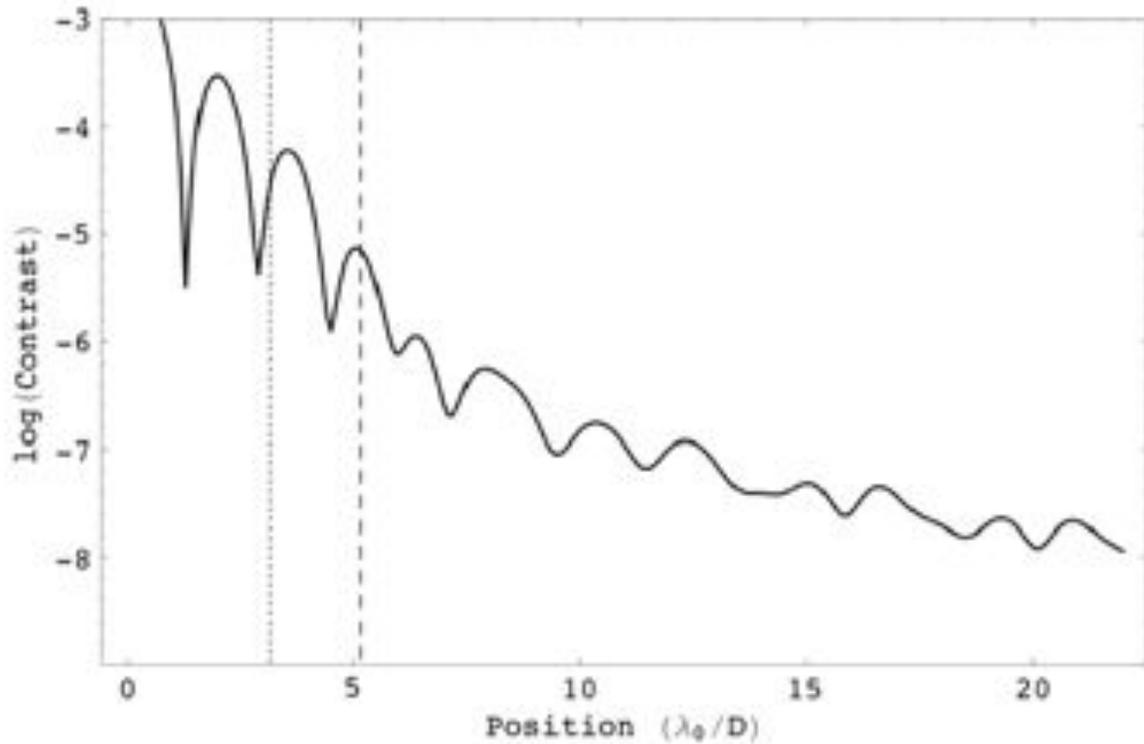
**Figure 3. H-band contrast without aberrations. The dotted line is the focal plane mask radius, and the dashed line is a conservative inner working angle (radius of the mask+two resolution elements).**



**Figure 4. Full images of the Lyot plane at J (left) and H-band (right). Most of the leakage for this optimum solution at H comes from the light around the central obstruction at J.**



**Figure 5. Effect of oversizing the central obstruction in the Lyot Stop.**



**Figure 6. H band PSF with the optimal solution and a 25% oversize of the central obstruction.**

**Table 1. Table of coronagraph design parameters.**

Optimum mask size at 1.65 microns	$5.3723 \lambda/D = 0.37$ arcsecond diameter
Beam diameter at apodizer	3.902mm
Beam diameter at apod. w/ 2% undersizing	$3.902\text{mm}/1.02 = 3.82\text{mm}$
New f-ratio after pupil undersizing	$146.1/0.98 = 149.1$
FPM hole diameter	$5.3723 * 1.65 * 149.1 = 1322$ microns
Lyot stop beam size for full pupil	3.956mm
Image of undersized pupil in this plane	$3.956 * 0.98 = 3.877\text{mm}$
2% undersized Lyot Stop size	$0.98 * 3.877 = 3.799\text{mm}$

### 2.1.1. Coronagraph Optical Train

The layout of the coronagraph is shown in the figure below and is based on the concept of Sivaramakrishnan et al. (2001). The f/15.4 beam from the Palomar AO system enters our coronagraph via an infrasil window which counteracts dispersion caused by the PALAO dichroic. The beam (2.391 inches above the optics baseplate) comes to a focus, strikes an OAP and is formed into a collimated beam. Next in the optical train is the apodizer. The beam then strikes the fast-steering mirror and continues onto the pair of atmospheric dispersion prisms (more detail on these is given below). The beam is brought back into a focus by an OAP in order to apply the primary coronagraphic correction at the Focal plane mask. The hole in the reflective mask serves as the occulter and the light travelling through the hole meets our infrared tip/tilt sensors. The unocculted portion of the image is reflected off the

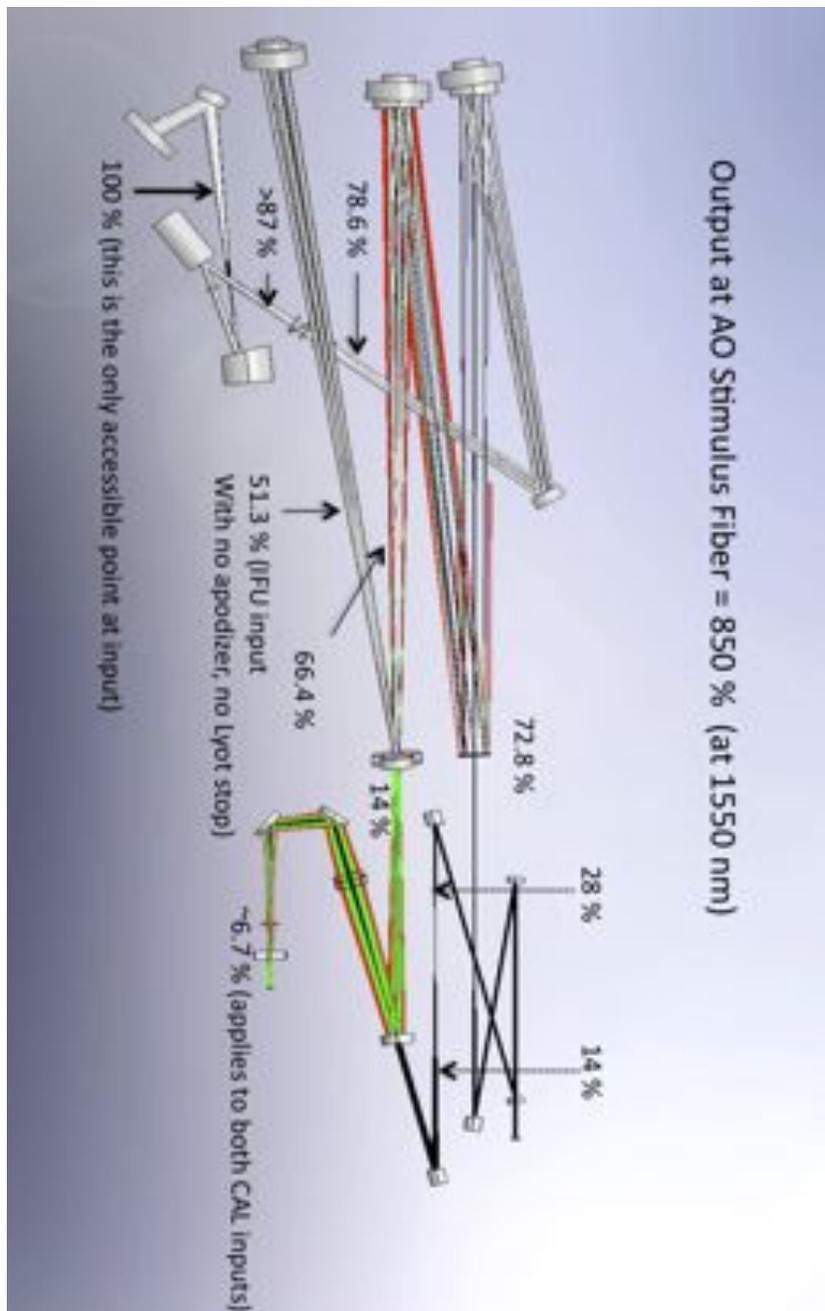
focal plane mask, and travels to another OAP which brings the beam back out of focus where it meets the Lyot stop. Similar to the focal plane mask, the Lyot stop is reflective, passing the unocculted portion of the image on to the rest of the system. Finally, this is brought to an image on our lenslet array of the spectrograph using a 600mm Spherical mirror (not shown in the figure below). The entrance beam into the spectrograph is a f/143 beam. We discuss each of these components and their mounts in detail here.

## Estimated throughput

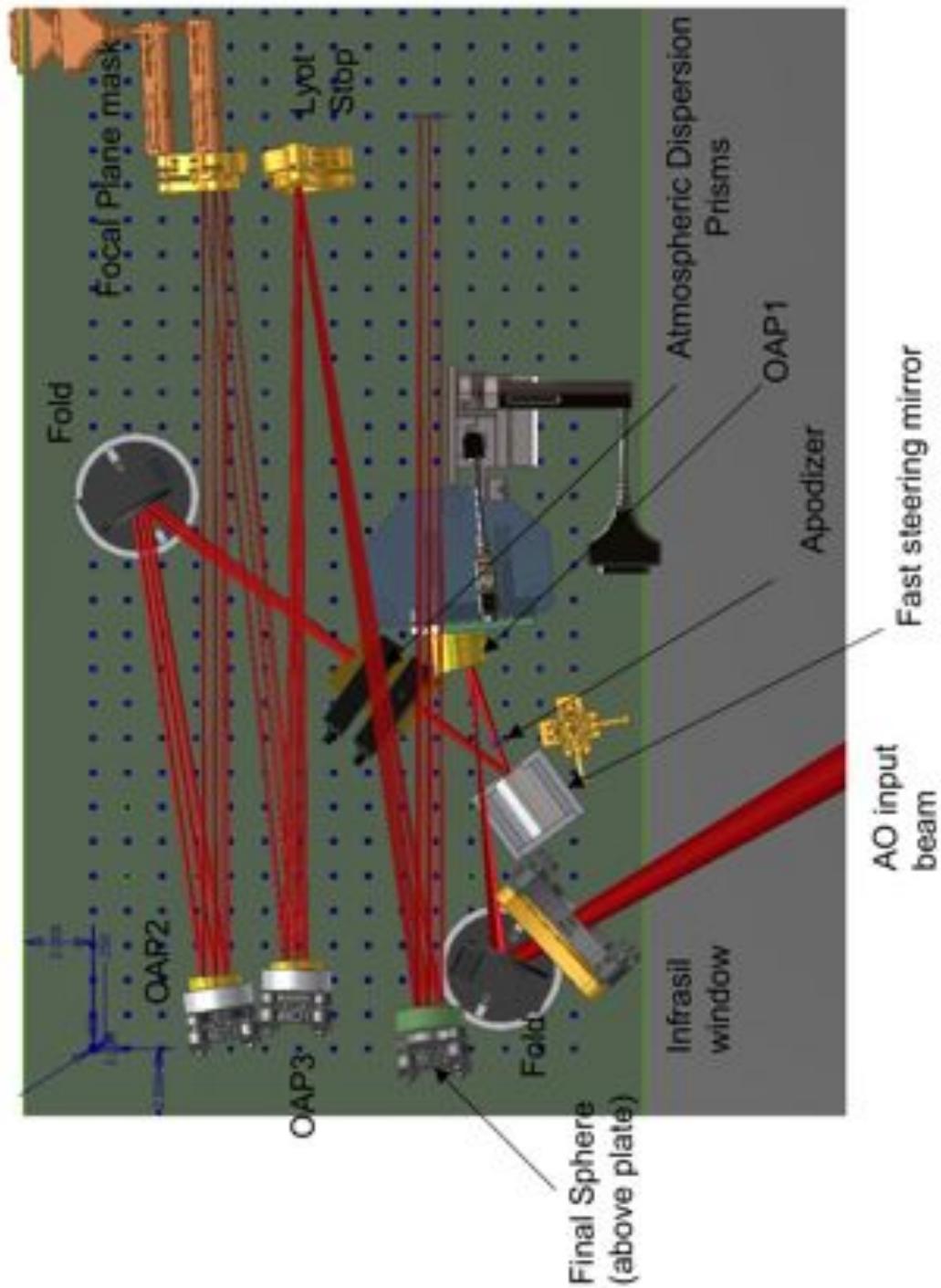
	Reference arm	Science arm
Tip tilt pick-off	0.50	
Spatial filter	0.50	
Beamsplitter	0.50	0.50
Anamorphs	0.92	0.92
Re-imaging lens doublet	0.92	0.92
Camera losses	0.55	0.55
Science/CAL split		0.2
Other	0.89	0.96
TOTAL THRUPUT	5.2 %	4.5 %

Throughput to CAL ~5 % (total estimated throughput ~0.25 %)

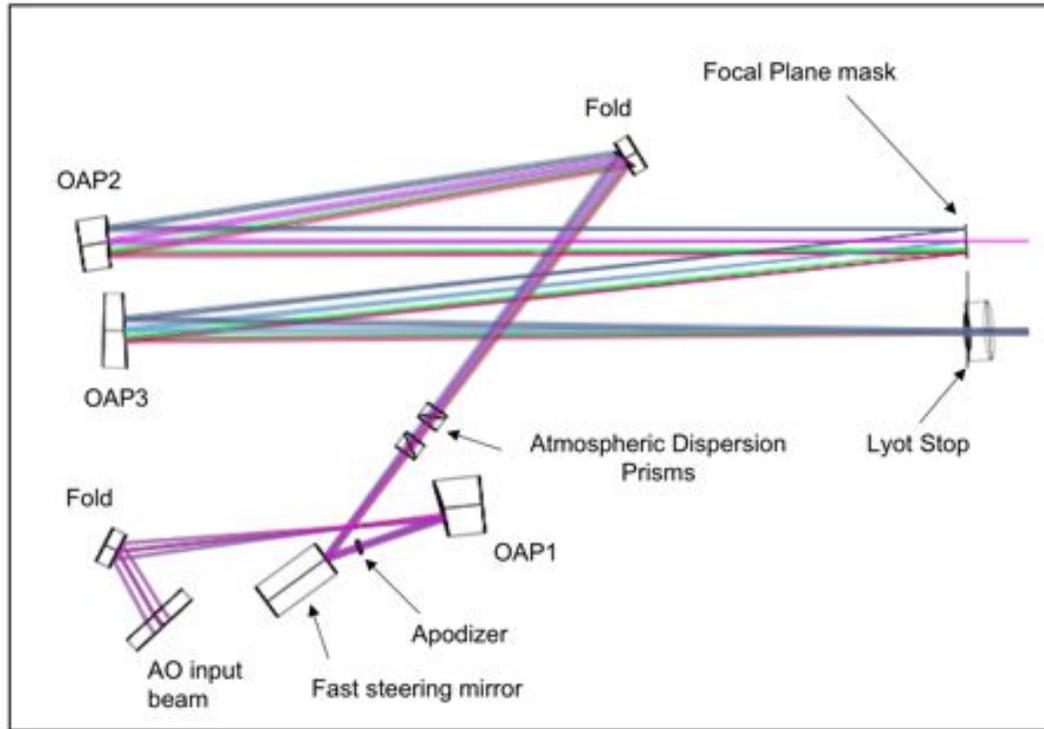
**Figure 7. Initial estimated throughput from February, 2010 through cal system (courtesy of GV).**



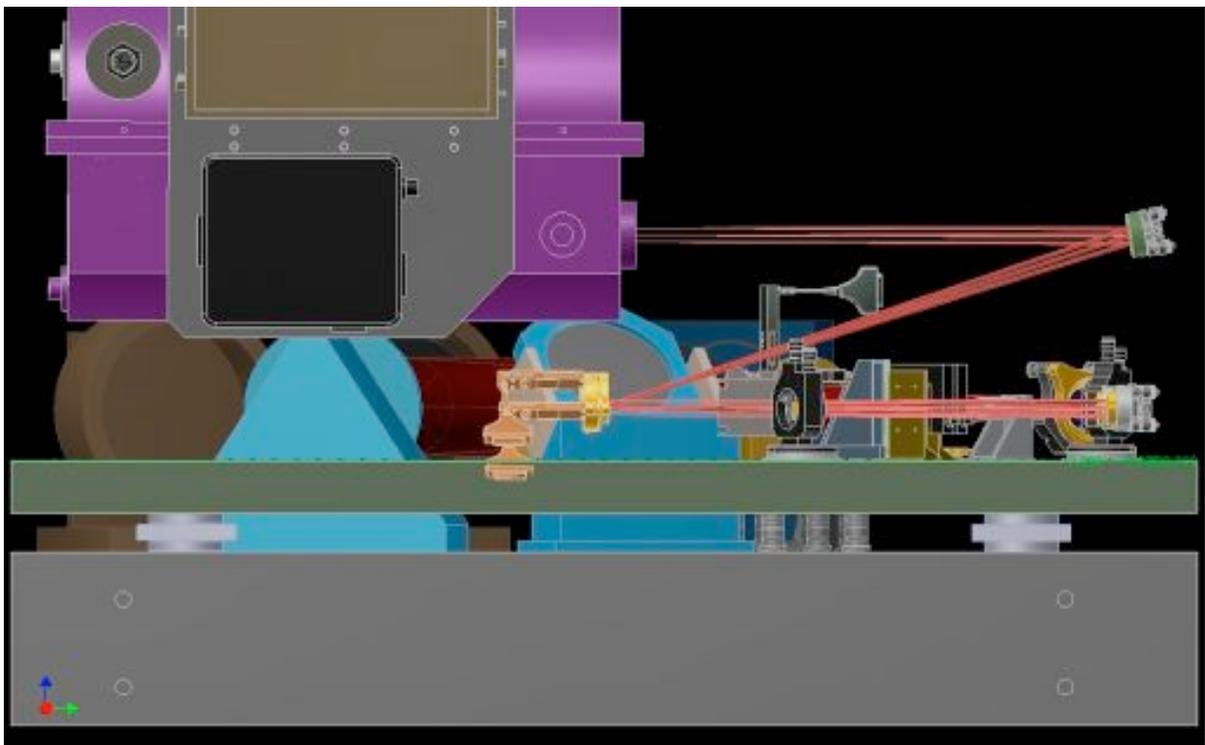
**Figure 8. Coronagraph throughput measurements as determined by Dr. Vasisht with help from Mr. Robert Ligon in March, 2010.**



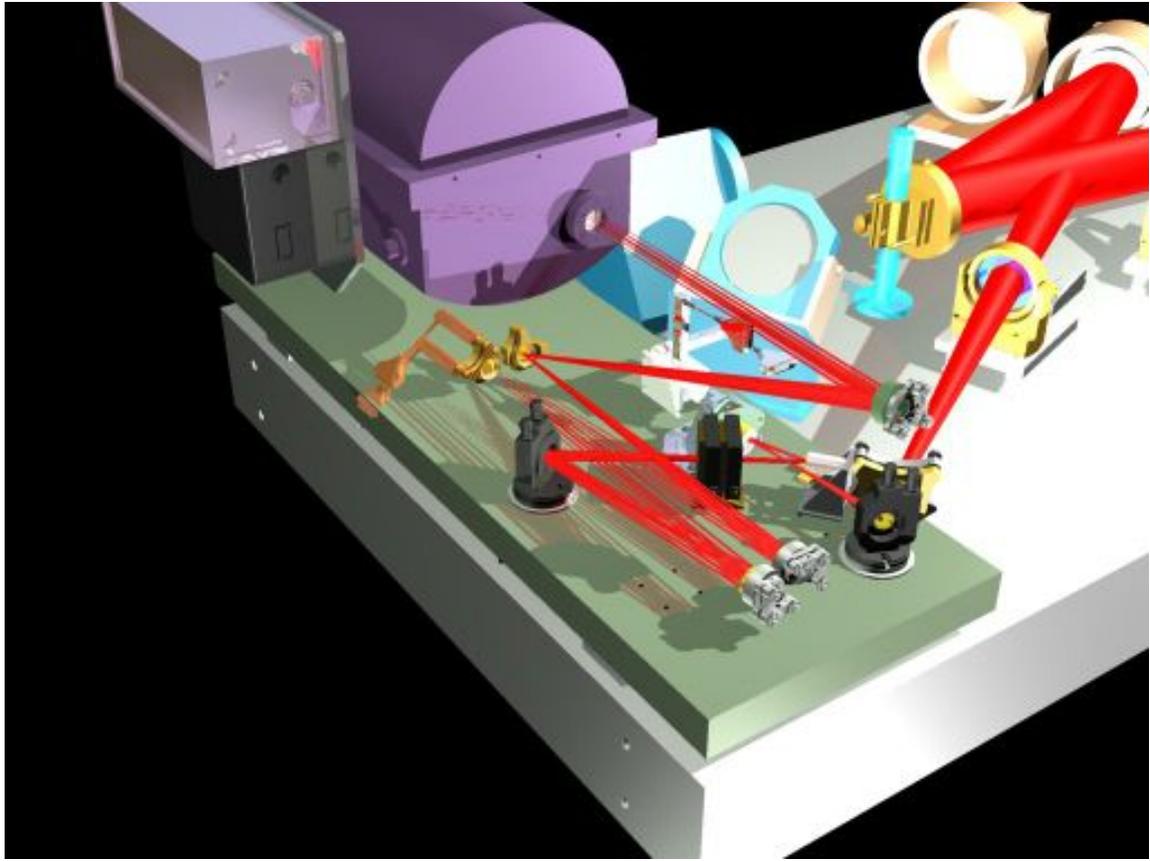
**Figure 9. Layout of the Project 1640 coronagraph. All of the optics are 2.4 inches above the optics baseplate except for the the Final Sphere (the last optic), which is 10.3 inches above the table.**



**Figure 10.** Same as the above figure, but excluding the final spherical mirror.



**Figure 11.** Side view of the P1640 coronagraph.



**Figure 12. Isometric rendering of P1640 coronagraph with IFU (purple dewar)**

#### **2.1.1.1. Infrasil Window:**

**Optic:** 2-inch flat made of infrasil 302, 10mm thickness. AR coated for 0.6-2.0  $\mu\text{m}$ . Lambda/20 rms irregularity at 632.8nm. Less than 0.05 waves surface power at 632.8 nm. Scratch/dig is better than 60/40, and less than 1 arc-minute wedge.

**Mount:** Newport U200-G2K-NL, thumb actuated gimbal mount, and custom base riser with 45 degree cut out to fit base of the U200. Also included are flanges to allow clamping to baseboard. Drawings list this part as AMNH1640-1(height 2.400”).

#### **2.1.1.2. Fold-Mirror 1 (FM1)**

**Optic:** 1-inch flat with gold coating,  $\lambda/20$ , superpolished, supplied by Opticology in New York City.

**Mount:** Newport VGM-1BD, custom baseplate to match VGM base holes and flange for clamping to baseboard. Some drawings may list this part as AMNH1640-2. (Height 2.400”). See appendix for detailed drawings of this mount.

#### **2.1.1.3. Off-Axis Parabola 1 (OAP1)**

**Optic:** Lyot Project OAP2 removed from mounting bracket

**Mount:** New Custom L-bracket with interface to OAP2's 3 tiered holes. Shims to adjust position for alignment. Drawing will list this part as AMNH1640-3. This is just a shortened copy of the Axsys part 2039-122-00. (height 2.400"). See detailed drawings in appendix.

#### 2.1.1.4. Apodizer

**Optic:** 12.7 mm transparent apodizer. Pupil is 3.9 mm in diameter. More detail is given in the following section.

**Mount:** Newport SN050-F3 lockable kinematic mount with ADAPT-SUP-0.5 to provide 8-32 mounting point from 2-56 screw through mount, MS-500-XYZ, MS-AP-3 Adapter plate, MS-ATK screw kit (x2), May need another 0.75 inch base plate: MRP3-0.25, MRP3-0.5 (3 x each), Model 38 (x2). (Height adjustable)



**Figure 13. Detail of the Jenoptik microdot apodizing pupil mask. The astrometric grid is evident in the upper left panel.**

#### 2.1.1.5. Fast Steering Mirror (FSM)--Tip/Tilt Control

**Optic:** Lyot Project FSM on PI S303.10 Stage

**Mount:** Interface plate from Lyot Project, to new Custom L-Bracket, Part AMNH1640-4. (Height 2.400"). See detailed drawing of this mount in the appendix.

#### 2.1.1.6. Atmospheric Dispersion Correction (ADC) prisms

**Optics:** Two cemented wedges of BaF<sub>2</sub> and CaF<sub>2</sub> (wedge angles of 26.467° and 29.159°, respectively). A single prism set is cored out of the cemented wedges. Prisms are contained in a 1-inch cell for mounting in the Newport SR50CC mounts. Central thickness is 12mm for the cemented set. See section below for detailed drawings.

**Mount:** 2 x SR50CC from Newport, custom mounting and spacing bracket, Part AMNH1640-5a and b. (Height 2.400") shown in drawing below. Four 8-32 screws secure the SR50CC motors to these mounts.

#### 2.1.1.7. Fold-Mirror 2 (FM2)

**Optic:** 1-inch flat with gold coating,  $\lambda/20$ , superpolished, supplied by Opticology

**Mount:** Newport VGM-1BD, custom baseplate to match VGM base holes and flange for clamping to baseboard, part AMNH1640-2. (Height 2.400")

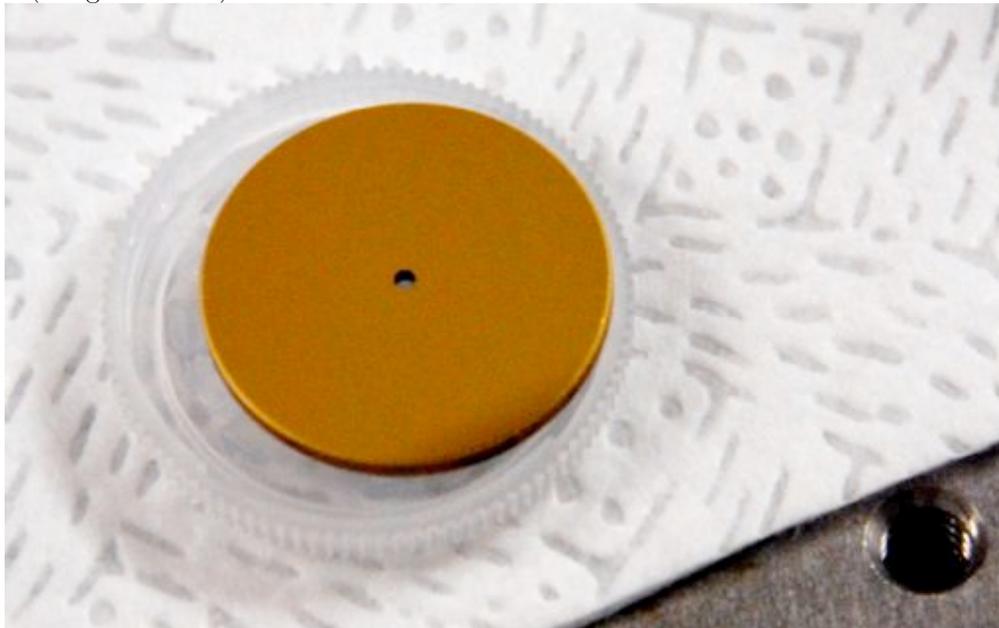
#### 2.1.1.8. Off-Axis Parabola 2 (OAP2)

**Optic:** 640.00 mm OAP from Precision Asphere, 35 mm in diameter.

**Mount:** Drawings will list this part as AMNH1640-6: three-tiered adaptor for 35-39 mm optics for 1 inch optics mounts. Interfaced to Newport SS100-F3H lockable kinematic mount, attached to 1.4 inches of post (by 8-32 screw) and held to table with clamp: parts PS-B-1, SS-1-A, PS-0.125, PSF (height 2.375 inches)

#### 2.1.1.9. Focal Plane Mask (FPM)

1 inch diameter Silicon FPM from MEMS Optical, with U100-G gimbal mount with CMA12CCCL actuators, on Newport Model M-B-2C base (x2) on MRP3-1 base, clamped to table. (Height 2.400")



**Figure 14. The P1640 Focal plane mask.**

#### 2.1.1.10. Off-Axis Parabola (OAP3)

**Optic:** 640.00 mm OAP from Precision Asphere, 35 mm in diameter.

**Mount:** Drawings will list this part as AMNH1640-6: three-tiered adaptor for 35-39 mm optics for 1 inch optics mounts. Interfaced to Newport SS100-F3H lockable kinematic mount,

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attached to 1.4 inches of post (by 8-32 screw) and held to table with clamp: parts PS-B-1, SS-1-A, PS-0.125, PSF (height 2.375 inches)

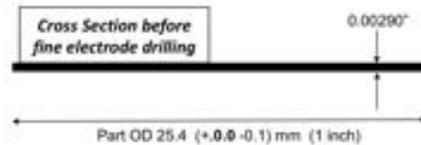
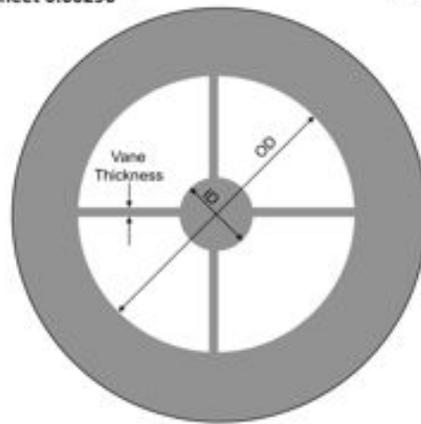
### 2.1.1.11. Lyot Stop (Beam splitter for Cal System)

**Optic:** 1-inch flat with gold coating,  $\lambda/20$ , superpolished, supplied by Opticology, initially, when Cal System is integrated, this must be replaced with an 80/20 mirror. Lyot Stop, Wire EDM machined 50  $\mu\text{m}$  thick pupil pattern, with spiders aligned with the telescope's (up-down, left-right), placed on the optical surface. Spiders are black anodized.

**Mount:** Newport VGM-1BD, custom baseplate to match VGM base holes and flange for clamping to baseboard, part AMNH1640-2 with angle. (Height 2.400", angle is 7 and 9°).

**Figure 15. Design drawing for Lyot mask (Current as of Fall 2009)**

Lyot Mask design description for CTM  
Notches to identify part numbers (on edge)  
Material: Stock Al sheet 0.00290"



#### Palomar Order 4 Sep 15 2009

Source: Repeat Palomar 3 order Classic Lyot and unobscured pupil  
Add APLC from older Soummer CTM orders  
ID and vanes remain same.  
All part ODs 1".  
Vendor: John J. Piseck john@ctm-corp.com  
1-866-CTM-CORP (1-866-286-2677)  
(315) 894-4377 Ext.227

**CONSTANT PARAMETERS**  
PART-OD: 25.4mm +0.0 -0.1mm (1")  
PART THICKNESS: 0.003 inch  
VANES' Symmetric, 90 degrees:  
PER ITEM DESIGN PARAMETERS:  
- OD  
- ID  
- Vane thickness

Anand Sivaramakrishnan  
Office: 212 313 7653  
Cell: 410 852 2201  
[anand@amnh.org](mailto:anand@amnh.org)

**Lyot Mask design description for CTM**

Palomar 4-1 (this order) same as Palomar 3-1 design

Palomar 4-2 (this order) same as Palomar 3-2 design

Palomar 4-3 (this order) a repeat of an older ID/OD design, but part OD 1" (25.4mm)

**Palomar Order 4 Sep 15 2009.**

Vendor: John J. Piseck john@ctm-corp.com  
 1-866-CTM-CORP (1-866-286-2677)  
 (315) 894-4377 Ext.227

3514.5	Qty	OD/mm	ID/mm	Vane thick. / micron	Total count
Palomar4 - 1	2	3.344	1.95	200	2
Palomar4 - 2	2	3.80	n/a - unobscured	n/a - unobscured	4
Palomar4 - 3	2	3.80	1.95	200	6
				Total parts	6
				Price per	\$585.75
				Total price:	\$3514.50

**Figure 16. More specs on the P1640 Lyot stop (Current as of Fall 2009)**



**Figure 17. Configuration of the Lyot wheel as of March 2010.**

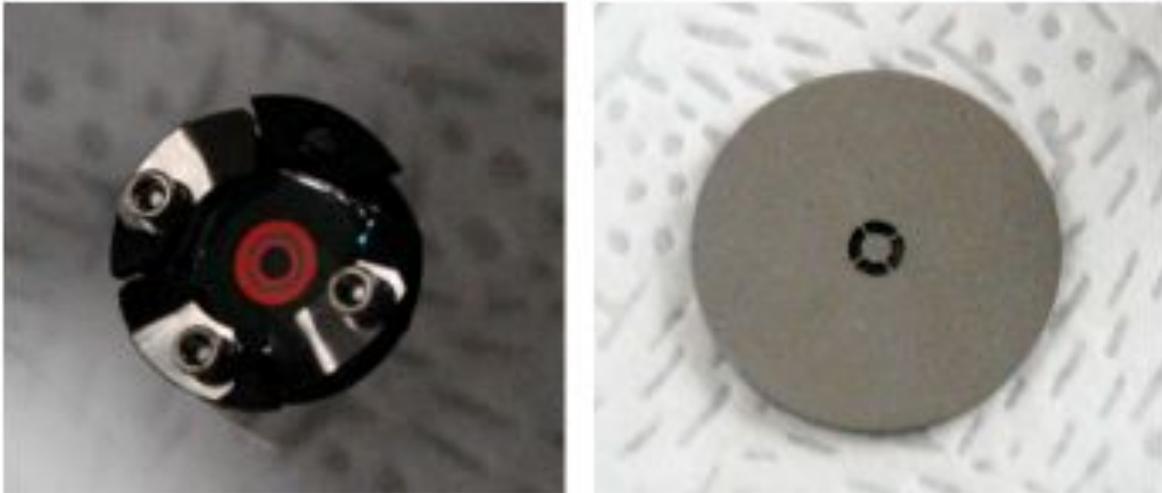
### 2.1.1.12. Final Sphere

**Optic:** 600.00 mm FL Sphere from Opticology, 38.1 mm in diameter.

**Mount:** Part AMNH1640-6, three-tiered adaptor for 35-39 mm optics for 1 inch optics mounts. Interfaced to Newport SS100-F3H lockable kinematic mount, attached to 1.4 inches of post (by 8-32 screw) and held to ramped AMNH1640-2 with clamp: parts PS-B-1, SS-1-A, PS-0.125, PSF (height 2.375 inches) above raised platform, supported by Newport 45s and the platform hardware from Lyot Project.

### 2.1.2. Coronagraphic Mask Optical Specs

Our three masks are shown below. Our apodizing mask is a 12.7mm transparent optic made by Jenoptik. It has a 3.9mm pupil and is shown in the photo below. The transmission profile on this mask follows the prolate spheroid apodization prescription as described in Soummer et al. (2003). The transmission profile is defined by a microdot pattern lithographically placed onto the suprasil substrate. The dots are placed on a 2 mm grid initially via electron-beam lithography, followed by a deposition of black chrome.



**Figure 18. The apodizing mask (left) and Lyot mask (right).**

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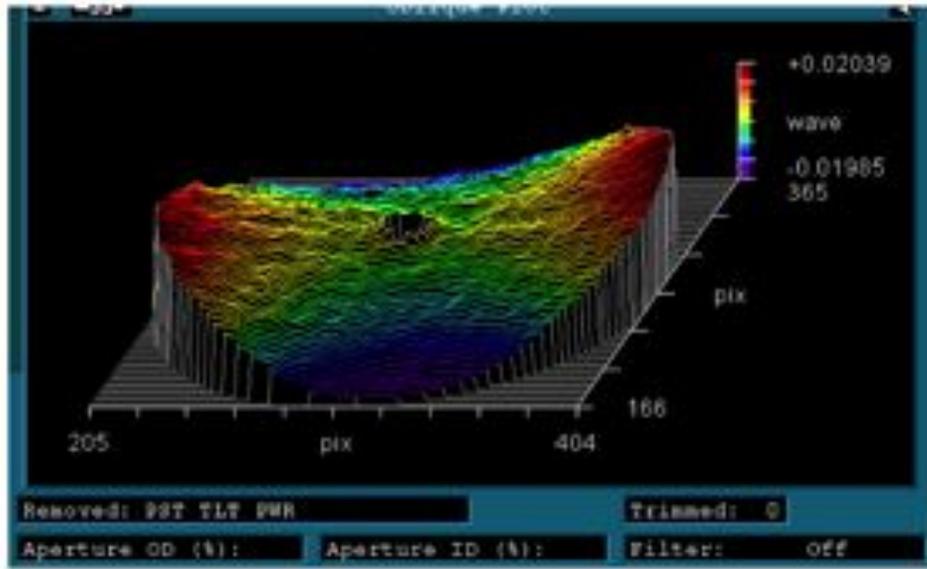


Figure 19. Zygo wave front measurements of the Focal plane mask.

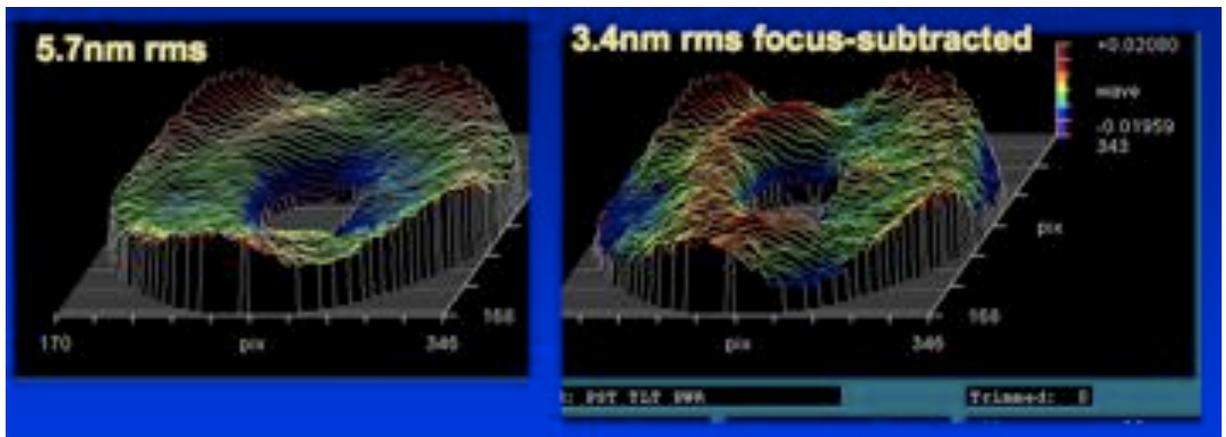
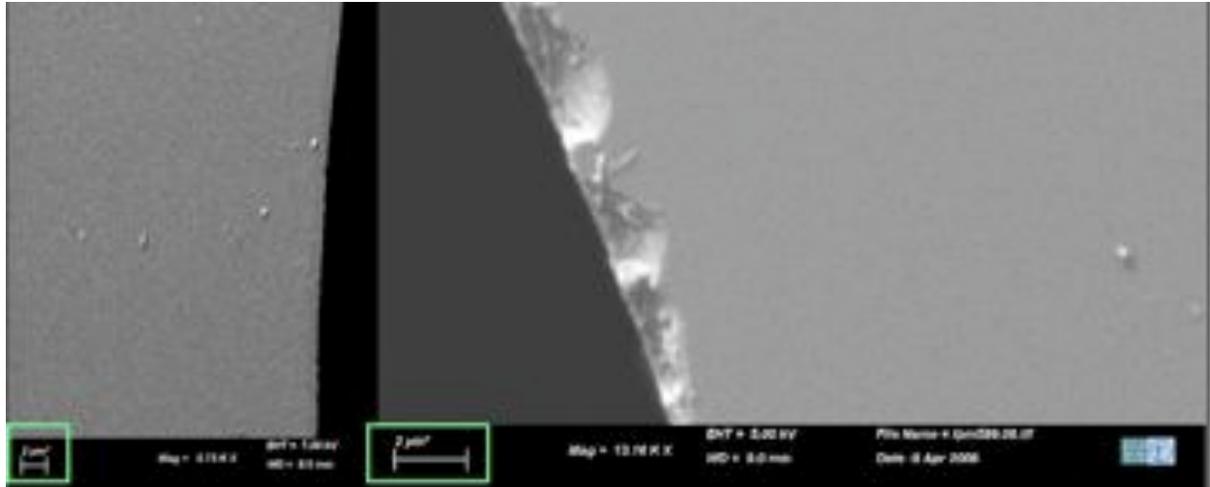
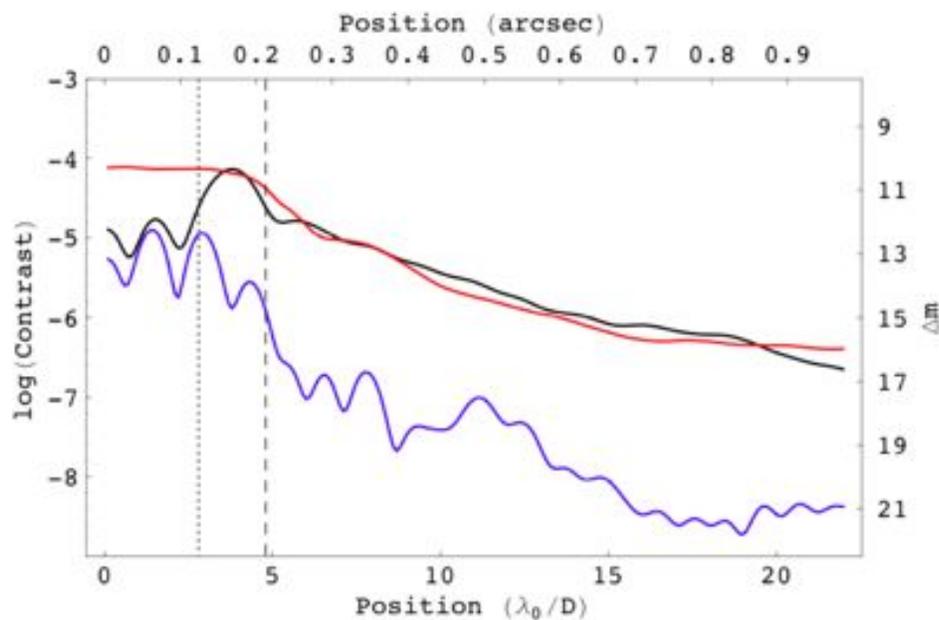


Figure 20. Zygo wave front measurements of the P1640 apodizer.



**Figure 21. A scanning electron microscope image of the focal plane mask edge.**

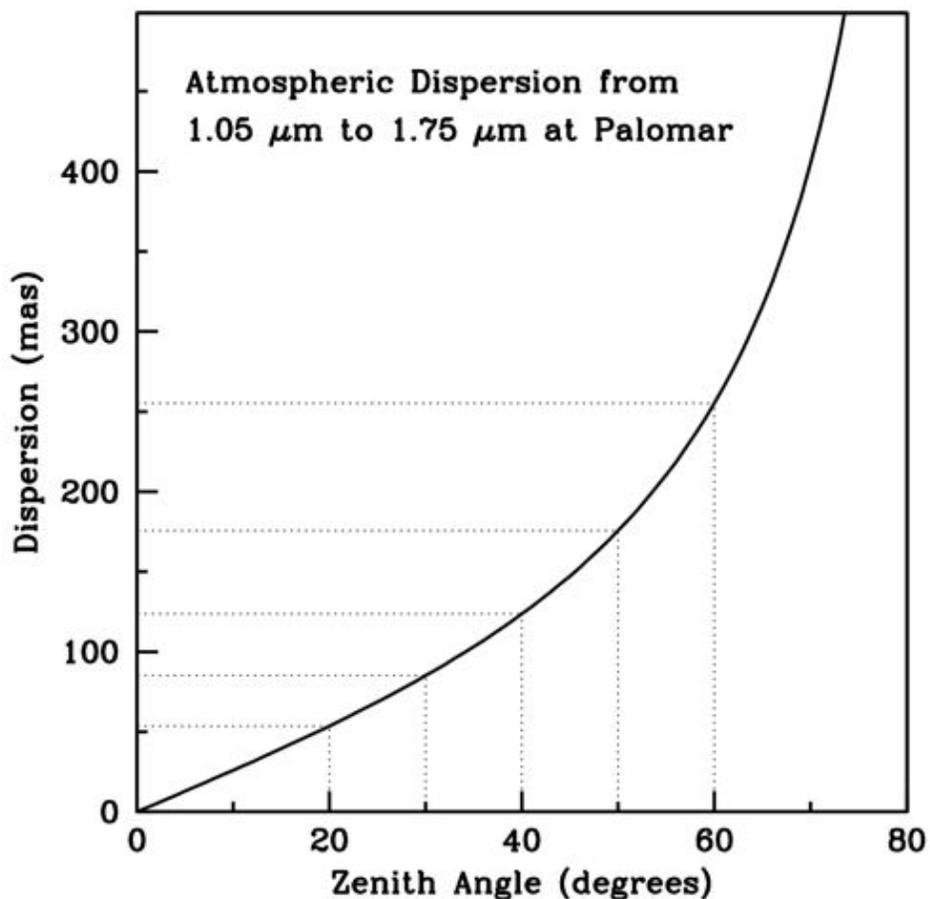


**Figure 22. Achieved contrast on the GPI APLC testbed at the AMNH Astrophysics Lab. We expect to achieve a similar level of coronagraphic suppression with P1640.**

### 2.1.3. Atmospheric Dispersion Correcting Prisms

Refraction in the earth's atmosphere will cause the position of a star at one wavelength to differ from the position at another wavelength. From the blue edge of the J-band ( $\sim 1.05 \mu\text{m}$ ) to the red edge of the H-band ( $\sim 1.75 \mu\text{m}$ ), this displacement can be 100mas. To correct for this, we use two sets of Risley prisms via the prescription in Wynne (1996). Each prism set is constructed by coring out a cylinder from two cemented wedges of  $\text{BaF}_2$  and  $\text{CaF}_2$ . The

amplitude of correction is determined by the zenith angle of the target star and the positions of these prisms are update every second.



**Figure 23. The Differential Atmospheric Dispersion from the first channel in a cube to the final channel, as a function of zenith angle.**

**Table 2. Summary of Design parameters for Atmospheric Dispersion Correcting prisms.**

Optimization wavelength range	1.00 – 1.85 $\mu\text{m}$
ADC deviation at 1.25 $\mu\text{m}$ on sky	0.015 arcsec
Incident material	CaF <sub>2</sub>
Wedge 1 material (incident face)	CaF <sub>2</sub>
Wedge angle	29.15878°
Thickness along mechanical axis	6.0000 mm
Wedge 2 material	BaF <sub>2</sub>
Wedge angle	26.46681°
Thickness along mechanical axis	6.0000 mm
Direction of marked arrow on cell	Exiting beam
Location of arrow marked on cell	Thick part of CaF <sub>2</sub> , thin part of BaF <sub>2</sub>

Atmospheric Dispersion Calculations from Chris Shelton

10/18/2007 3:03:32 PM

Telescope diameter (m) : 5.16  
 Beam diameter (mm) : 4.21  
 Optimization wavelength range (um) : 1.00 to 1.85  
 Plot wavelength range (um) : 1.00 to 1.85  
 Magnification: 1225.9  
 Zenith angle (degrees): 50.00  
 Barometric pressure (millibar) : 827  
 Effective temperature of air column (C) : 10.0  
 Max allowed surface angle from axis (deg) : 30.0  
 Range of surface thickness (mm) : 6.00 to 10.00  
 Pupil distance (mm) : 112.00  
 Pupilsweight : 1.000E-0002  
 Pupiloffsetweight : 1.000E-0002  
 Pivotwavelength (if any) (um) : 1.250  
 Pivotweight : 1.000E-0003  
 Min allowed 25mm internal transmission at 400nm : 0.980  
 Min allowed 25mm internal transmission at 1535nm : 0.980  
 Min allowed 25mm internal transmission at 2325nm : 0.980

\* The following are for one of the two ADC prism assemblies \*

alpha	theta	th	z	y
0.000000				
0.0000	0.0000	100.0000	100.0000	0.000000
0.4762	1.4954	5.9738	6.0000	0.000000
-0.3566	27.9622	6.0267	6.0000	0.049653
0.0025	-1.1966	111.9997	112.0000	0.012144
0.0000	0.0000			0.017031

Raytrace prescription, including chief ray surface thickness (mm), and glass type with index at 1.250 um, and coord break tilt angles (deg)

1	0.0		-1.49539
2	0.0	BaF2	1.467190
3	5.9738		1.01916
4	0.0		-27.48597
5	0.0	CaF2	1.427460
6	6.0267		28.31881
7	0.0		0.83997
8	0.0		
9	111.9997		-1.19907
11		PUPIL	

Mechanical prescription, including glass type, wedge angle of glass (deg), and thickness of glass along mechanical axis (mm)

1	BaF2	26.46681	6.0000
2	CaF2	-29.15878	6.0000
3	Distance to pupil (mm)	112.0000	

\* The following are for the complete ADC (both prism assemblies) \*

Pupil decenter at 1.250 um (mm) : 0.034

ADC deviation at 1.250 um (arcsec on sky) : 0.015

Telescope pointing offset wrt vacuum (arcsec on sky) : 55.790

Average pupil decenter (mm) : 0.000

Merit function (arcsec on sky) : 0.027

Wavelength (um)	Angular Displacement in arcsec on the sky				Pupil decenter (mm)
	Air	ADC	Residual	Diff limit	
1.0000	55.899	0.046	0.0630	0.0488	0.0560
1.0106	55.893	0.046	0.0570	0.0493	0.0556
1.0212	55.886	0.045	0.0512	0.0498	0.0551
1.0319	55.880	0.044	0.0458	0.0504	0.0546
1.0425	55.874	0.043	0.0406	0.0509	0.0540
1.0531	55.868	0.043	0.0356	0.0514	0.0533
1.0637	55.862	0.042	0.0309	0.0519	0.0526
1.0744	55.857	0.041	0.0264	0.0524	0.0519
1.0850	55.851	0.039	0.0222	0.0530	0.0511
1.0956	55.846	0.038	0.0182	0.0535	0.0503
1.1062	55.841	0.037	0.0143	0.0540	0.0495
1.1169	55.836	0.036	0.0107	0.0545	0.0485
1.1275	55.831	0.034	0.0073	0.0550	0.0476
1.1381	55.827	0.033	0.0041	0.0555	0.0466
1.1487	55.822	0.031	0.0011	0.0561	0.0456
1.1594	55.818	0.030	-0.0018	0.0566	0.0445
1.1700	55.814	0.028	-0.0045	0.0571	0.0434
1.1806	55.809	0.027	-0.0070	0.0576	0.0423
1.1912	55.805	0.025	-0.0093	0.0581	0.0411
1.2019	55.801	0.023	-0.0115	0.0587	0.0399
1.2125	55.798	0.021	-0.0135	0.0592	0.0387
1.2231	55.794	0.020	-0.0154	0.0597	0.0374
1.2338	55.790	0.018	-0.0172	0.0602	0.0361
1.2444	55.787	0.016	-0.0188	0.0607	0.0348
1.2550	55.783	0.014	-0.0202	0.0612	0.0334
1.2656	55.780	0.012	-0.0216	0.0618	0.0320
1.2763	55.777	0.010	-0.0228	0.0623	0.0306
1.2869	55.773	0.008	-0.0239	0.0628	0.0291
1.2975	55.770	0.005	-0.0248	0.0633	0.0276

1.3081	55.767	0.003	-0.0256	0.0638	0.0261
1.3188	55.764	0.001	-0.0264	0.0644	0.0246
1.3294	55.761	-0.001	-0.0270	0.0649	0.0230
1.3400	55.759	-0.004	-0.0275	0.0654	0.0214
1.3506	55.756	-0.006	-0.0279	0.0659	0.0197
1.3613	55.753	-0.008	-0.0281	0.0664	0.0181
1.3719	55.750	-0.011	-0.0283	0.0670	0.0164
1.3825	55.748	-0.013	-0.0284	0.0675	0.0146
1.3931	55.745	-0.016	-0.0284	0.0680	0.0129
1.4038	55.743	-0.019	-0.0283	0.0685	0.0111
1.4144	55.741	-0.021	-0.0281	0.0690	0.0093
1.4250	55.738	-0.024	-0.0278	0.0695	0.0075
1.4356	55.736	-0.026	-0.0274	0.0701	0.0057
1.4463	55.734	-0.029	-0.0269	0.0706	0.0038
1.4569	55.731	-0.032	-0.0264	0.0711	0.0019
1.4675	55.729	-0.035	-0.0257	0.0716	-0.0000
1.4781	55.727	-0.038	-0.0250	0.0721	-0.0020
1.4888	55.725	-0.040	-0.0242	0.0727	-0.0040
1.4994	55.723	-0.043	-0.0233	0.0732	-0.0060
1.5100	55.721	-0.046	-0.0223	0.0737	-0.0080
1.5206	55.719	-0.049	-0.0213	0.0742	-0.0100
1.5313	55.717	-0.052	-0.0202	0.0747	-0.0121
1.5419	55.715	-0.055	-0.0190	0.0752	-0.0142
1.5525	55.714	-0.058	-0.0177	0.0758	-0.0163
1.5631	55.712	-0.061	-0.0164	0.0763	-0.0185
1.5737	55.710	-0.065	-0.0150	0.0768	-0.0206
1.5844	55.708	-0.068	-0.0136	0.0773	-0.0228
1.5950	55.707	-0.071	-0.0120	0.0778	-0.0250
1.6056	55.705	-0.074	-0.0104	0.0784	-0.0273
1.6162	55.704	-0.077	-0.0088	0.0789	-0.0295
1.6269	55.702	-0.081	-0.0070	0.0794	-0.0318
1.6375	55.700	-0.084	-0.0052	0.0799	-0.0341
1.6481	55.699	-0.087	-0.0034	0.0804	-0.0364
1.6588	55.697	-0.091	-0.0015	0.0810	-0.0388
1.6694	55.696	-0.094	0.0005	0.0815	-0.0411
1.6800	55.695	-0.098	0.0025	0.0820	-0.0435
1.6906	55.693	-0.101	0.0046	0.0825	-0.0459
1.7013	55.692	-0.105	0.0068	0.0830	-0.0483
1.7119	55.690	-0.108	0.0090	0.0835	-0.0508
1.7225	55.689	-0.112	0.0112	0.0841	-0.0533
1.7331	55.688	-0.115	0.0135	0.0846	-0.0558
1.7438	55.687	-0.119	0.0159	0.0851	-0.0583
1.7544	55.685	-0.123	0.0183	0.0856	-0.0608
1.7650	55.684	-0.126	0.0208	0.0861	-0.0634
1.7756	55.683	-0.130	0.0233	0.0867	-0.0659
1.7863	55.682	-0.134	0.0259	0.0872	-0.0685

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1.7969	55.681	-0.138	0.0285	0.0877	-0.0711
1.8075	55.679	-0.142	0.0312	0.0882	-0.0738
1.8181	55.678	-0.145	0.0339	0.0887	-0.0764
1.8288	55.677	-0.149	0.0367	0.0893	-0.0791
1.8394	55.676	-0.153	0.0395	0.0898	-0.0818
1.8500	55.675	-0.157	0.0424	0.0903	-0.0845

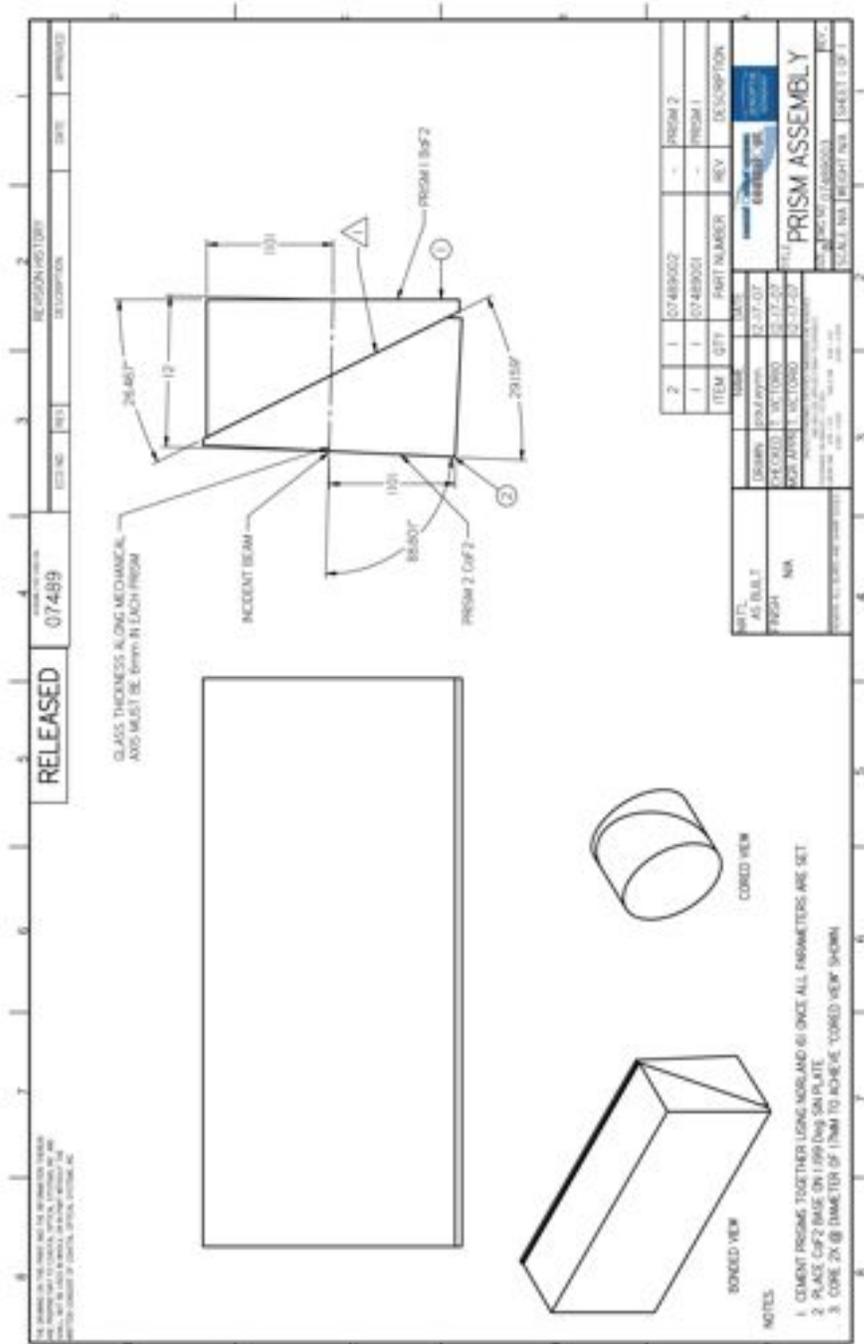
### 2.1.3.1. ADC Calibration steps from Nick Law

“I’d be happy to share my ADC control code. It has all the calculations you’d need to get the ADC working (calculating rotation angles as a function of time and target coordinate and so forth), but it has no TCS interoperability. We just typed the sky coordinates into it when we went to a new target. This was hardly ideal but worked well enough for a few nights... is it those calculations that you’re after?”

For calibration we tweaked two things: the total ADC rotation angle and the strength of the correction as a function of relative rotation angle between the prisms. We first worked out the theoretical values, which turned out to be fairly close (10% off in strength, 10 degrees or so in rotation). We then used the short exposure speckle pattern to get the fine corrections.

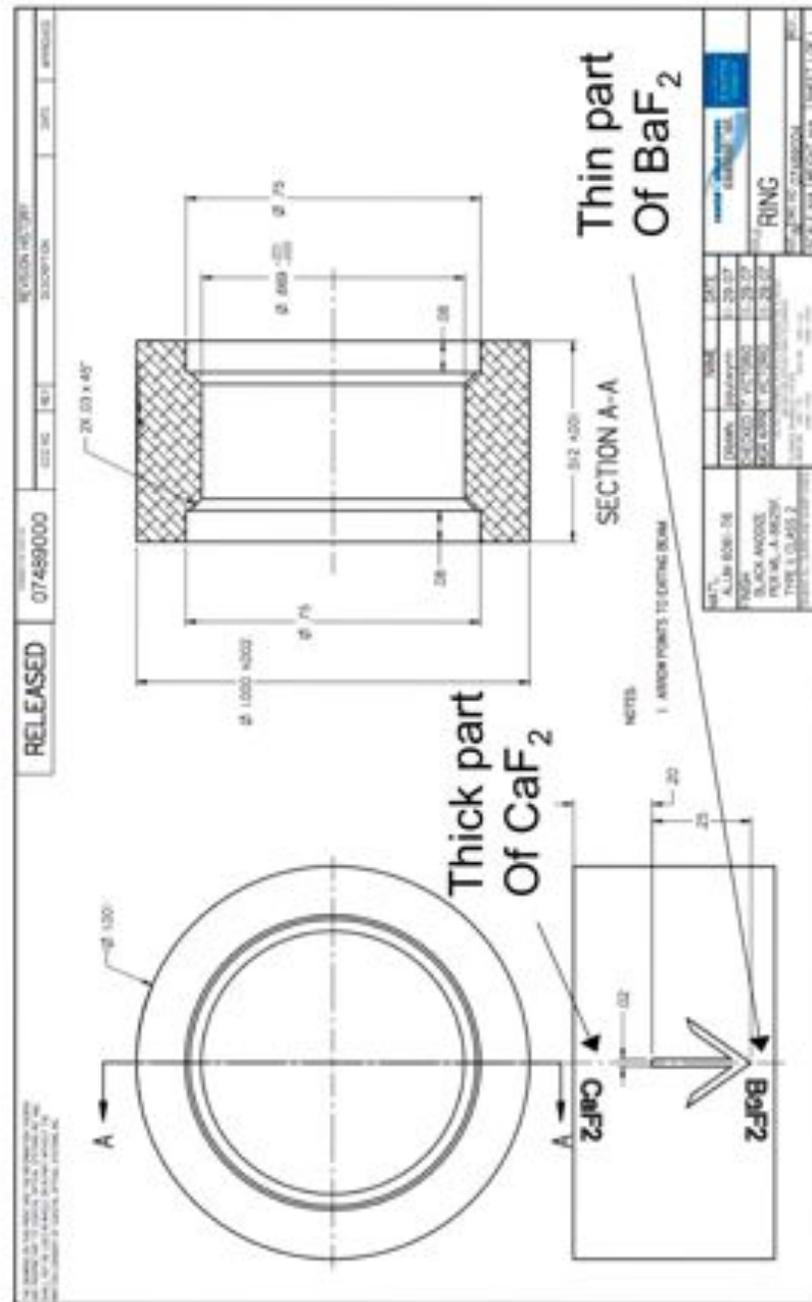
As you of course know, in the short-exposure PSF in a reasonably broad band the speckles all streak towards the PSF core. A mis-calibrated ADC makes the speckles streak towards some other point. The radial position of that point is set by how wrong the strength of the ADC correction is, and the azimuthal position is set by errors in the total rotation of the ADC. Using that it’s fairly simple to adjust the correction parameters to put the “speckle streak point” in the center of the PSF, at which point your ADC is calibrated. I think this is quite a sensitive procedure - at least very fine adjustments were required to get it right. We repeated this procedure for all our filters. Telescope time is of course needed for this, but it’s quite quick. After our first few tries we got it down to about a couple of minutes per calibration.”

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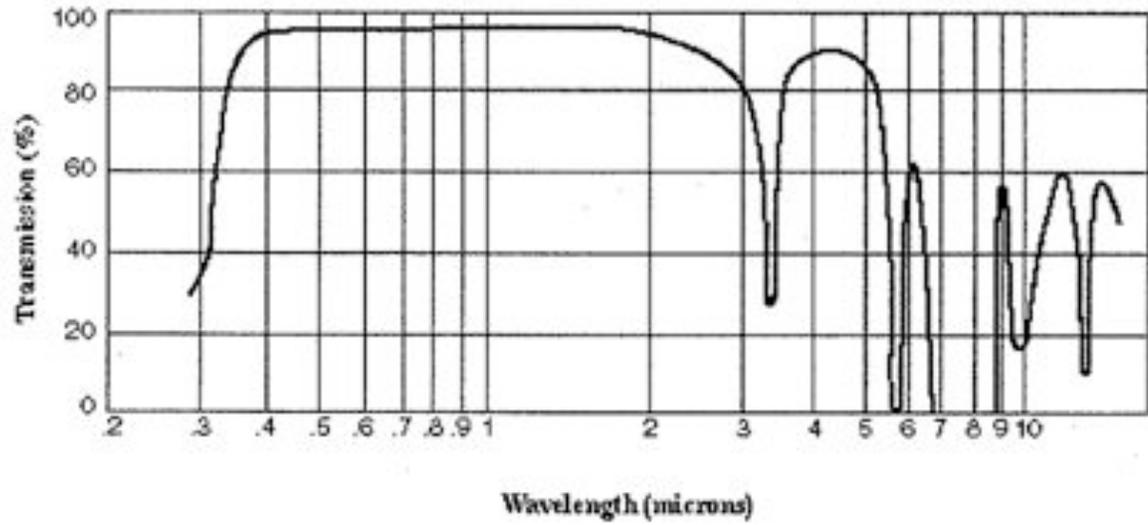


**Figure 24. Design for ADC prisms. The two wedges of CaF<sub>2</sub> and BaF<sub>2</sub> are cemented together and cored out.**





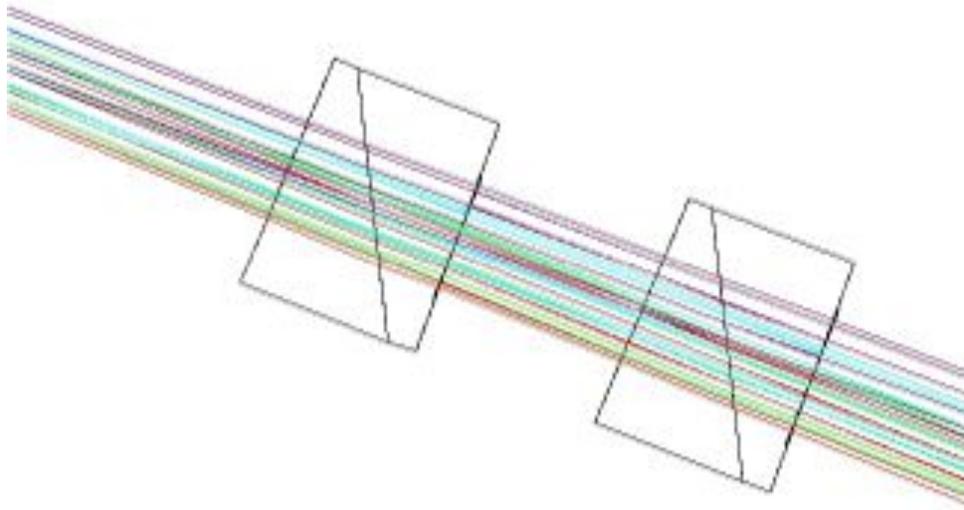
**Figure 26.** The arrow on each assembly indicates the correct orientation. It points in the direction of the exit beam. The placement of the arrow around the ring coincides with the thickest part of the  $\text{CaF}_2$  wedge, and the thinnest part of the  $\text{BaF}_2$  wedge.



**Figure 27. Prism glue transmission curve**



**Figure 28. Inserting the ADC prism assembly into the SR50 Newport motor**



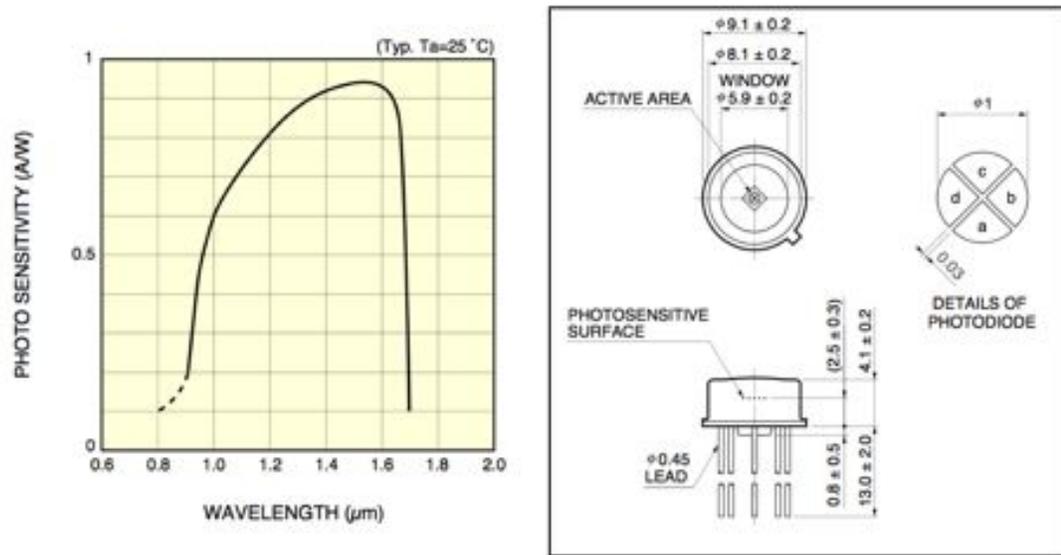
**Figure 29. Zemax drawing (from Chris Shelton) of the prism pairs in the beam.**

#### 2.1.4. Tip/Tilt System

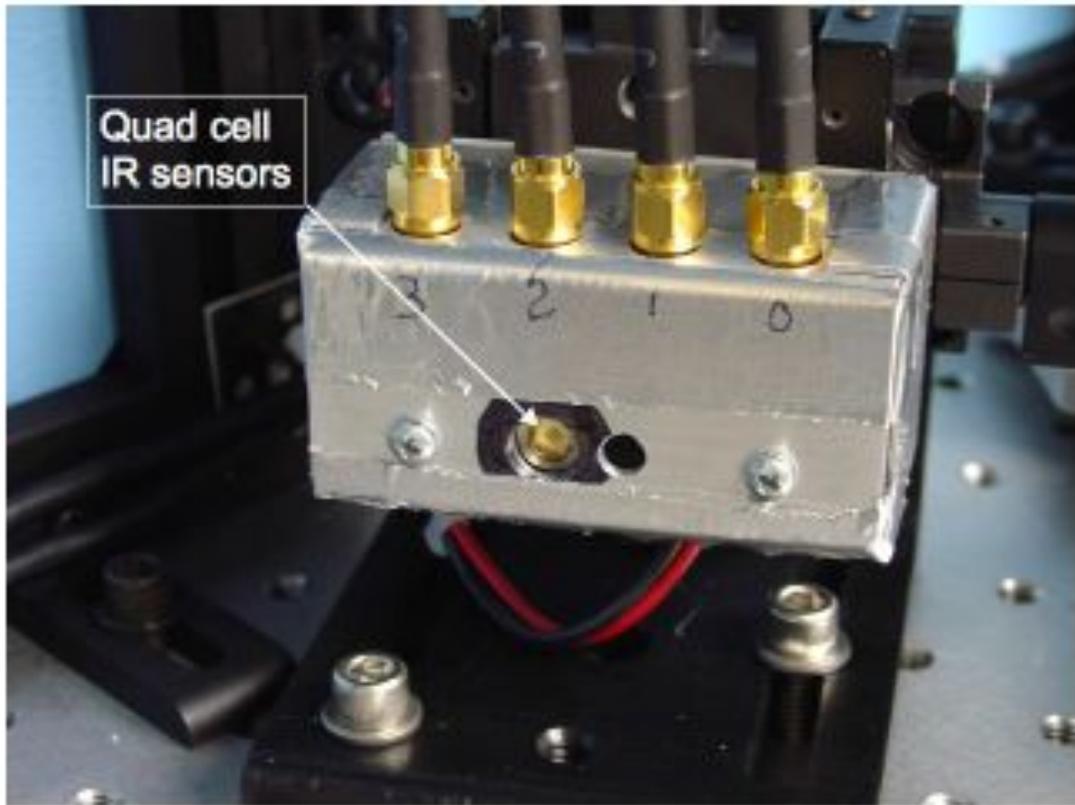
We are using a Physik Intrumente S-330.30 Piezo tip/tilt platform in conjunction with an infrared position sensor comprised of four individual PIN photodiode detectors built by Hamamatsu (G6849 series). The sensor detector area is 1 mm in diameter and sensitive from 0.9 to 1.7  $\mu\text{m}$ . Following correcting for flat field errors and dark subtraction, a simple centroiding algorithm is used to determine the stellar position. We estimate we can track stars of at least 7<sup>th</sup> magnitude with a S/N of 4 under median conditions. These IR sensors are placed on a x-y translation stage for fine adjustments of the star under the mask.

**Table 3. Table of specs for the Hamamatsu G6849-01 series InGaAs PIN photodiode quad cell array used with the P1640 tip/tilt system.**

Parameter	
Active area	.79mm <sup>2</sup> (1mm diameter photosensitive area)
Operating Temperature range	-40 to +85 °C
Spectral response range	0.9 -1.7 $\mu\text{m}$
Peak sensitivity wavelength	1.55 $\mu\text{m}$
Typical photosensitivity	0.9 A/W at 1.3 $\mu\text{m}$ , 0.95 A/W at 1.55 $\mu\text{m}$
Typical Dark Current	0.15 nA
Typical Noise equivalent power	$1 \times 10^{-14} \text{ W/Hz}^{1/2}$

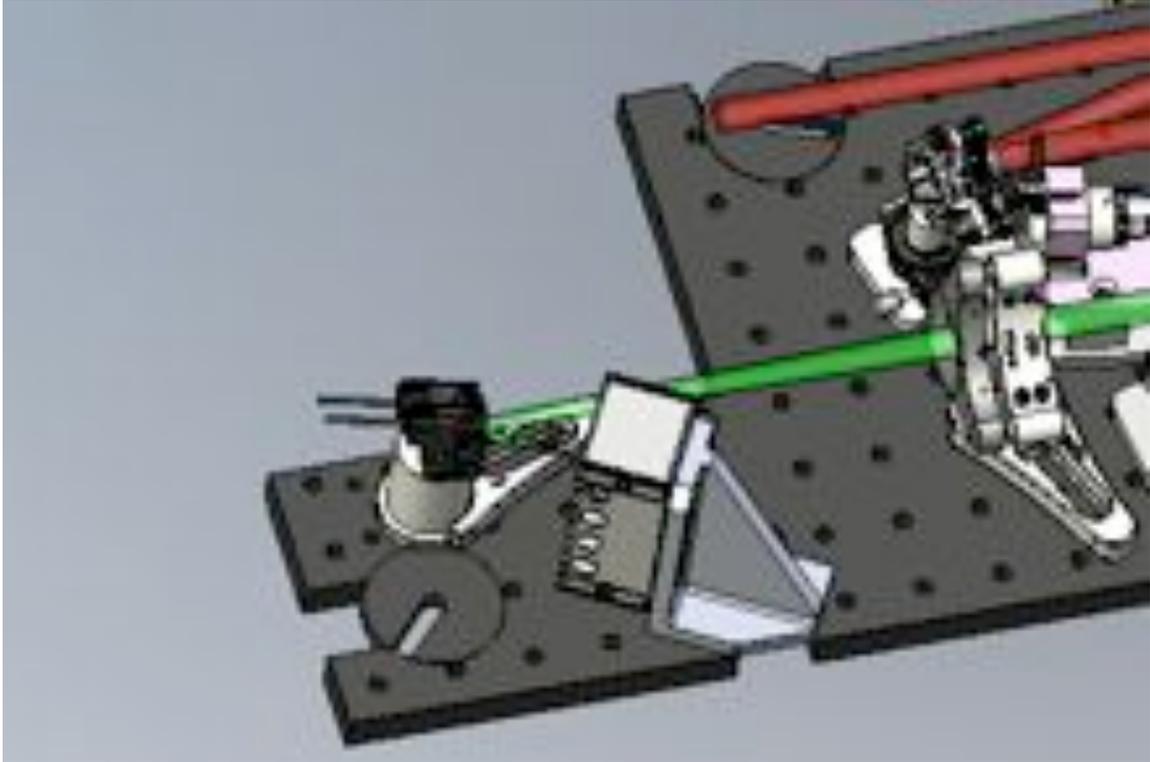


**Figure 30. Left: photosensitivity of the Hamamatsu InGaAs PIN photodiodes. Right: The dimensional specifications of the quad cell array (units are mm).**



**Figure 31. The Hamamatsu infrared photodiode quad cell housing inside the coronagraph.**

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**Figure 32. New picture of the location of the tip/tilt sensor relative to the cal system workplate.**

#### **2.1.4.1. Electronics**

The electronics are comprised of an A/D converter board in the FSM computer. We have a LABview interface as well as an amplifier and PZT stage.

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**Figure 33. P1640 electronics rack containing all of the electronics associated with the Tip-tilt system as well as the temperature control and Data Acquisition Computer.**

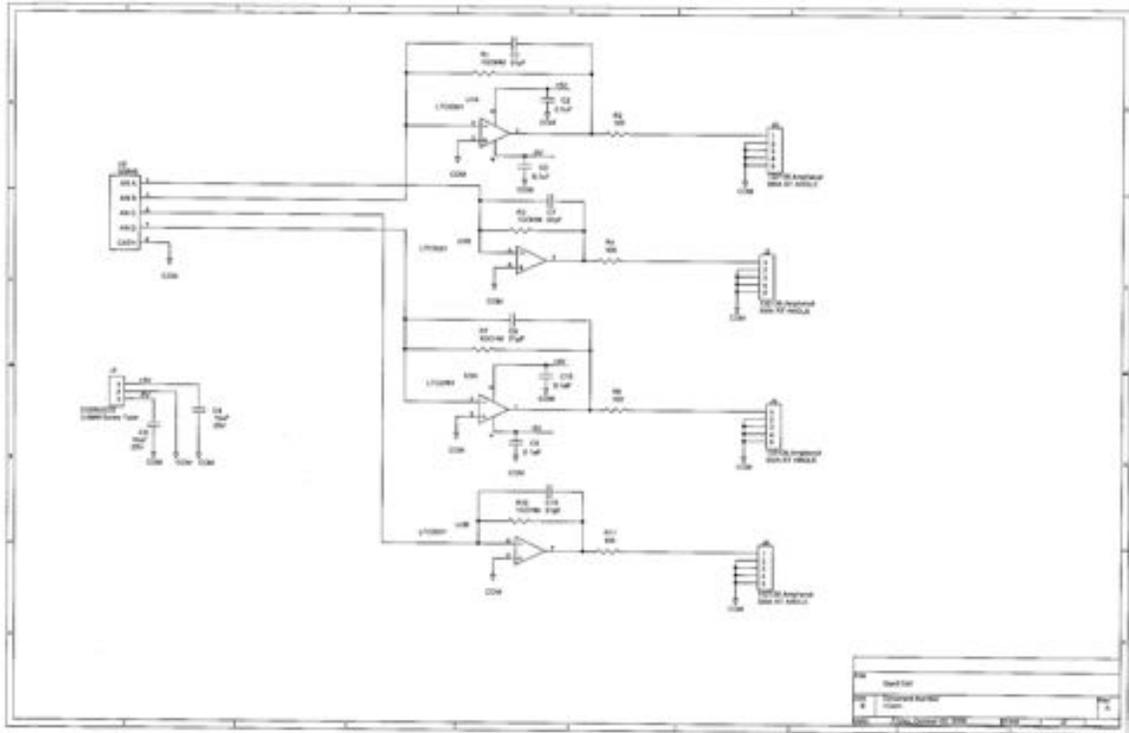
#### **2.1.4.2. Pre-photodiode Optics**

The pre-optics are composed of a flat mirror directly after the FPM, a 150mm focal length achromat 1-inch Thorlabs lens (part number AC254-150-C). This is mounted in a standard 1-inch mount on a post.

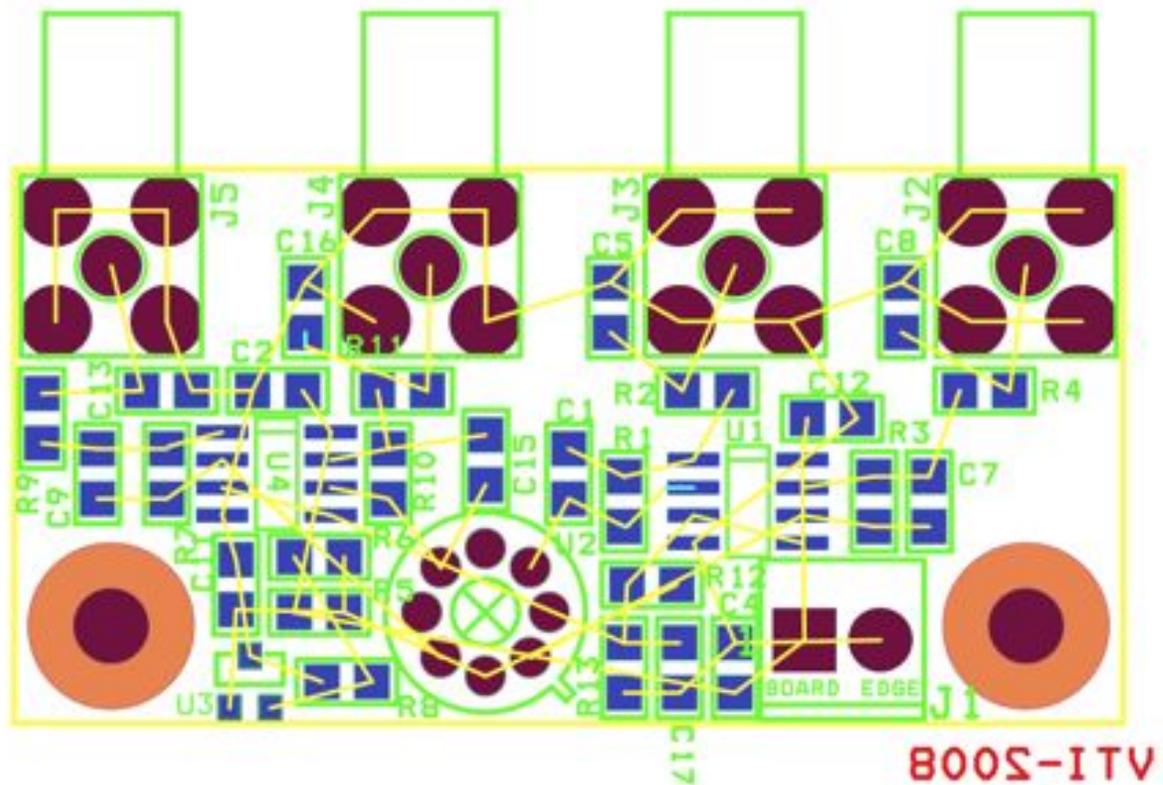
#### **2.1.4.3. Circuit diagrams**

The circuit diagram for the Hamamatsu IR sensor power supply is shown in the following diagram. The base power for the quad cell system is 120V, with an upper range of 13% (132V), and a lower range of 10% (104V). In the Cass cage, the voltage has dropped as low as 105V during the night, approaching the lower limit.

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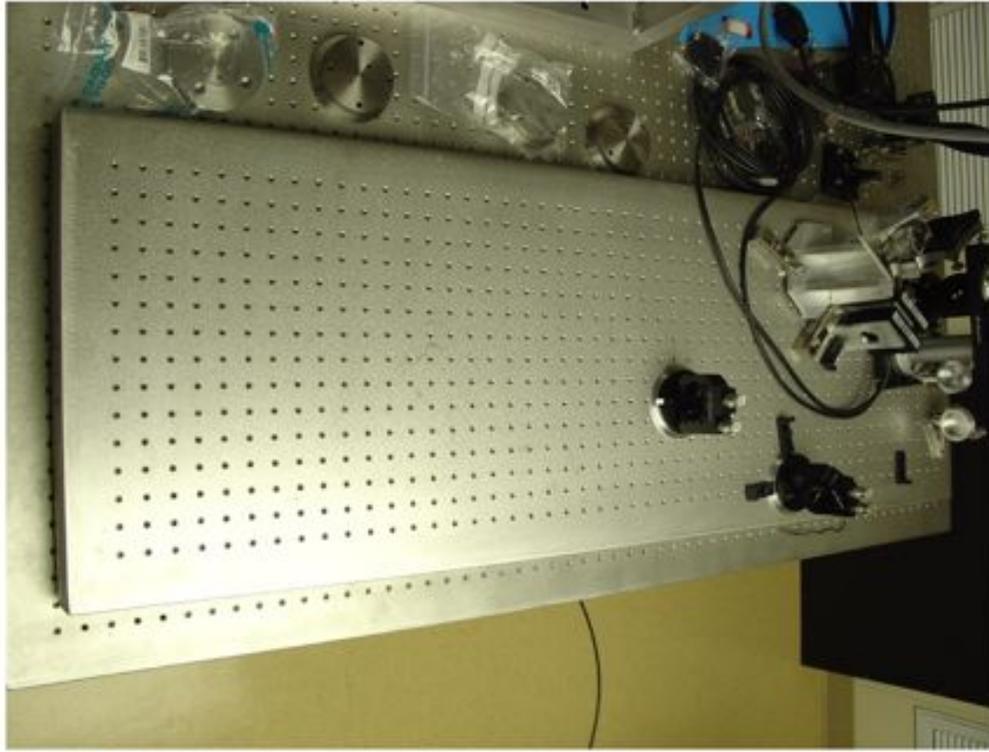
**Figure 34. Circuit Diagram for Hamamatsu infrared PIN photodiode quad-cell assembly.**



**Figure 35. Quad cell detector board layout. The individual quad cells are labelled J2-J5 in the diagram.**

### 2.1.5. Coronagraph Optical Bench

The coronagraph is a Thorlabs custom breadboard measuring 18" x 54" x 2.36". One side has a standard  $\frac{1}{4}$ -20 grid of 1-inch holes, while the other side has tapped holes for five custom mounting pucks (see below).



**Figure 36. The Thorlabs 18" x 54" coronagraph optical bench with several pieces of the coronagraph in place.**

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**Figure 37. The positions of the four pucks on the underside of the bench are marked on the work side of the bench.**

## 2.2. IFU

The second major component of Project 1640 is a lenslet-based integral field spectrograph (IFU hereafter) operating in the J and H bands ( $1.05 - 1.75\mu\text{m}$ ). The spectrograph is entirely encased in a cryogenic dewar that is cooled by liquid nitrogen operating at roughly  $10^{-7}$  Torr ( $\sim 10^{-4}$  mbar) when cold. Starting from the outside in, this section gives an overview of the primary components of the IFU: The cryogenic dewar, the optics and their mounts, and the detector system.

### 2.2.1. Dewar

Our cryogenic dewar is very similar to that used for the PHARO infrared camera at Palomar. Our dewar was built in 2006 by Precision Cryogenics in Indianapolis, Indiana. The dewar is made almost entirely of 6061-T6 Aluminum with an outer shell divided into an upper and lower part. The upper half ranges from  $\frac{1}{4}$  to  $\frac{3}{4}$  inches in thickness and provides strong support for the overall assembly, while the lower part is lighter weight. These two halves wrap around the workplate, the inner heat shields, and the two Liquid Nitrogen (LN<sub>2</sub>) tanks and each half has a  $\frac{3}{4}$  inch flange, or lip, where the two are joined. The optics workplate is comprised of a 1-inch thick, light-weight piece of Aluminum and is mounted to the outside of the dewar, at the lower flange, by four G-10 fiberglass mounting tabs. These tabs help the workplate to be thermally insulated from the outside of the dewar. The assembly has a mounting bracket (see Section below) to provide focus movement and prevent

any flexure while the telescope is rotated. While at Palomar, the whole assembly hangs down from the AO bench.

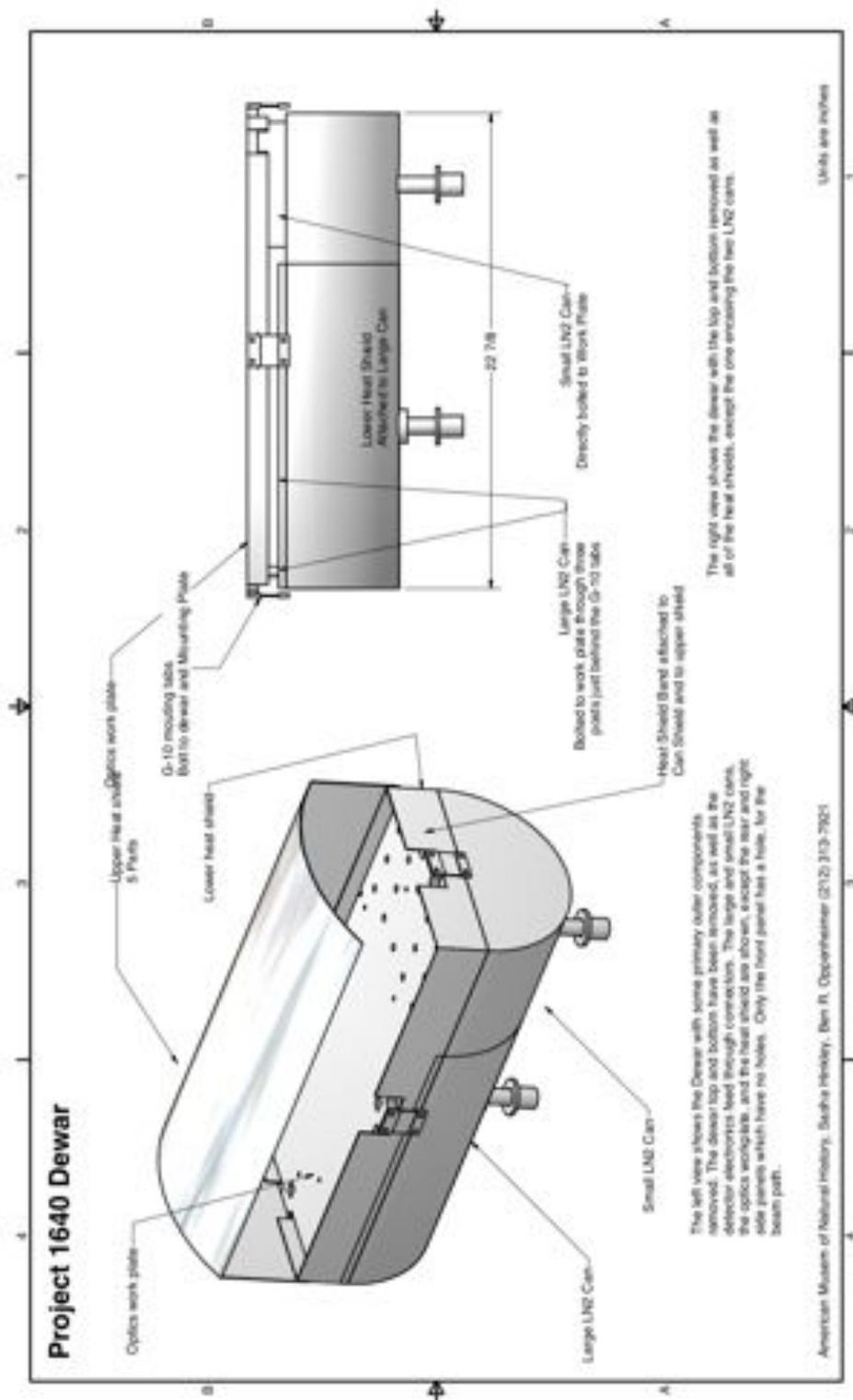
The bottom half of the Project 1640 dewar is the same as that for PHARO, but mirrored internally so that the detector is on the opposite end of the dewar from the window. We maintain our temperature near 77K, with 0.01 K rms stability. The LN2 fill holes are in the same place as on PHARO, but unlike PHARO's five ports, this dewar has four ports: two for the LN2 inputs into each can, one for the vacuum pump, and another for attachment of a vacuum gauge.

**Radiation shielding and Liquid Nitrogen tanks:** Inside the outer surface of the dewar are the upper and lower radiation shields. The shields are wrapped in multiple layers of mylar insulation. Like the PHARO dewar, the Project 1640 dewar has two separate LN2 tanks. The smaller, 3.3L inner can is directly bolted into the optics base plate via fourteen 10-32 screws. The underside of the baseplate has a region scalloped out for the small can for even more effective coupling between the two. The primary role of the small can is to provide a local heat sink for the detector and optics. The larger, 11L can maintains close contact with the radiation shield and serves as the more global dewar cooler. This large can is bolted to the workplate via three posts just behind the G-10 tabs. The dewar's internal parts remain at 77K for 60 hours without refilling the nitrogen tanks (see hold time plot below).

**Optics base plate:** All of the optical mounts for the IFU are mounted onto a single baseplate inside the dewar. This is a single, rectangular piece of 1-inch thick 6061-T6 Aluminum, 23 3/8" x 11/38 in size. Several regions have been scalloped out of the underside of the baseplate to reduce the weight of the piece. In addition a charcoal getter (for absorbing volatiles) wrapped in metal screen and aluminum foil has been installed on the underside of this plate.

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**Figure 39. Project 1640 Dewar showing radiation shielding and outer portions of Liquid Nitrogen tanks.**

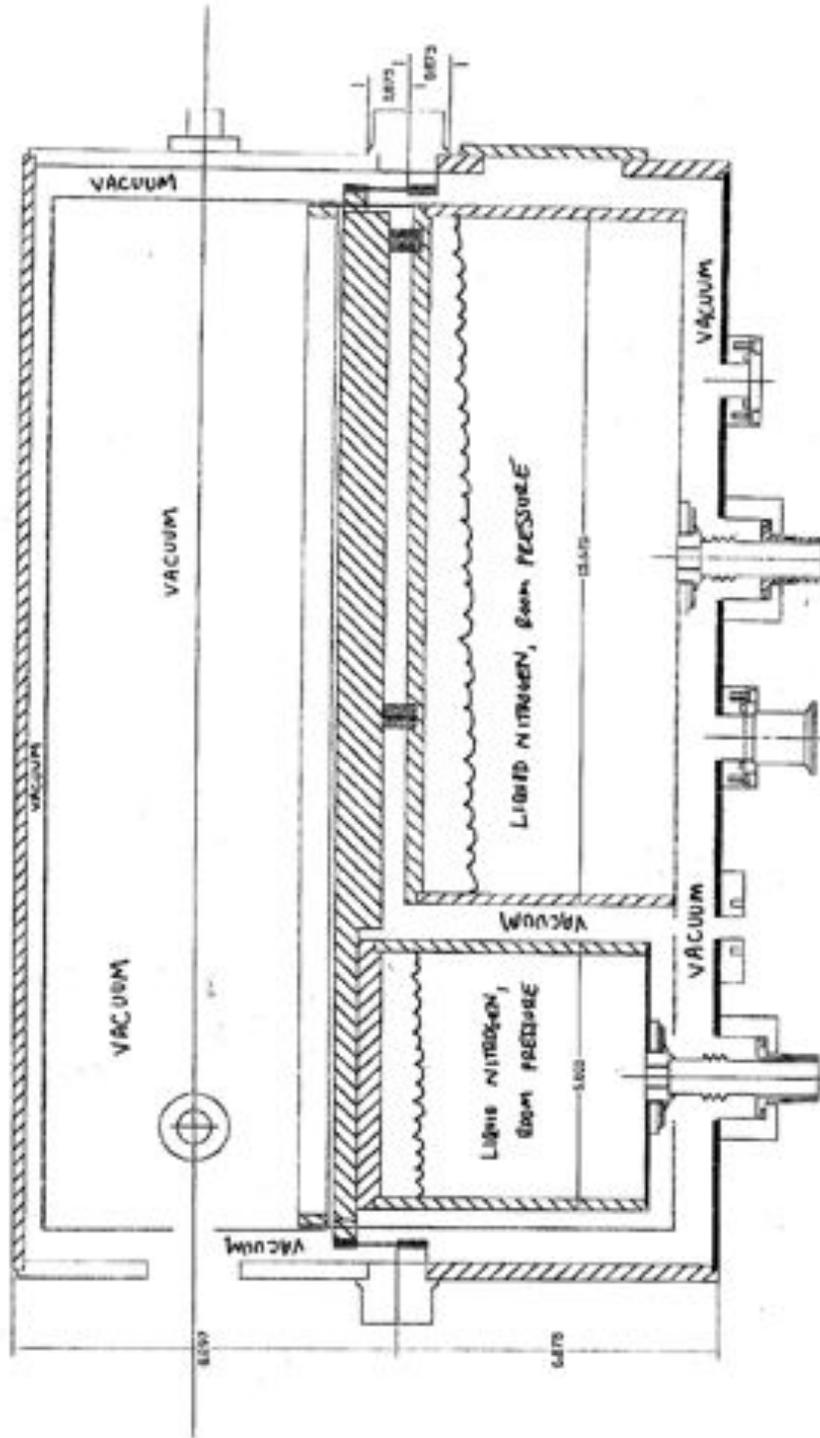


Figure 40. Production drawings showing internals of the P1640 Dewar.



**Figure 41. Lower wells in the P1640 dewar (left) and the small tank fill tube (right) showing its o-ring crucial for vacuum integrity.**

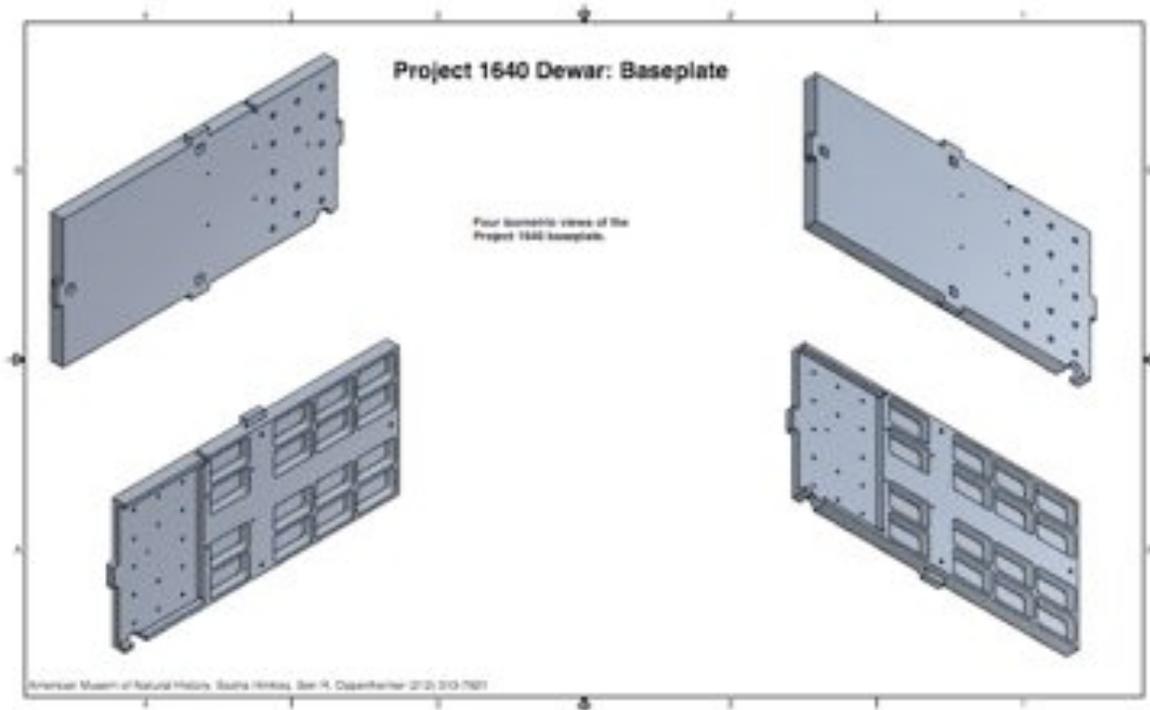


**Figure 42. The heatshield retaining rim being removed (left) and the two LN2 tanks after the optics plate has been removed (right). The small tank is evident on the right side with its fourteen 10-32 tapped holes. The large tank is soldered to the heat shield.**

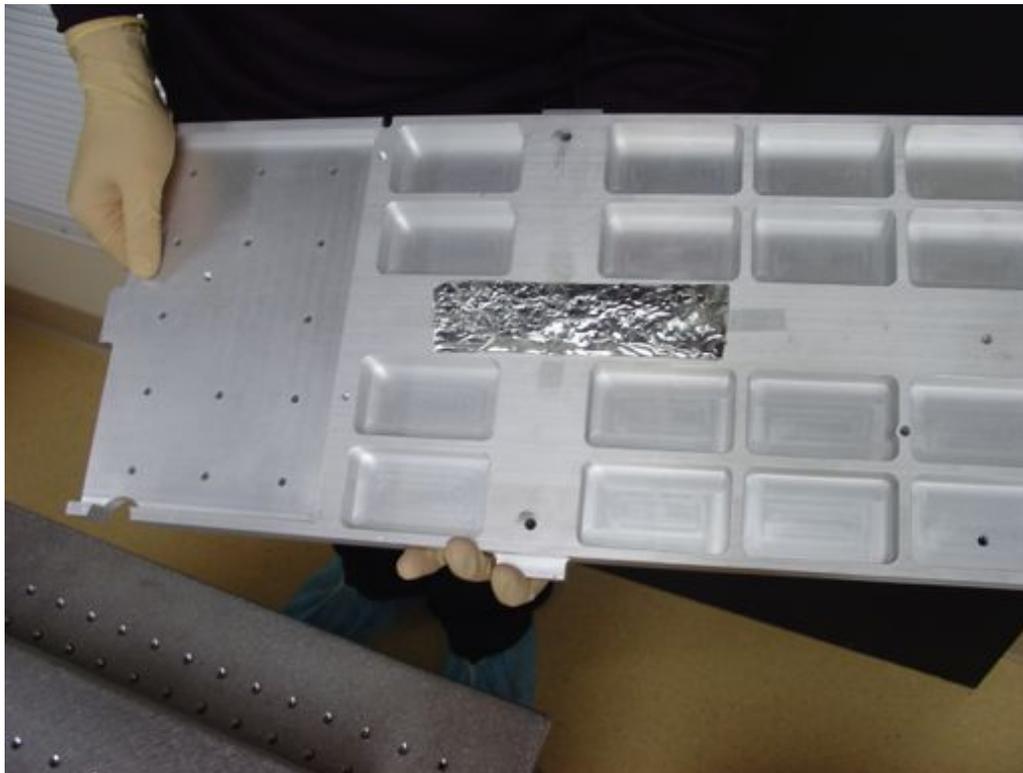








**Figure 46. Isometric views of the P1640 baseplate showing the region carved out for the small LN<sub>2</sub> tank, as well as the scalloped regions to reduce load.**



**Figure 47. The P1640 charcoal getter placement on the baseplate.**

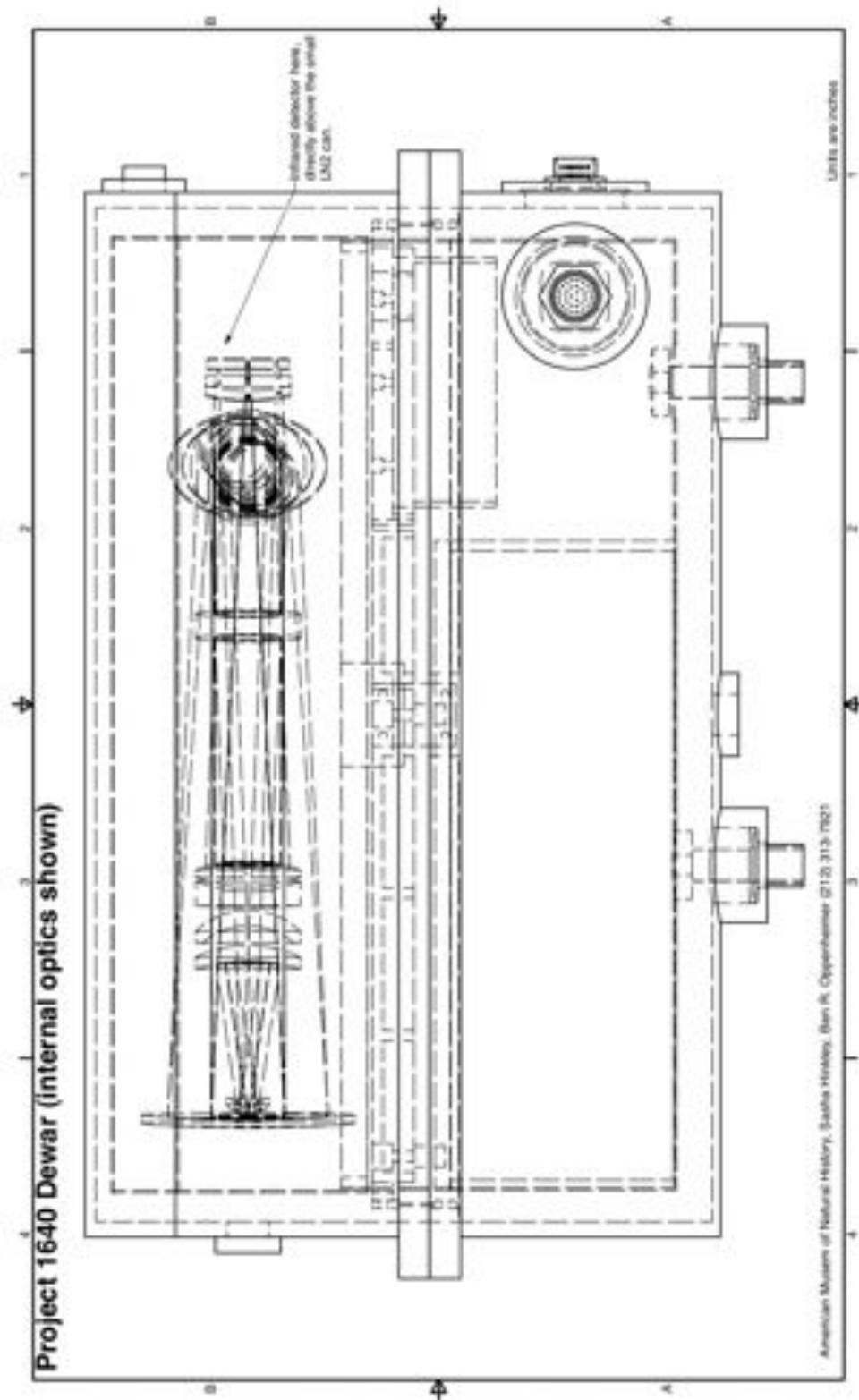


Figure 48. Dewar internals showing the placement of the optics.

**Dewar window:** The beam from the coronagraph enters the dewar through a single, 2-inch piece of  $\text{CaF}_2$  (1/2-inch thick) that has been anti-reflection coated for the region  $0.5 - 2.0 \mu\text{m}$ . This is sealed against the dewar via an o-ring, a trough for which has been milled into the outside of the dewar (see photo). The window is kept firm in place via a brass outer housing, which is bolted directly to the outer shell of the dewar.



**Figure 49. The dewar window o-ring (left) and the window with its blanking plate (right).**

### 2.2.2. Dewar Snout

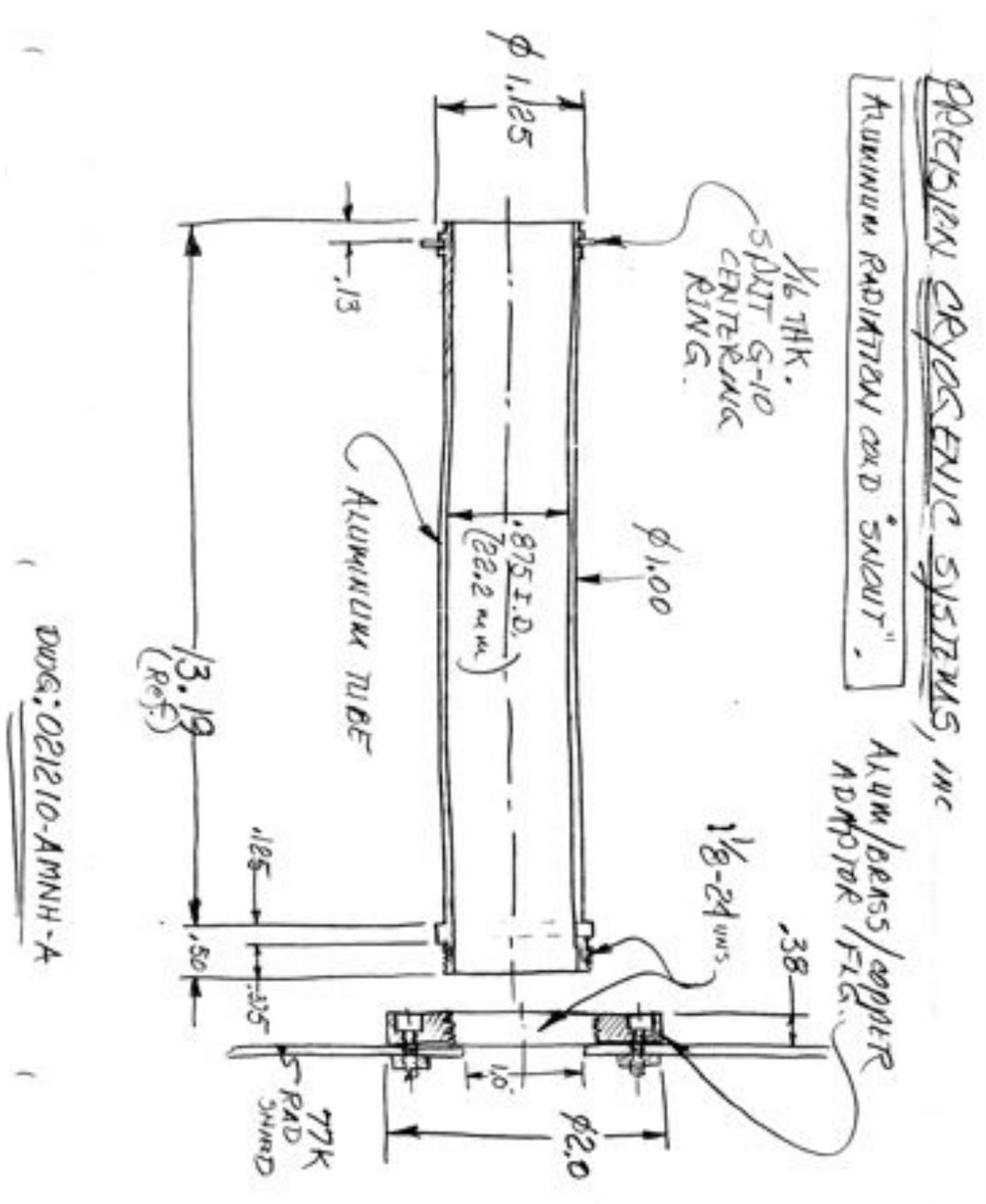


Figure 50. Internal blackened tube for the dewar snout. This piece is cryogenic.

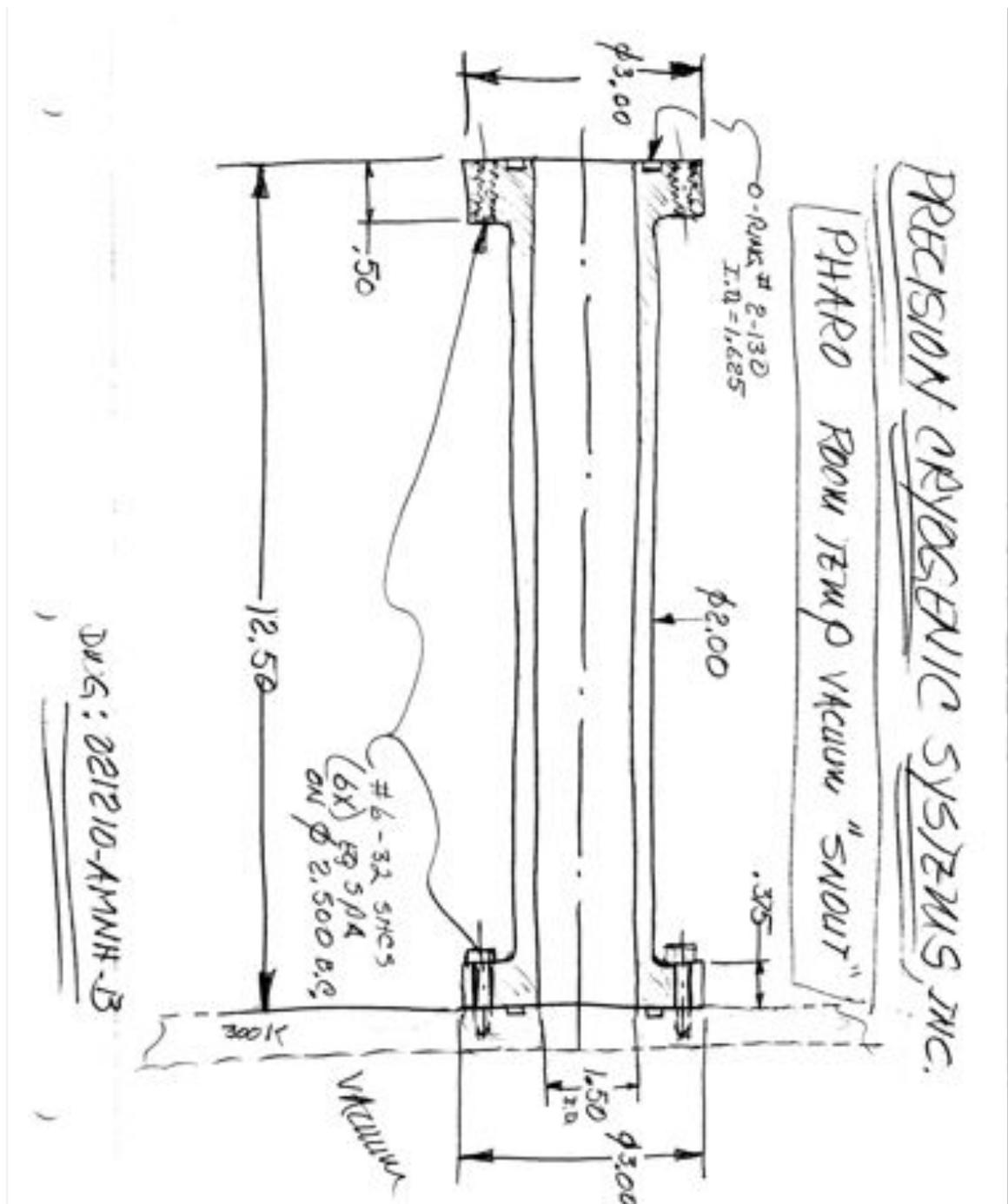
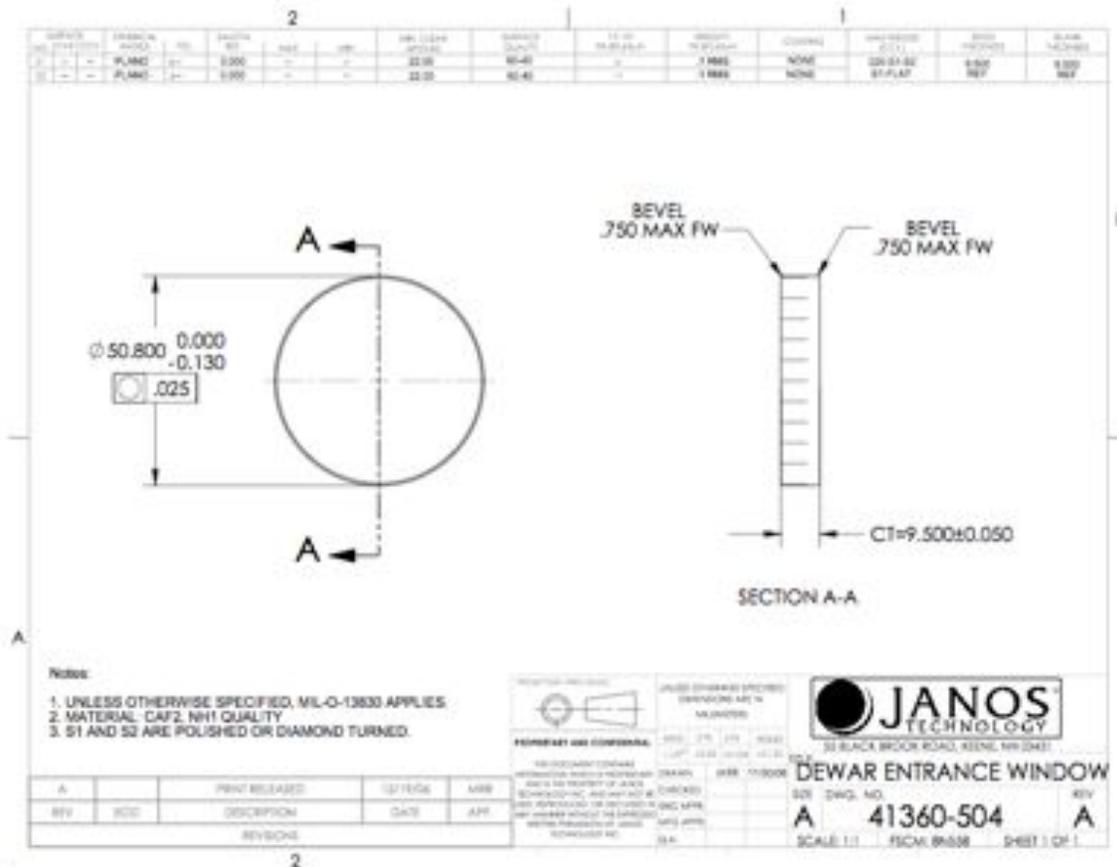


Figure 51. The outer, warm portion of the dewar snout. This piece is screwed directly into the outer wall of the dewar.



**Figure 52. The CaF<sub>2</sub> dewar window.**

### 2.2.3. Optical Design and Optics

The optical design for our integral field spectrograph is shown in the Figure below. The overall design can be categorized into four components: a lenslet array; a dioptric collimator with a 200 mm focal length consisting of five lenses made up of three different glasses (SK8, SF2, BaF<sub>2</sub>) which re-images the telescope pupil on the prism; a prism/disperser element; and a camera component. All our transmissive optics, except for the lenslet array were manufactured by Janos Technology, while the reflective optics were manufactured by Axsys technologies. We discuss each of these components in more detail below.

The optical design has been fully modeled using the Zemax design software, including the effects of thermal contraction as the system is cooled. The system does not perform at room temperature. All optics with the exception of the lenslet array are oriented square with the optics baseplate. The lenslet array is rotated 18.43°. The prism is oriented to disperse the light parallel to the workplate. This places the detector square with the mounting plate as well, requiring only a rotation on the lenslet array. Wavelength filtering is achieved with J and H-band filter (1.05 – 1.75 μm), with OD3-OD4 blocking outside this range, placed directly in front of the detector.

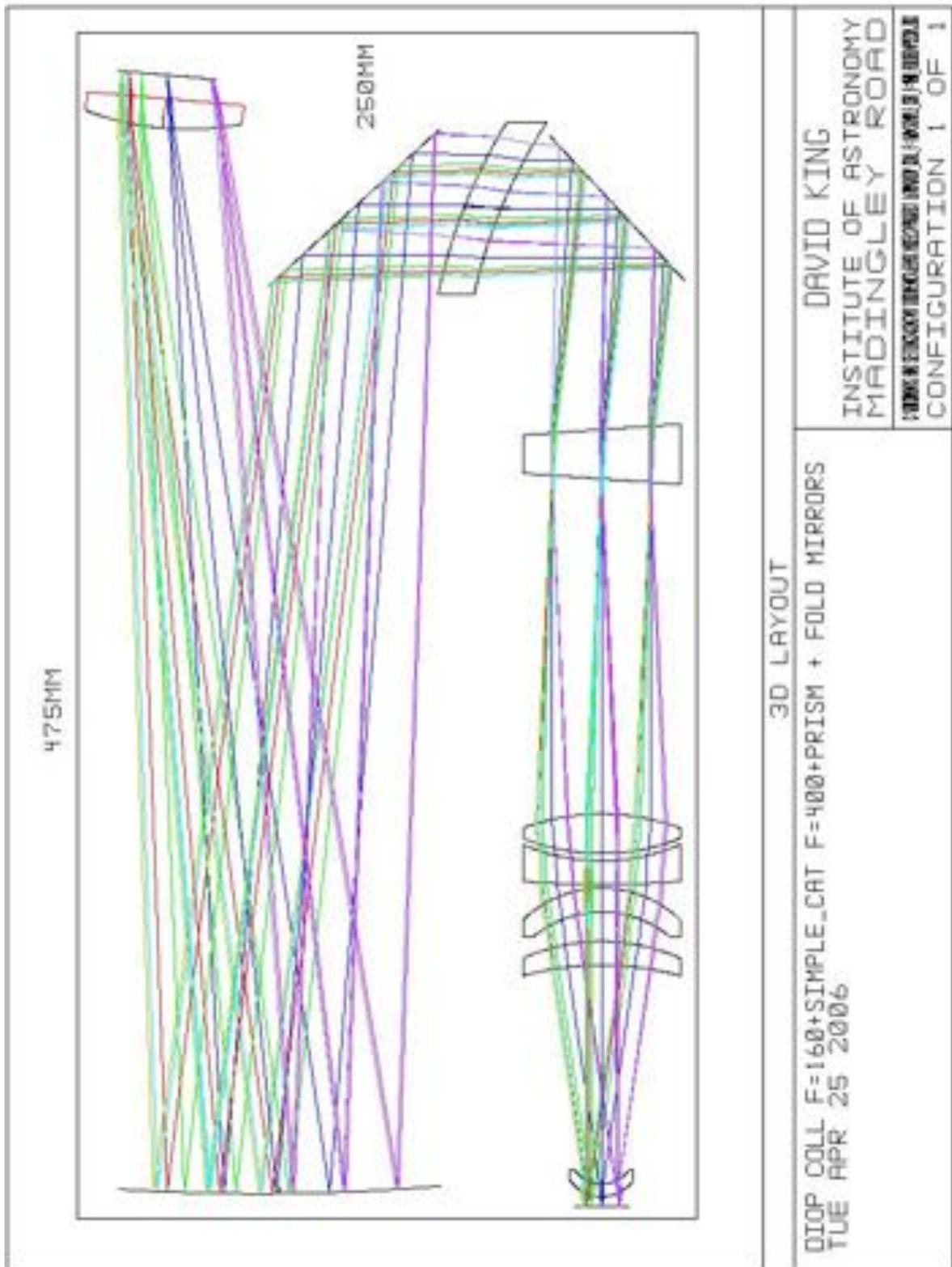
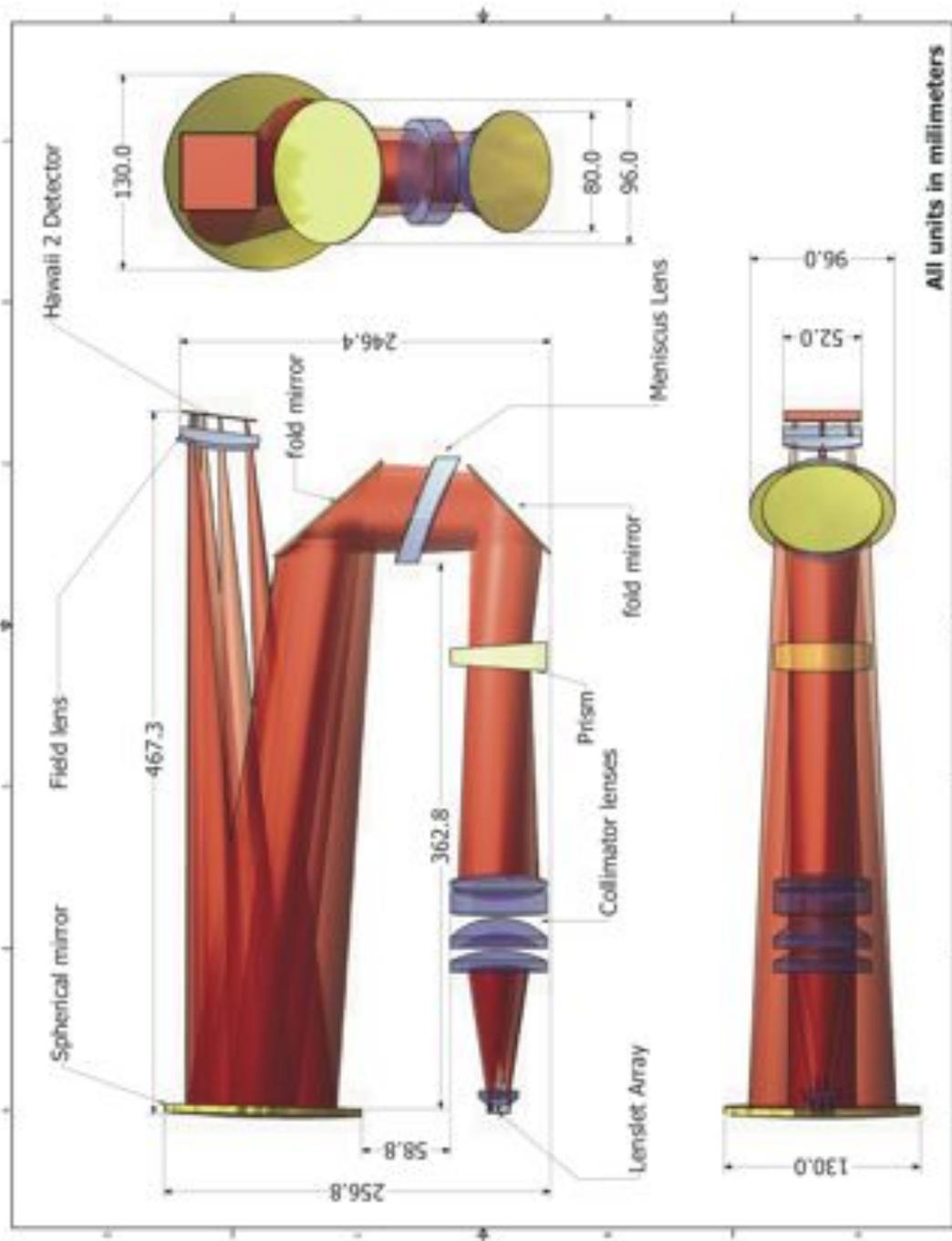


Figure 53. Zemax layout of optical design.

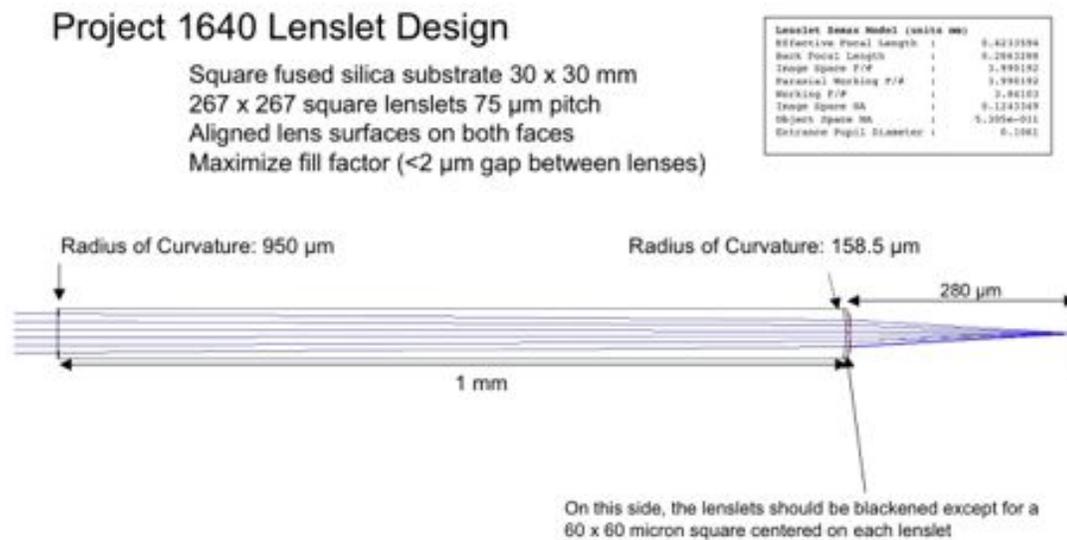


**Figure 54. Optical Layout of the P1640 IFU.**



### 2.2.3.1. Microlens Array

The square lenslet array, manufactured by MEMS Optical (Boston), consists of two powered faces etched into a 1mm thick wafer of fused silica. The first face, placed in the focal plane at the output of our coronagraph, has lenslets with a radius of curvature of 950  $\mu\text{m}$  and is primarily used to separate the light from each segment of the image, so that the higher powered exit surface retains as much of the light as possible (with minimal loss due to roll-over between the lenslets). The rear face lenslets have a 159  $\mu\text{m}$  radius of curvature to create the pupil images 280  $\mu\text{m}$  behind the lenslet array substrate. The effective f-number of each lenslet is  $f/4$ , measured using the diagonal of each square lenslet (106.1  $\mu\text{m}$ ). Each lenslet has a pitch of 75  $\mu\text{m}$ . We have 270 x 270 lenslets on our array, but only use 200 x 200 lenslets. The array is mounted 4mm directly in front of the first lens of the collimator. The table below lists many of the characteristics of the array.



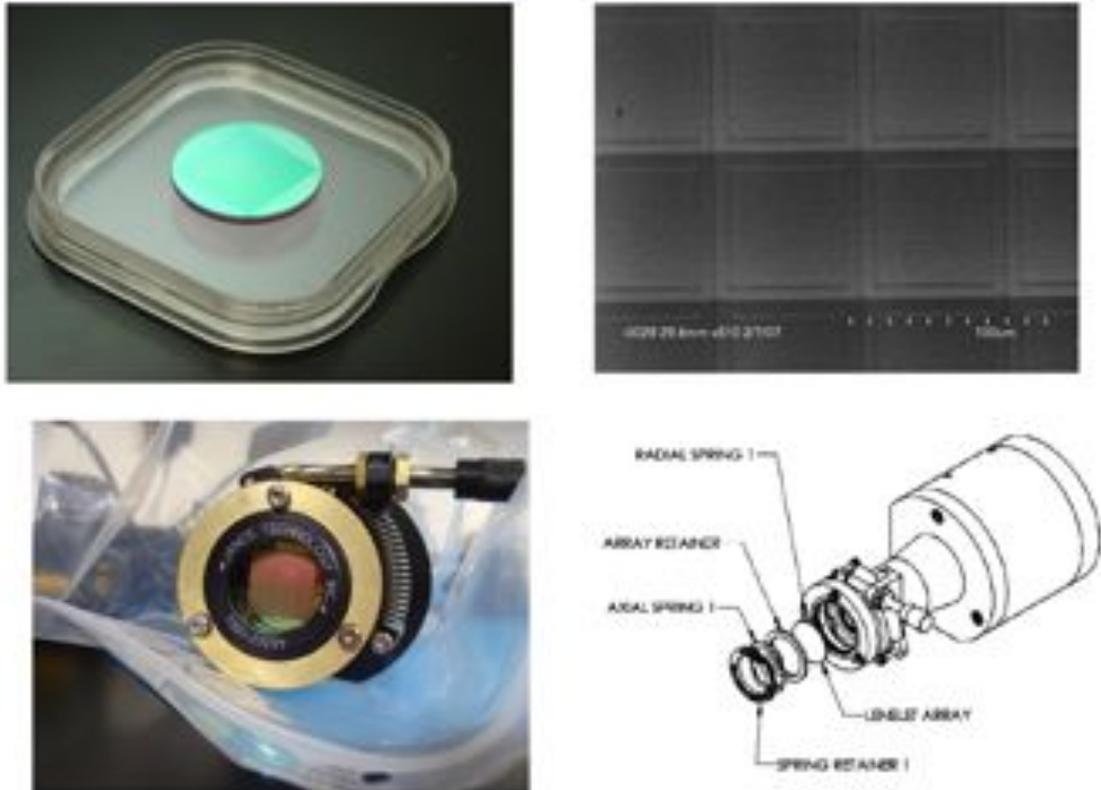
**Figure 56. Lenslet Array Design Specs.**

The exact clocking of the lenslet array can be changed with the turnable knob on the front of the collimator housing. This adjustment knob has fine-threaded screw (100 threads/inch—**CHECK THIS!!**), so the rotation can be controlled easily. The clocking assembly has a retaining spring against which this fine threaded screw works. The assembly can occasionally become sticky, and the rotation may need to be assisted manually, i.e. just rotating the threaded knob may not always be sufficient. The lenslet array is kept in its housing by means of a retaining ring and a wave spring. See figure below.

#### **Procedure for inserting lenslet array into collimator housing:**

- 1) Use an adjustable spanning wrench to remove the outer spring retainer. Size 2-56 screws may be used to remove the retaining ring if a spanner wrench is not available.
- 2) Remove “axial spring 1” and “array retainer”
- 3) Insert lenslet array into assembly V-groove

- 4) Compress provided “radial spring 1” and place above lenslet array. Verify that the spring holds the array into the groove. Use caution when installing the spring, as deflection beyond nominal may affect the integrity of the spring.
- 5) Insert “array retainer” and “axial spring 1” into the assembly
- 6) Insert “spring retainer 1” and turn the retainer until the engraved surface is flush with the assembly face to achieve the proper spring compression.



**Figure 57. Top row: the lenslet array (left) and SEM detail of the structure. Bottom row: the lenslet in its housing in the collimating assembly (left) and an exploded view of the lenslet assembly (right).**

**Table 4. Original manufacturing specs for MEMS Optical microlens array.**

Parameter	Value
Wavelength	1.0 – 1.8 $\mu\text{m}$
Lens pitch	75 $\mu\text{m}$ x 75 $\mu\text{m}$
Radius of Curvature Side 1	950 $\mu\text{m}$
Clear Aperture Side 1	73.5 $\mu\text{m}$ square
Radius of Curvature Side 2	158.5 $\mu\text{m}$
Clear Aperture Side 2	60 $\mu\text{m}$ square

Wafer diameter	30.00mm
Substrate Material	IR grade fused silica
Substrate Thickness	1.00mm
AR coating	Both sides.

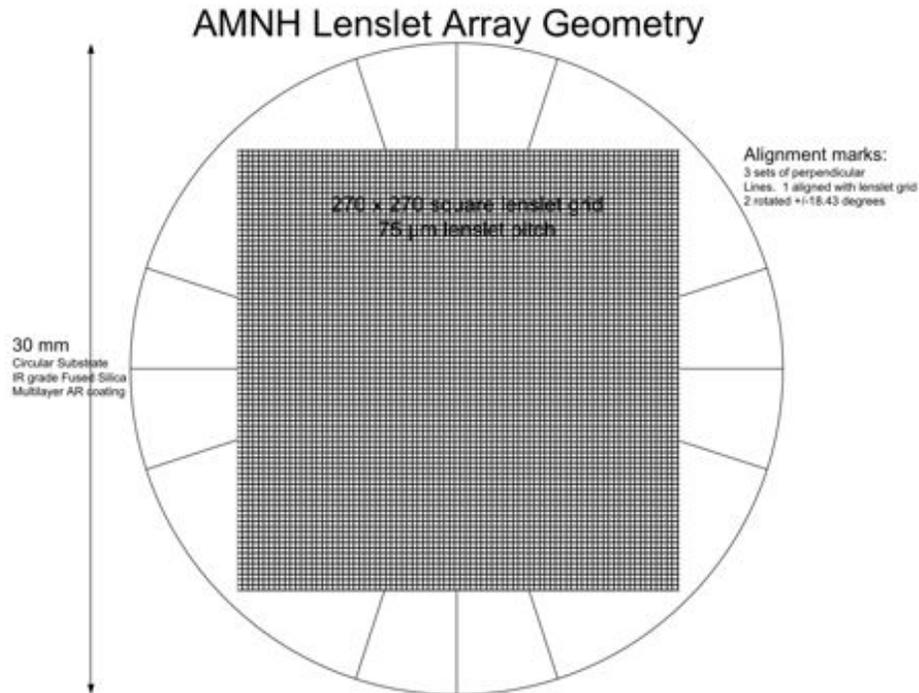
**Table 5. Fitted radii of curvature for lenslets.**

Wafer ID	T4F (mm)	T4B (mm)	T6F (mm)	T6B (mm)
<b>1</b>	.93280	.15740	.93200	.16050
<b>2</b>	.93310	.15890	.94380	.15930
<b>3</b>	.94190	.15840	.92020	.16270
<b>4</b>	.94450	.15720	.94450	.16060
<b>5</b>	.97110	.15480	.97630	.15970
<b>6</b>	.94090	.15760	.94410	.15960
<b>7</b>	.92970	.15780	.94890	.16040
<b>8</b>	.94250	.15710	.96540	.15990
<b>9</b>	.93430	.15610	.94950	.16060
<b>10</b>	.92980	.15680	.93280	.16010
<b>Average:</b>	.94006	.15721	.94575	.16034
<b>Std Dev:</b>	.0122	.0012	.0162	.001
<b>P-V Nonuniformity</b>	2.20%	1.30%	2.97%	1.06%
<b>Deviation from Design RoC:</b>	-1.05%	-0.81%	-0.45%	1.2%

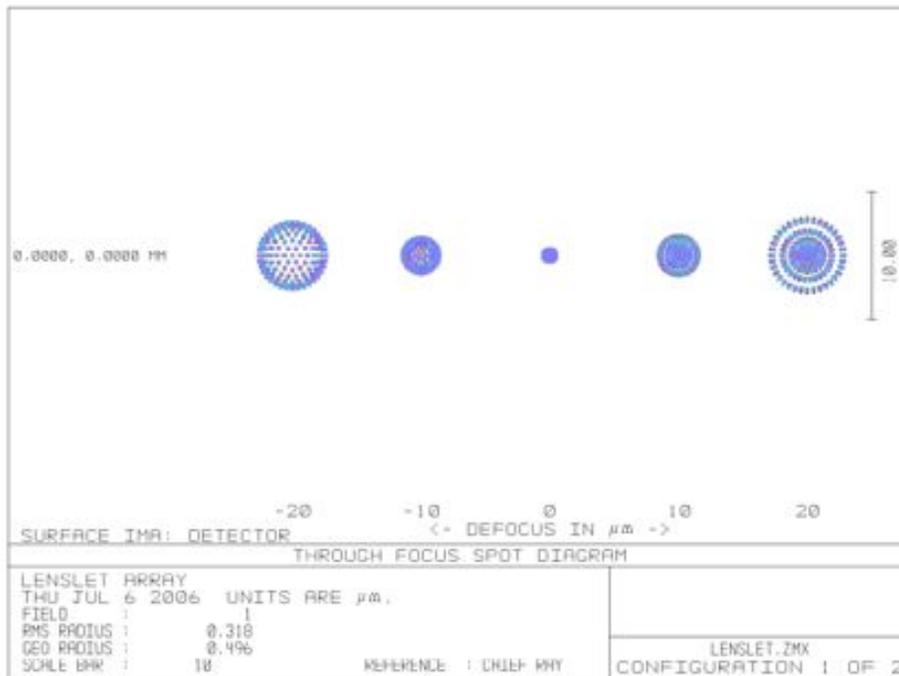
**Table 6. Wave front errors for the 10 lenslet wafers. The first value in each cell is the RMS, the second is peak-to-valley. Both the RMS and the peak to valley values are listed as their fraction of a wavelength at 1.65 $\mu$ m.**

Wafer	T4F (nm)	T4B (nm)	T6F (nm)	T6B (nm)
1	6 ( $\lambda/600$ ),50 ( $\lambda/72$ )	22 ( $\lambda/163$ ),184 ( $\lambda/19$ )	6 ( $\lambda/600$ ),47 ( $\lambda/76$ )	22 ( $\lambda/163$ ),498 ( $\lambda/7$ )
2	6 ( $\lambda/600$ ),42 ( $\lambda/85$ )	20 ( $\lambda/180$ ),467 ( $\lambda/7$ )	7 ( $\lambda/514$ ),60 ( $\lambda/60$ )	23 ( $\lambda/156$ ),174 ( $\lambda/20$ )
3	6 ( $\lambda/600$ ),43 ( $\lambda/83$ )	20 ( $\lambda/180$ ),161 ( $\lambda/22$ )	7 ( $\lambda/514$ ),45 ( $\lambda/80$ )	19 ( $\lambda/189$ ),167 ( $\lambda/21$ )
4	6 ( $\lambda/600$ ),51 ( $\lambda/70$ )	23 ( $\lambda/156$ ),168 ( $\lambda/21$ )	5 ( $\lambda/720$ ),46 ( $\lambda/78$ )	20 ( $\lambda/180$ ),311 ( $\lambda/11$ )
5	7 ( $\lambda/514$ ),56 ( $\lambda/64$ )	23 ( $\lambda/156$ ),182 ( $\lambda/19$ )	7 ( $\lambda/514$ ),52 ( $\lambda/69$ )	21 ( $\lambda/171$ ),347 ( $\lambda/10$ )
6	6 ( $\lambda/600$ ),46 ( $\lambda/78$ )	21 ( $\lambda/171$ ),428 ( $\lambda/8$ )	6 ( $\lambda/600$ ),47 ( $\lambda/76$ )	23 ( $\lambda/156$ ),288 ( $\lambda/12$ )
7	6 ( $\lambda/600$ ),44 ( $\lambda/81$ )	22 ( $\lambda/163$ ),171 ( $\lambda/21$ )	6 ( $\lambda/600$ ),50 ( $\lambda/72$ )	19 ( $\lambda/189$ ),149 ( $\lambda/24$ )
8	6 ( $\lambda/600$ ),46 ( $\lambda/78$ )	25 ( $\lambda/144$ ),220 ( $\lambda/16$ )	6 ( $\lambda/600$ ),44 ( $\lambda/81$ )	23 ( $\lambda/156$ ),243 ( $\lambda/14$ )
9	6 ( $\lambda/600$ ),43 ( $\lambda/83$ )	21 ( $\lambda/171$ ),169 ( $\lambda/21$ )	6 ( $\lambda/600$ ),50 ( $\lambda/72$ )	19 ( $\lambda/189$ ),189 ( $\lambda/19$ )
10	6 ( $\lambda/600$ ),43 ( $\lambda/83$ )	23 ( $\lambda/156$ ),194 ( $\lambda/18$ )	5 ( $\lambda/720$ ),44 ( $\lambda/81$ )	19 ( $\lambda/189$ ),187 ( $\lambda/19$ )

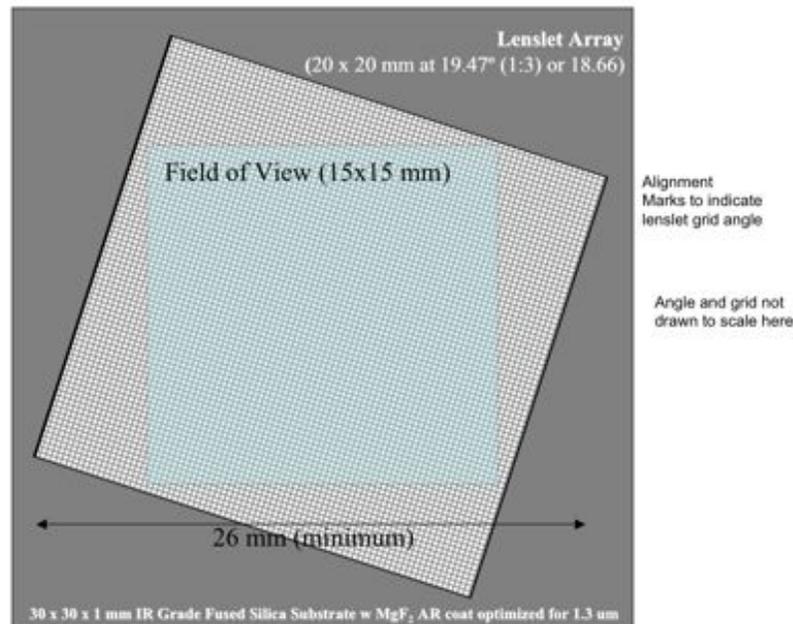




**Figure 59. Machine drawing of the microlens array. The lines going off at 18.43 degrees from vertical define our degree of rotation.**



**Figure 60. Zemax spot diagrams showing lenslet array defocus.**



**Figure 61. The IFU field of view superimposed onto the rotated lenslet array (schematic).**

### 2.2.3.2. Collimating Optics

The collimator assembly consists of five lenses mounted in a single housing. The lens materials are: BaF<sub>2</sub>, SF<sub>2</sub>, and SK8 (detailed drawings of each lens are given in the appendix). The collimator forms 40 mm pupil images at the prism's incident surface. The collimator assembly is secured to its mount via four 8-32 screws from the underside. The mount is a single piece of aluminum which serves also as the mount for the prism. Using a single mount ensures alignment and stability between the collimator assembly and the prism. This mount (drawing below) is attached to the optics baseplate via six 1/4 – 20 screws (The baseplate has six tapped holes for the mount). The position of this mount, relative to the baseplate is shown in a drawing below. The position of this mount is critical for the overall performance of the instrument. The collimator assembly housing and the prism are mounted at different heights, so the portion of the mount containing the prism is raised slightly to achieve the proper height for the prism.

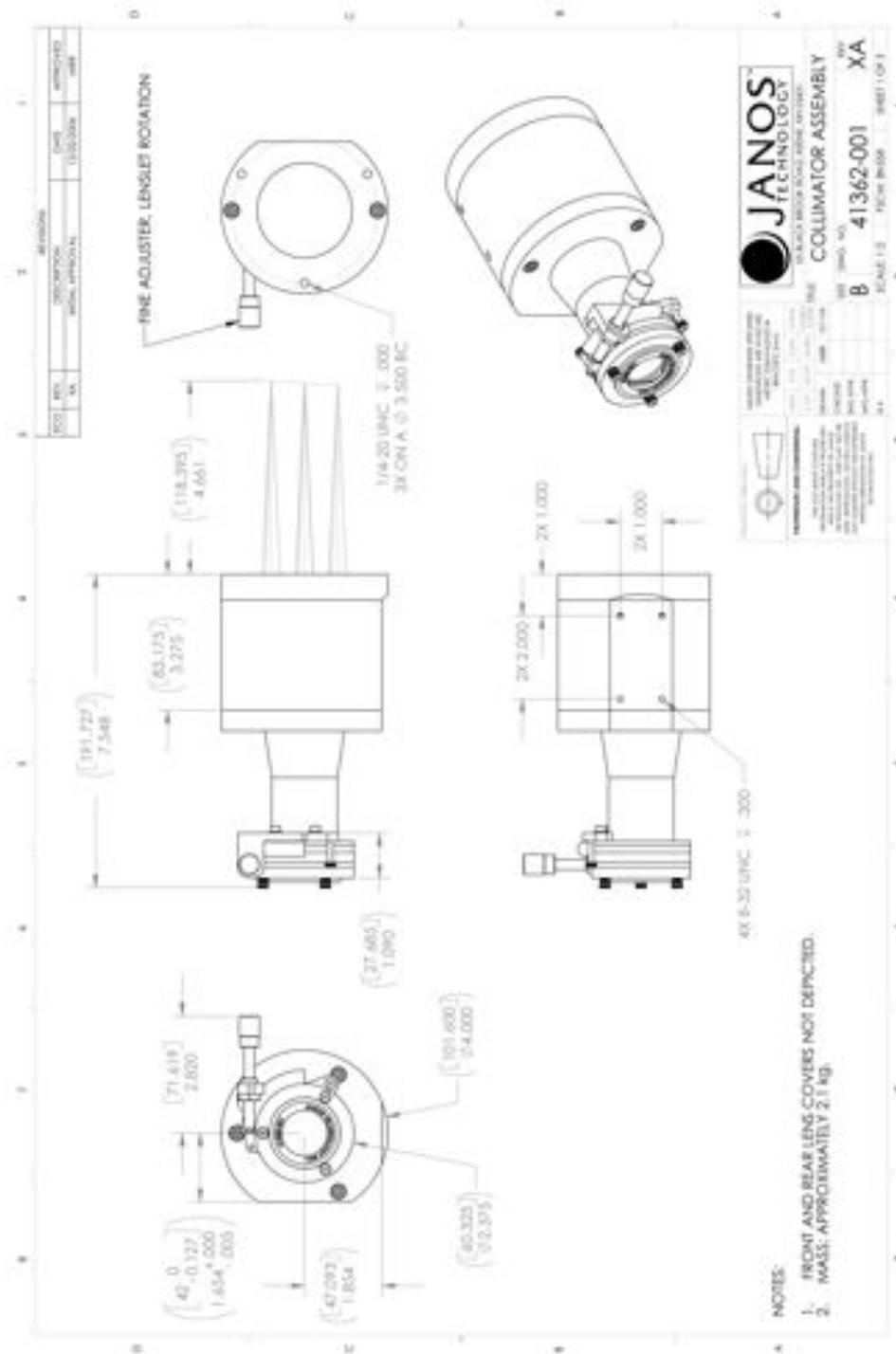
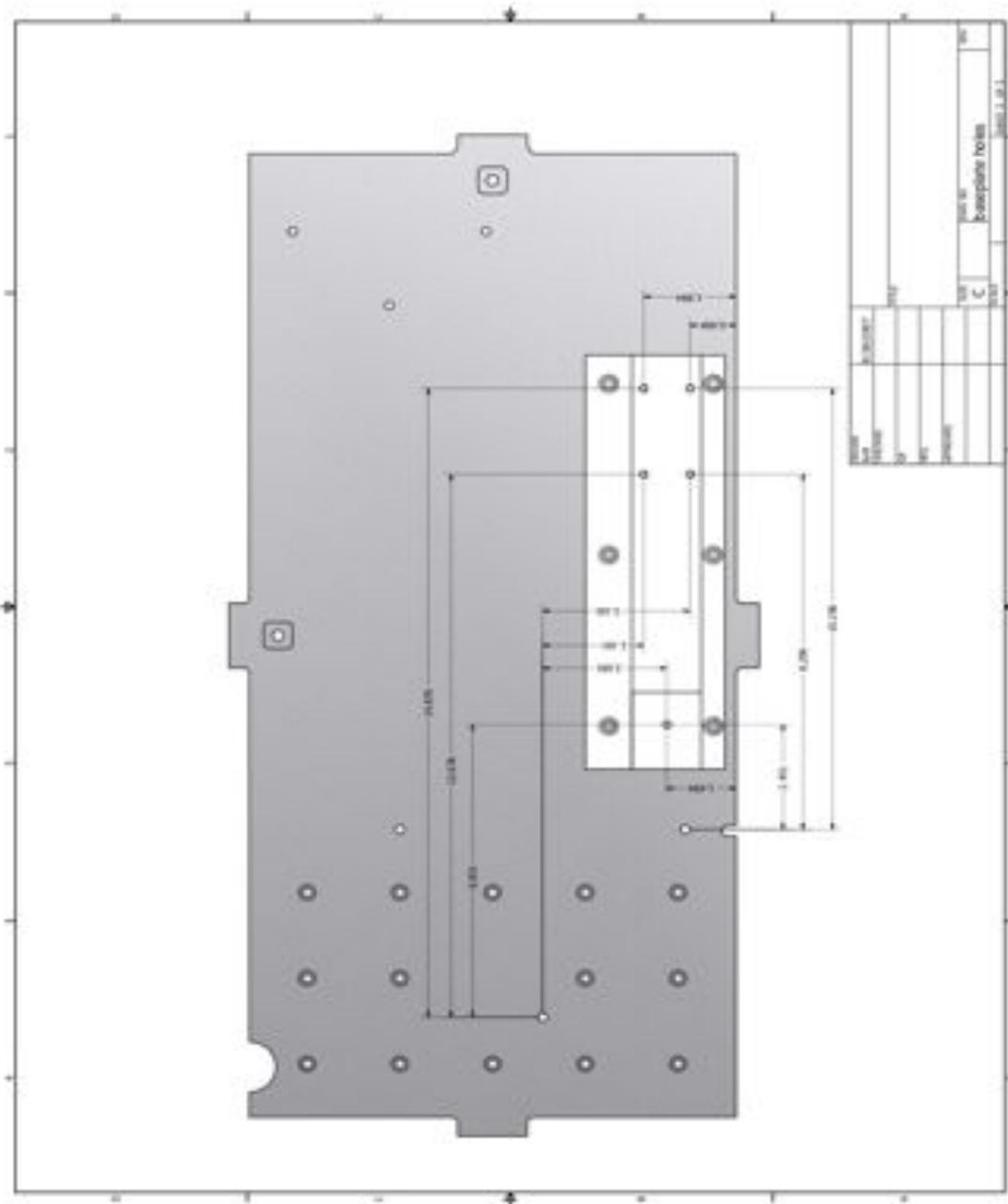


Figure 62. Machine drawings for the collimating assembly holder.

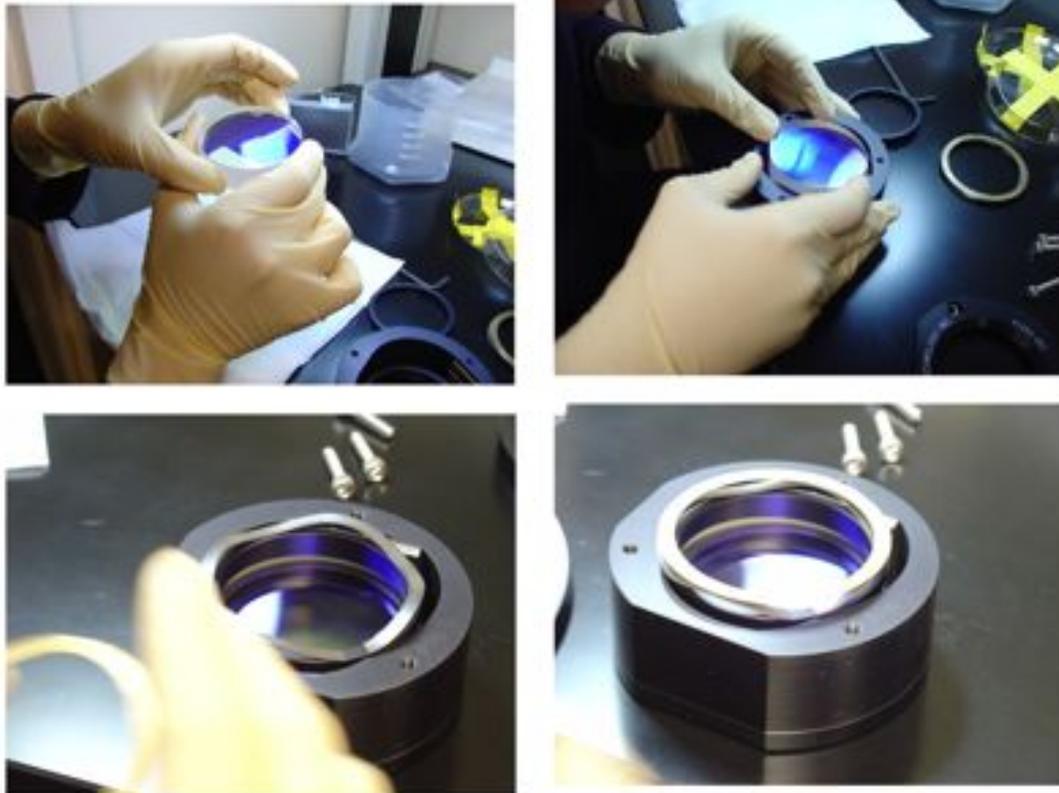




**Figure 64. The placement of the collimator and prism mount relative to the optics plate. The six 1/4-20 tapped holes for the mount were drilled according to their location relative to the Axsys mount holes as shown.**

### 2.2.3.3. Prism/Dispersing Element

Our prism is a single piece of BK7 glass, with a wedge angle of  $4^\circ$  on each face, 60mm in diameter and a central thickness of 15.135mm. This prism is optimized for the wavelength range ( $1.05 - 1.75 \mu\text{m}$ ) with a dispersion direction parallel with the plane of the workplate. The prism is secured in its housing via a wave spring and a retaining ring. Three 10-32 screws secure the housing face, and hence the prism, to the rest of the housing.



**Figure 65. The JH prism: This montage shows the prism being mounted into its mount. Note that the wave spring needs to be mounted prior to the retaining ring (bottom row).**

The prism assembly shares the same mount as the collimator assembly. This assembly rests on a portion of the mount that has been raised slightly, due to the varying heights between the collimator and the prism. We have also developed a customized pupil mask to be placed onto the prism mount. This prevents stray light from entering into the optical path. This mask is secured onto the prism mount via the three 10-32 screws. However, washers are necessary on each of the screws to act as spacers and ensure that the mask does not make contact with the prism.

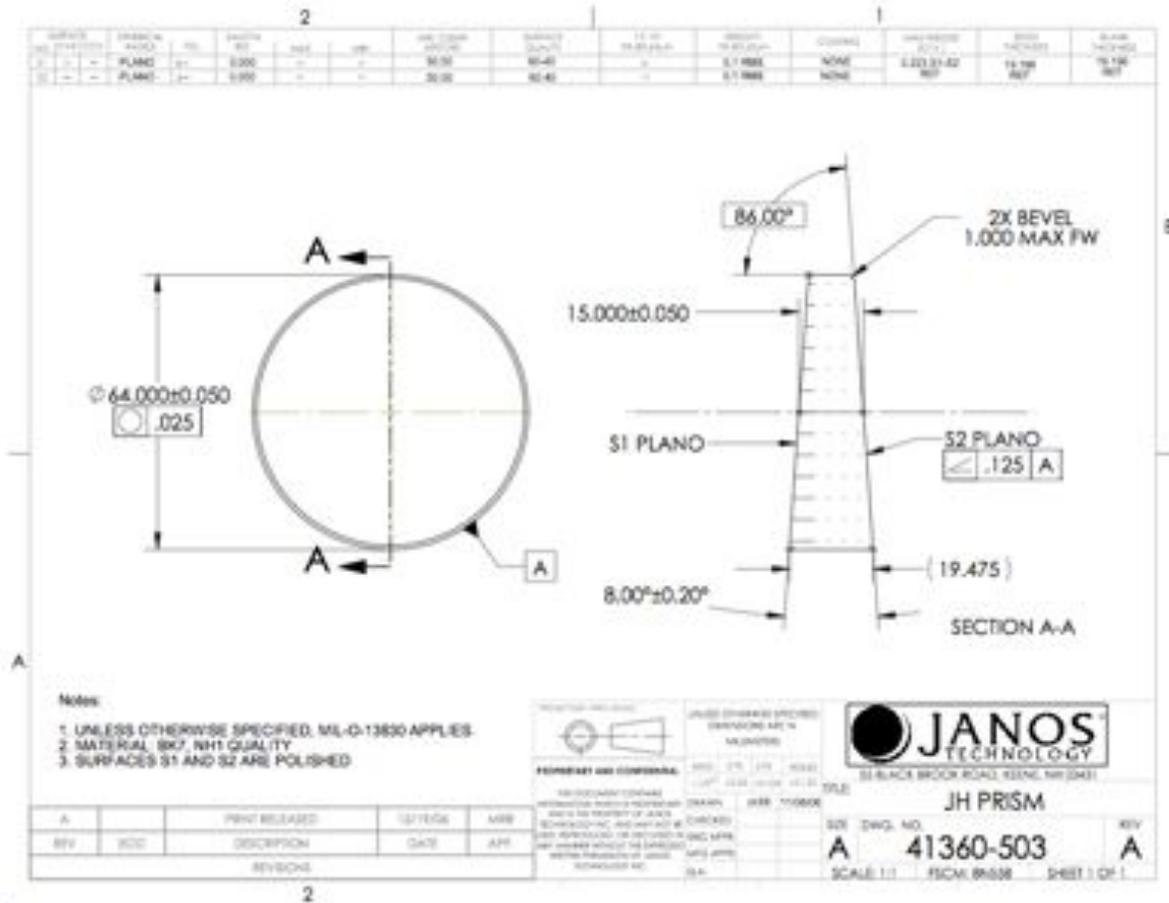
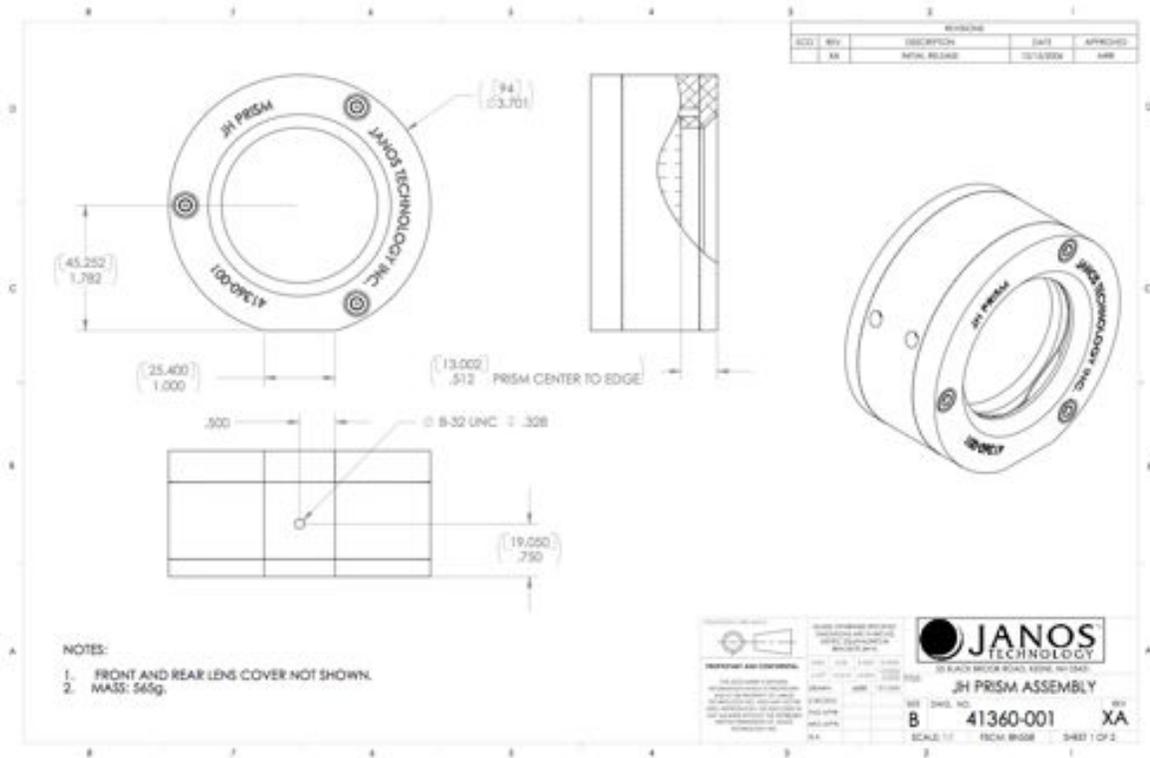


Figure 66. Design drawings for the prism.



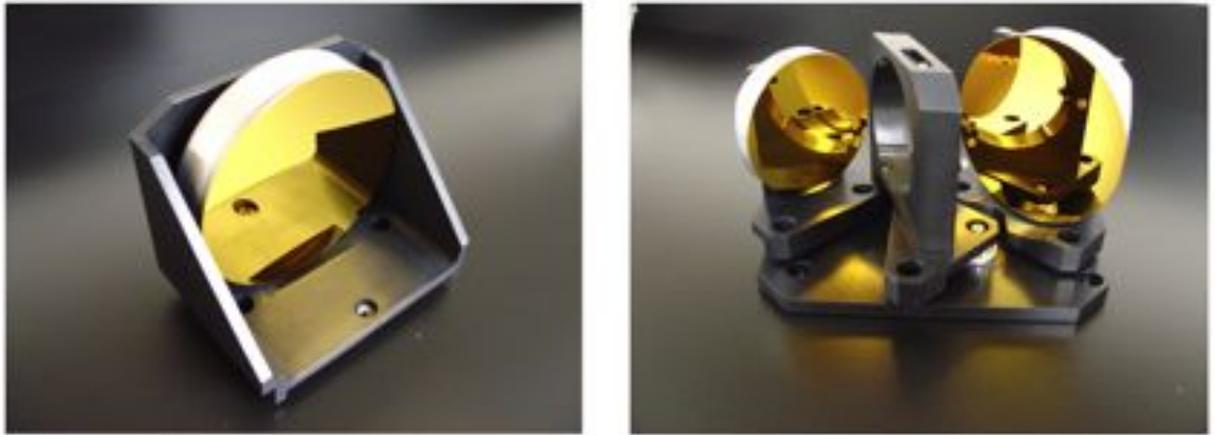
**Figure 67. Machine drawings for the prism assembly.**



#### 2.2.3.4. Camera Optics

The camera portion of the spectrograph consists of a meniscus corrector lens, spherical mirror, and a field-flattening lens (“field lens”) in front of the detector. Two fold mirrors accommodate the packaging of the instrument and a spherical mirror brings the beam to a focus on the detector

**Reflective Optics:** The sphere has a radius of curvature of 888.226 mm and a diameter of 130 mm. We also utilize two fold mirrors to accommodate packaging. All mirrors are made of diamond turned aluminum, coated with nickel, polished to  $\lambda/20$  RMS surface error.



**Figure 69. The Spherical mirror, which forms an image on the focal plane array (left) and the fold/meniscus lens assembly. All mirrors are diamond turned aluminum, coated with nickel followed by gold.**

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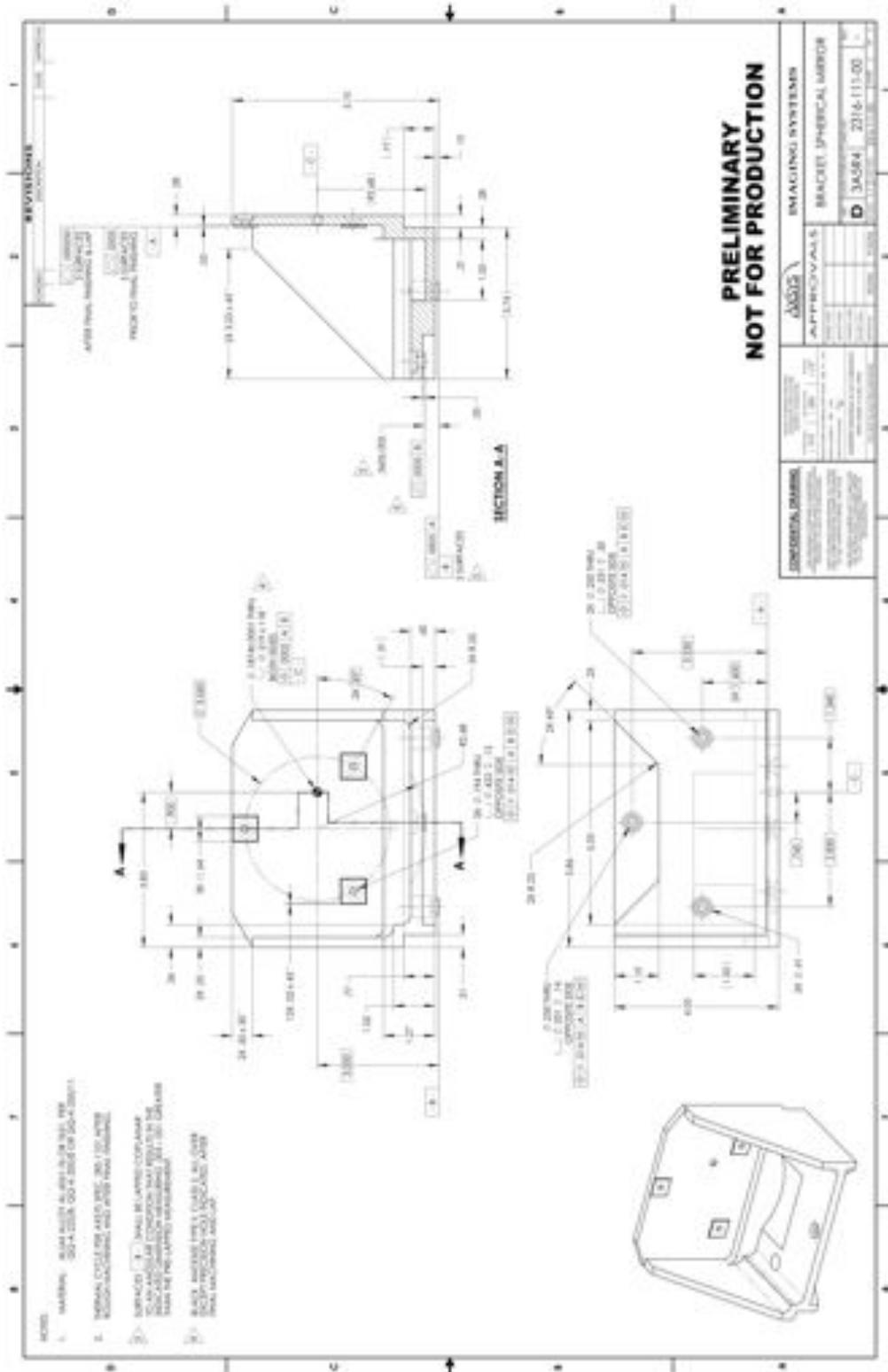


Figure 71. Spherical mirror mount.

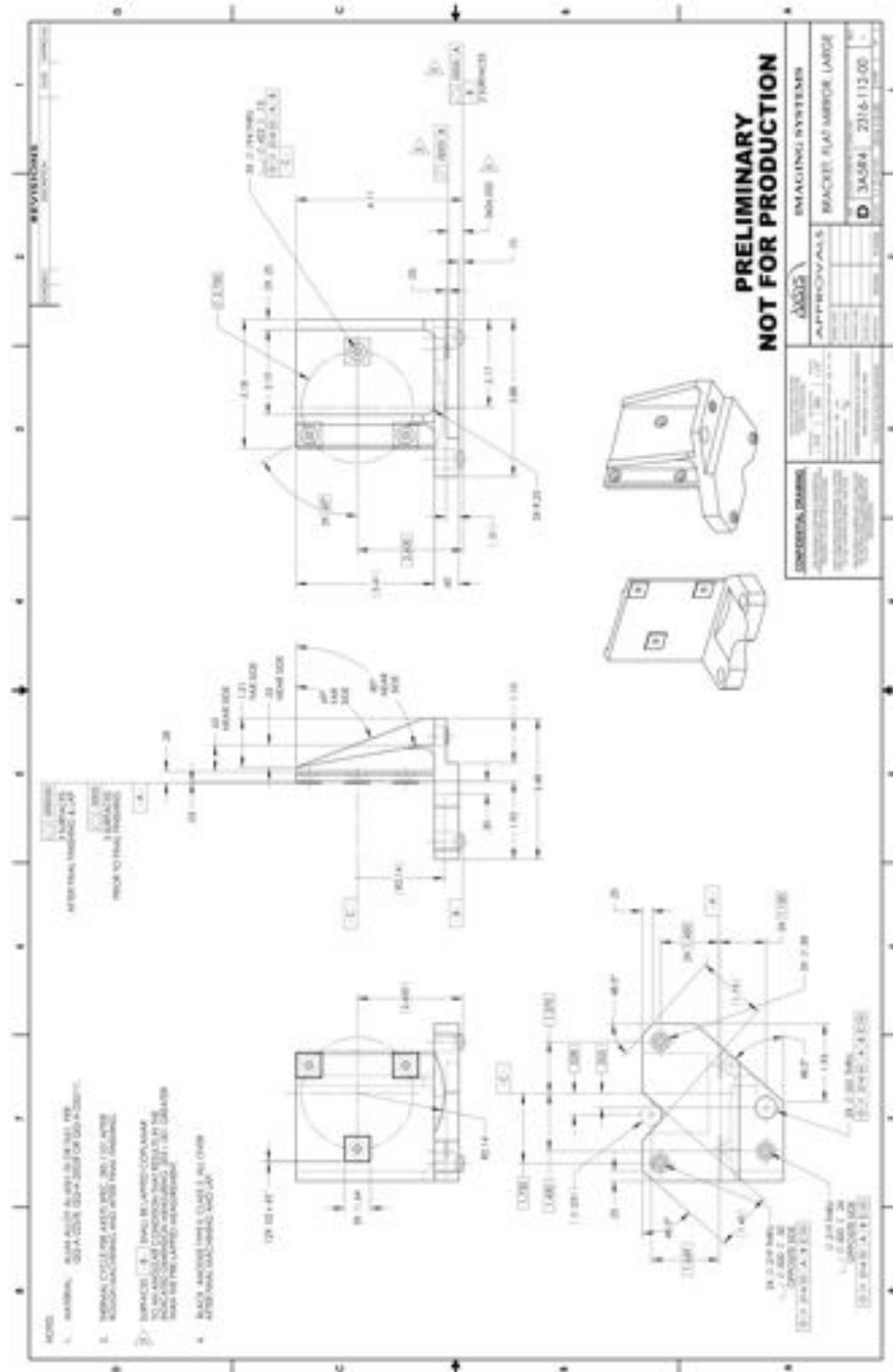
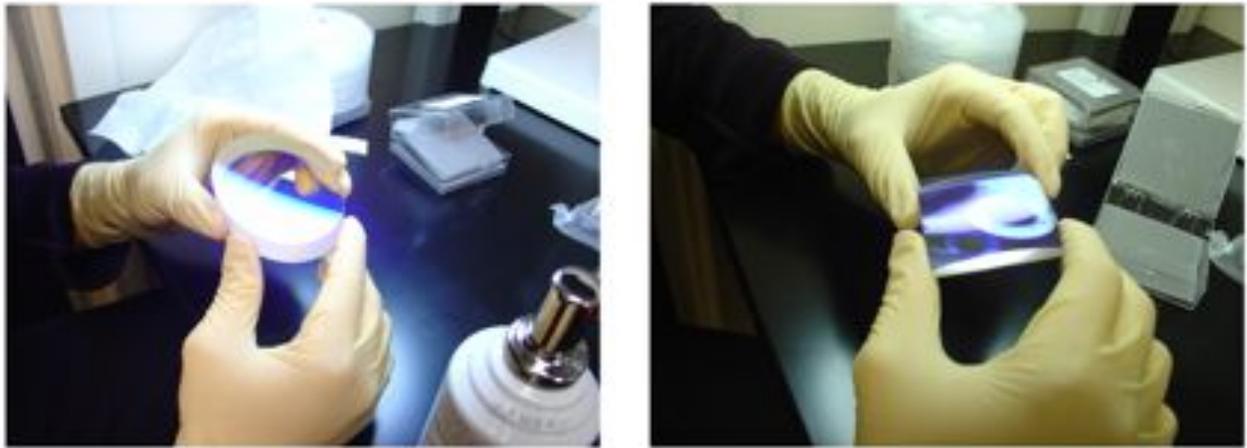


Figure 72. Internal bracket for spherical mirror mount.

Transmissive Optics:

There are two transmissive optics in the camera portion of the spectrograph, the meniscus and field lens. Both are made of fused silica. The meniscus corrector lens has two surfaces with radii of curvature 216.82 and 227.90 mm, and was cored out of a larger (240mm diameter) parent lens. It is 14.4 mm thick, 70 mm in diameter and 80 mm off axis. The field lens creates a flat focal plane for the final detector. This lens is incorporated into the mount holding the detector and has adjustment capabilities in three-dimensions. This lens serves the double purpose of additional protection for the detector. The field lens has a rear flat surface and a front surface with radius of curvature of 105.55 mm. This lens is 57 mm square and 12mm thick.



**Figure 73. The meniscus lens (left) and the field lens (right).**

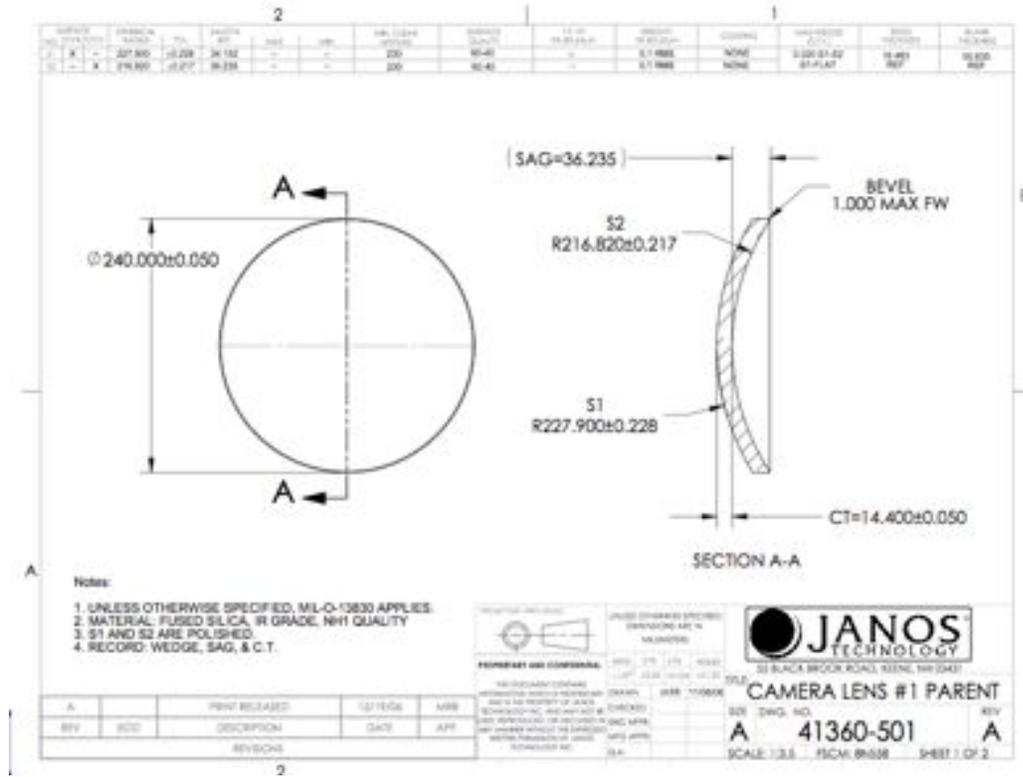


Figure 74. Design drawing for the meniscus lens parent.

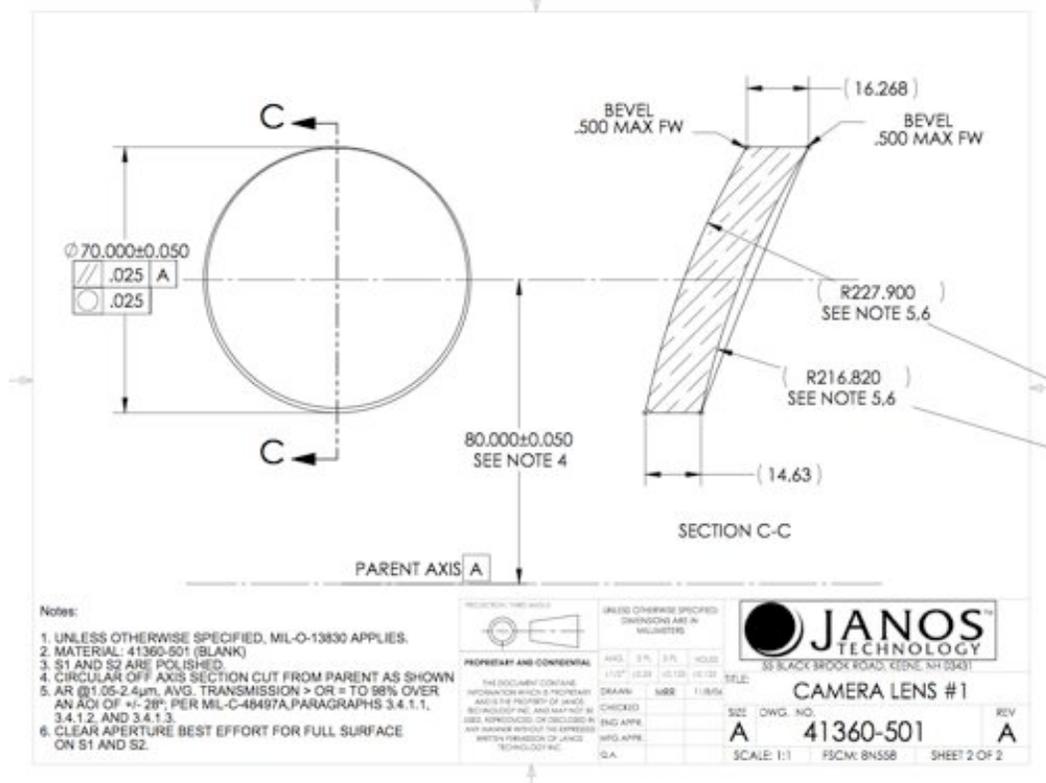
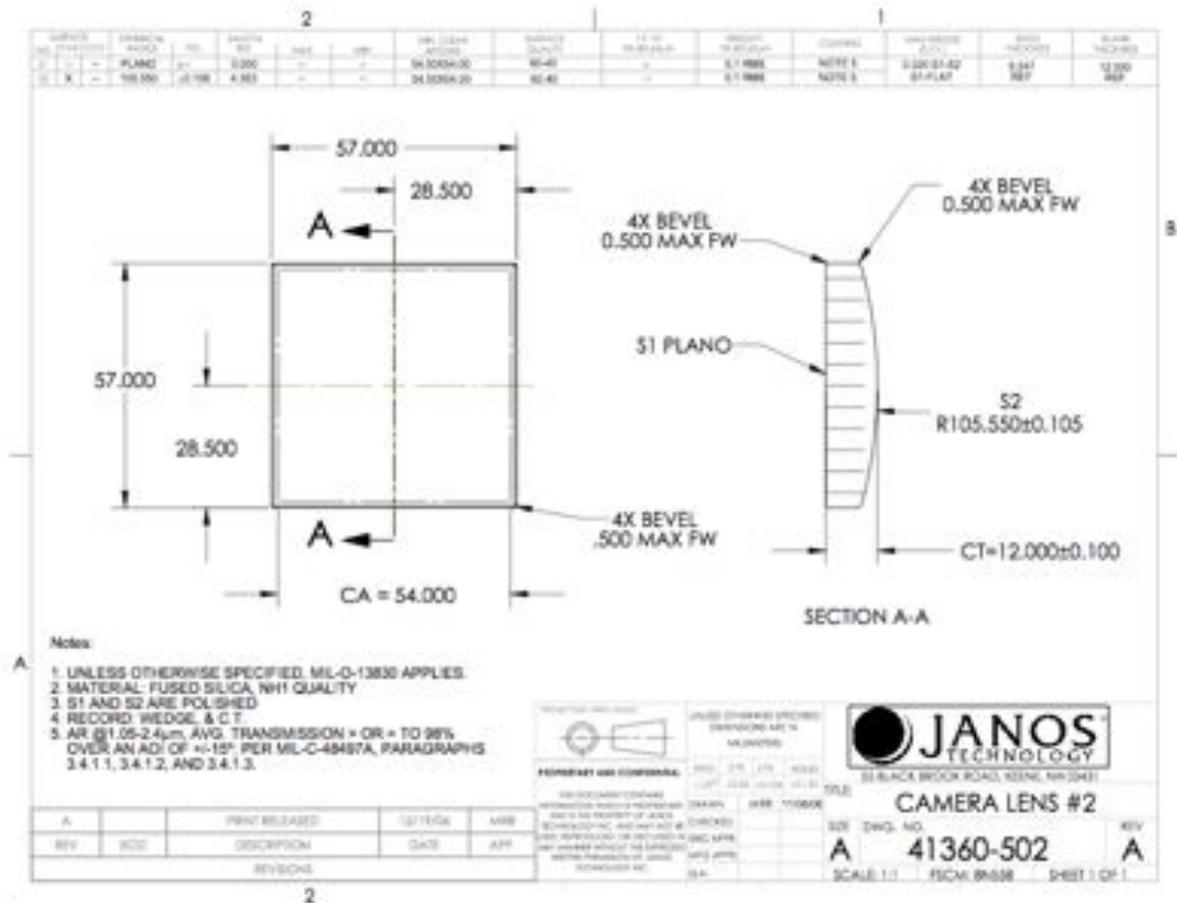


Figure 75. Design drawing for the meniscus lens.



**Figure 76. Design drawing for the field lens.**

**Meniscus Lens Mount:** The mount for the meniscus lens is incorporated into the mount containing the two flat mirrors made by Axsys Technology. The lens is pressed into the mount via three flexible fingers which make contact with the face of the lens outside the clear aperture. In addition, a single flexible finger on the top portion of the mount provides pressure on the lens to keep it centered in the mount. The mount for this meniscus lens can be removed from the rest of the assembly containing the two flats.

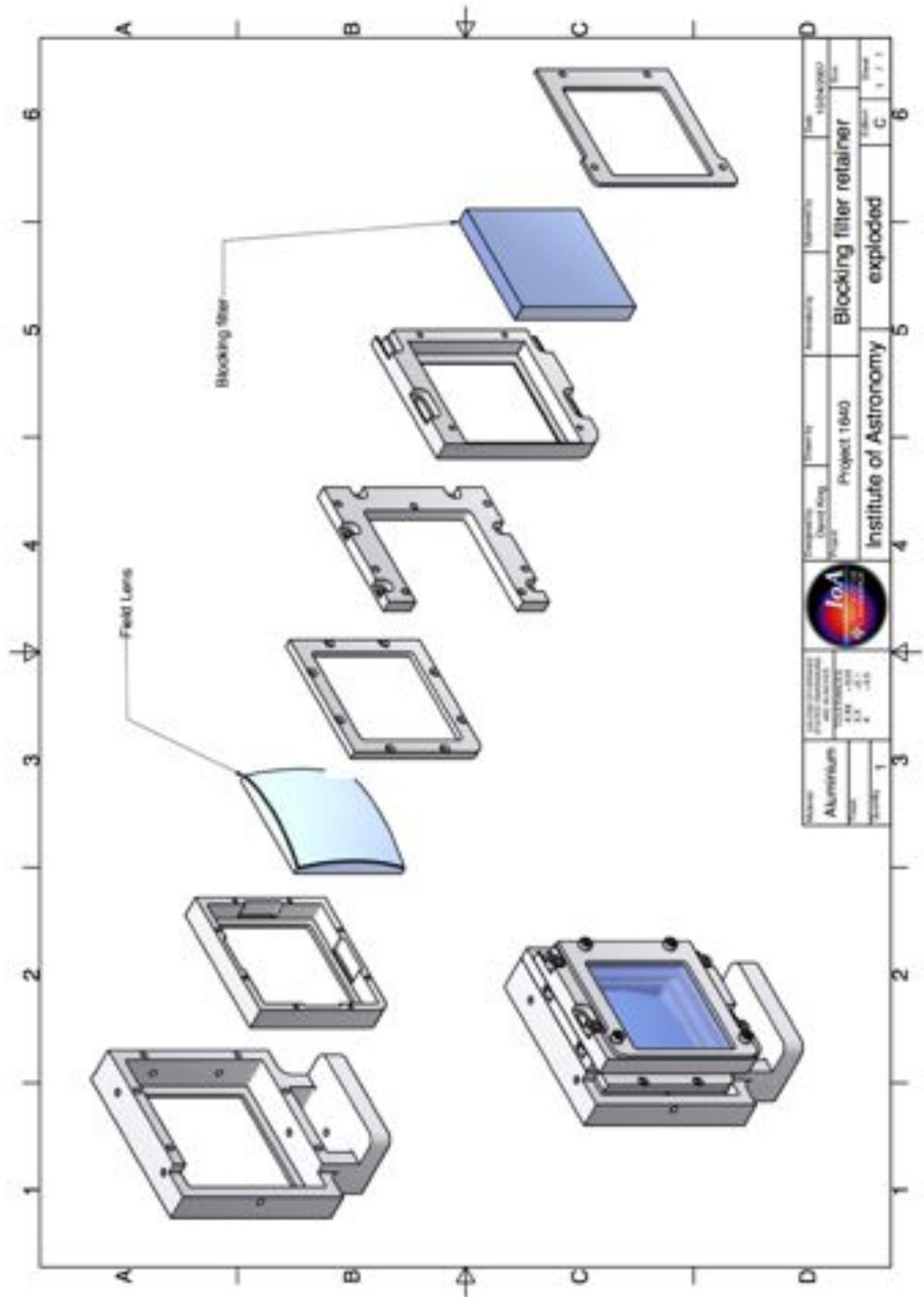
**Field Lens Mount:** The mount for the field lens is somewhat more complicated. The lens is housed in an aluminum lens cell. The inner square region for the lens is 61mm, allowing a 2mm gap on either side of the 57mm field lens. The lens is held in the center of the cell by a set of four phosphor-bronze springs (see photo below). The lens is held in place by a retainer piece that screws via six 6-32 screws into the lens cell. The inside edge of this retaining face is beveled to accommodate the curved front face of the lens. To ensure there is no contact between the retaining face and the lens, two gaskets were cut from 0.015-inch thick nylon sheets. These gaskets act as a compliant material between the retaining face and the lens and does not change its properties at cryogenic temperatures. Also a similar shaped gasket of 50  $\mu$ m thick nylon sits between the back plano face of the lens and the back register of the lens cell outside the clear aperture of the lens.

This lens cell assembly (lens, cell, retaining face) is placed into a lens cell holder piece. Six 6-32 set screws are used to keep this lens cell centered in the holder. One side of the holder has two set screws while the opposing face has a single screw. To keep the lens cell firmly against the back register of the lens cell holder, a “U” shaped retaining piece is attached to the lens cell holder via six 6-32 screws. Simply securing this retaining piece onto the lens cell holder is not sufficient to keep lens cell in place. However, the retaining face has three 6-32 set screws to press the lens cell back against the back register of the lens cell holder. The blocking filter carriage assembly is screwed directly to this lens cell retaining piece. This entire lens cell assembly is screwed into the bottom plate of the detector mount via two 10-32 screws. Slots in the lens cell assembly base allow the whole assembly to move forward or backward (10mm stroke) for focusing purposes.

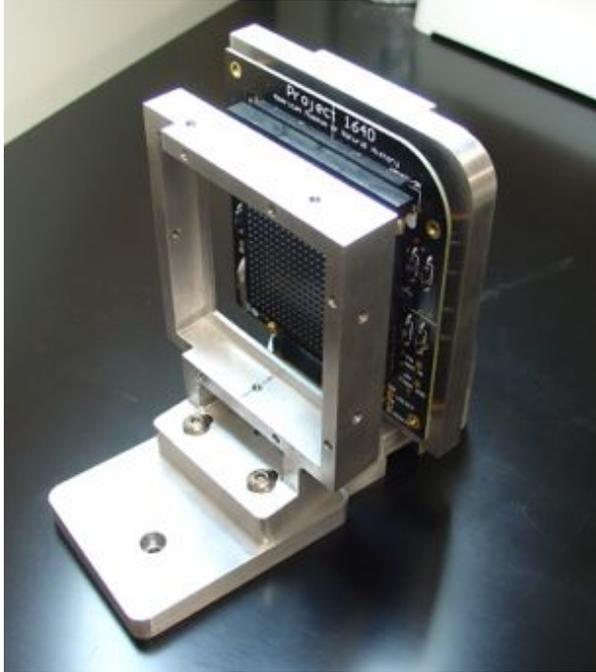


**Figure 77. The left shows a mock field lens in the lens cell with the phosphor bronze springs used to hold the lens in place. The right panel shows the teflon gasket which serves as a compliant material between the lens and its retaining face.**

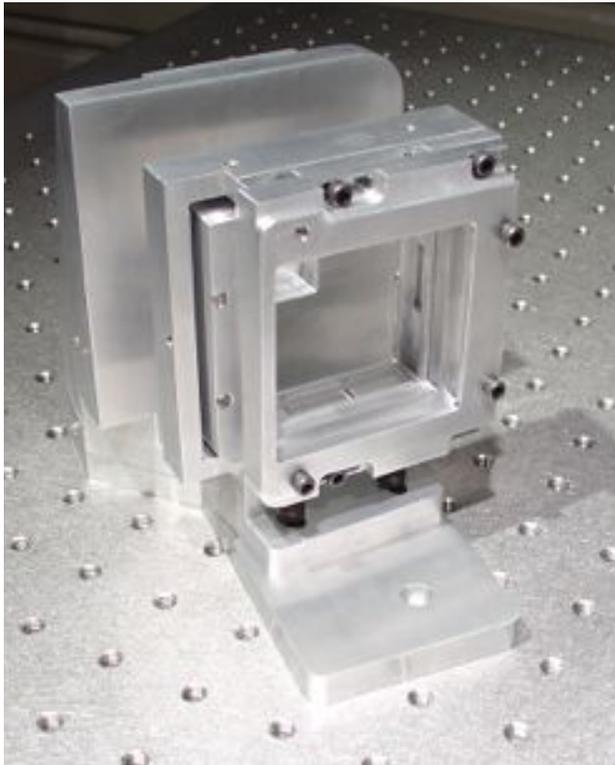
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**Figure 78. An exploded view of the field lens mount assembly, including the mount for the blocking filter. The compliant teflon gaskets are not shown.**



**Figure 79. The field lens holder mounted on the rest of the detector assembly.**



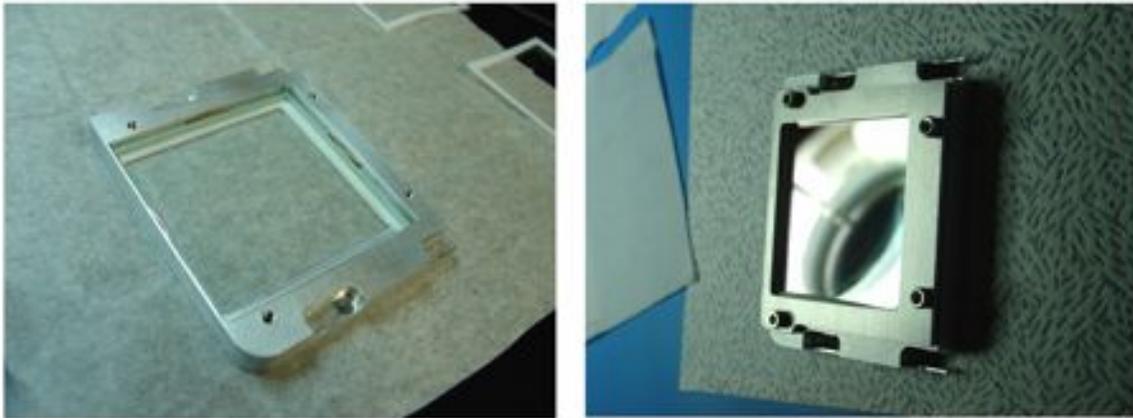
**Figure 80. The entire field lens mount and blocking filter mount, installed into the rest of the detector mount.**

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### 2.2.3.5. Blocking Filter

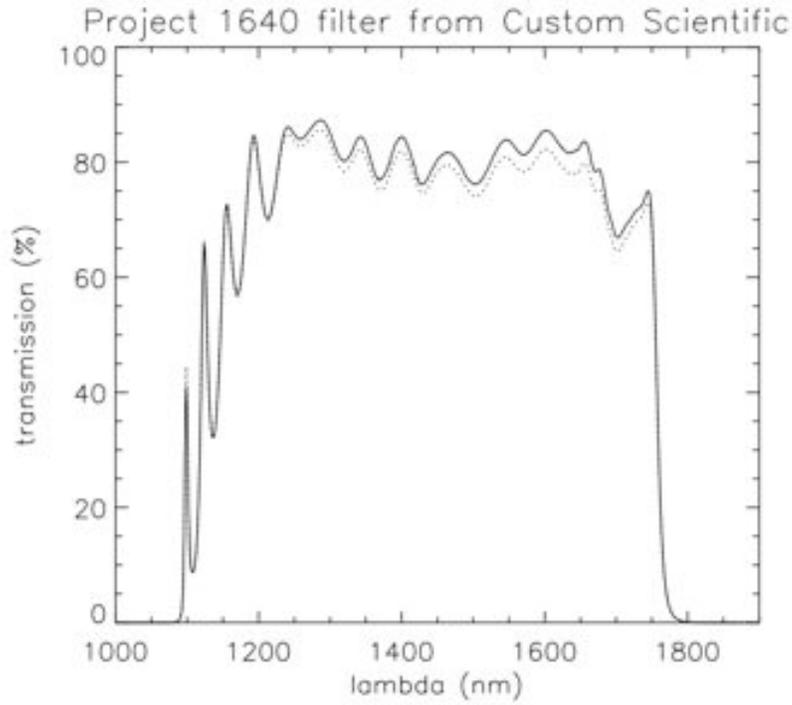
We use a 60x60mm square blocking filter to achieve the passband for the instrument. The filter has a 57x57mm clear aperture and is comprised of three cemented pieces of glass: a 2mm thick piece of Schott RG850, and two pieces of Schott B270 with thickness 2mm and 3mm. The filter has an 8mm thickness. The edges of the filter have been sealed with a hermetic polymer.



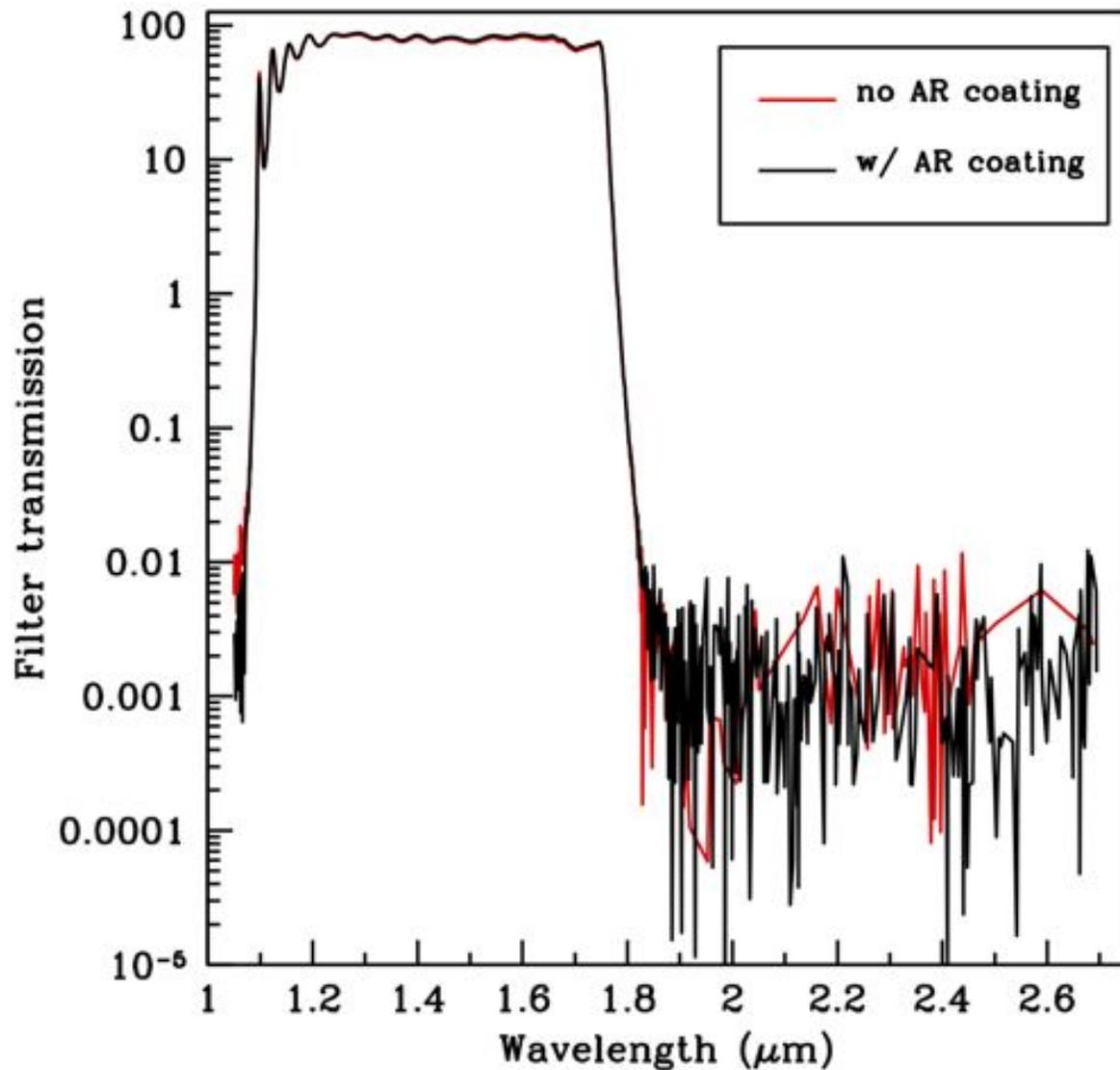
**Figure 82. Left: A mock filter placed into the filter holder. The 50 micron teflon gasket is visible on the back register as are the phosphor bronze springs at the edges. Right: The actual blocking filter with the retaining face installed.**

The filter mount is comprised of two pieces: a filter carriage to hold the glass substrate and a retaining face to keep it fixed against the back register of the carriage. As with the field lens, a 50 $\mu$ m teflon gasket is placed between the glass and the rear register. Also phosphor bronze springs are used to hold the filter centered in its carriage. Note that there is only a 1mm gap between the carriage and the glass substrate. 0.015" teflon gaskets are placed between the filter and the retaining face outside the clear aperture. The screws for mounting the filter assembly sit in slotted holes to allow 8mm movement of the carriage when incorporated into the rest of the field lens mount.

The filter was specified to allow greater than 75% transmission from 1050-1750nm. The actual transmission curve is shown in the plot below. Note that the filter is slightly out of spec, and "turns on" closer to 1100nm, with some sharp peaks in the region 1100-1200nm. The filter was also specified to have OD5 blocking from 400-1000nm and OD4 blocking from 1800-2700nm. The filter comes close to these benchmarks. The dotted line in the transmission spectrum was measured prior to the AR coating, while the solid line is post coating.



**Figure 83. Transmission curve for the JH blocking filter used. The solid line is the spectrum after the AR coating, while the dotted is prior to the coating.**

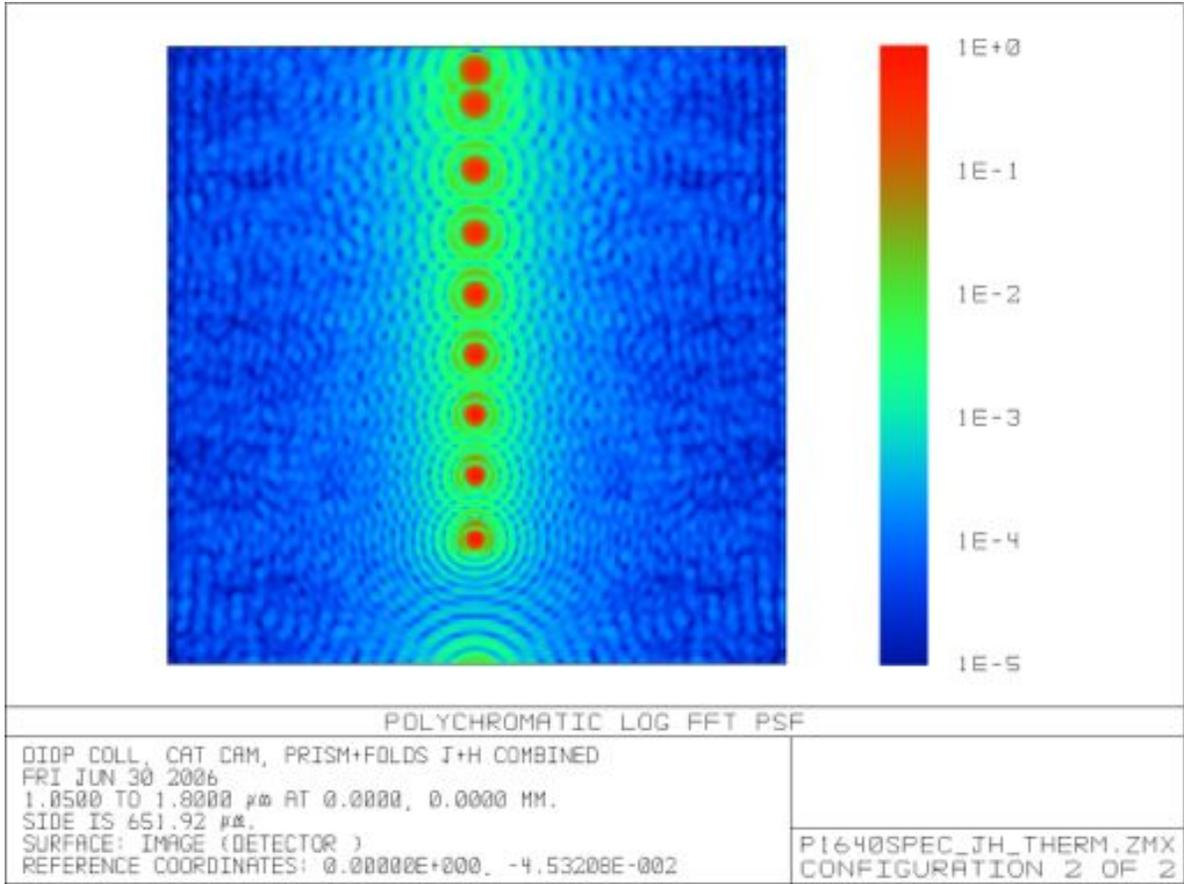


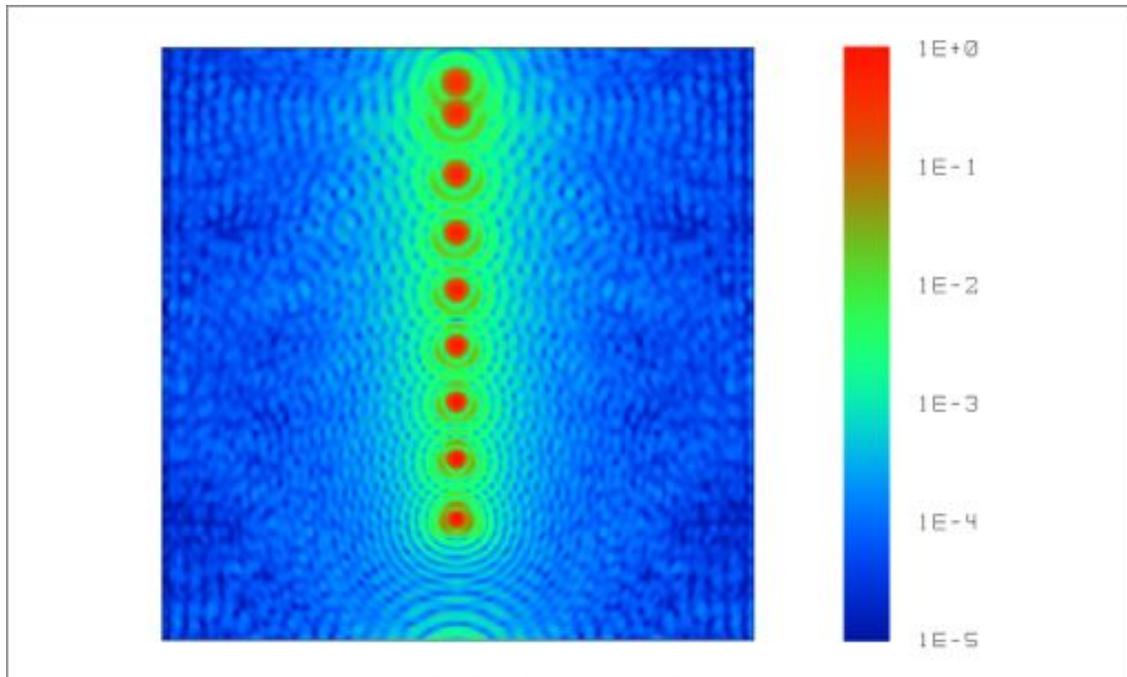
**Figure 84.** Same as above, but now in log scale.

#### 2.2.4. Optical performance

Here we include some zemax optical performance metrics

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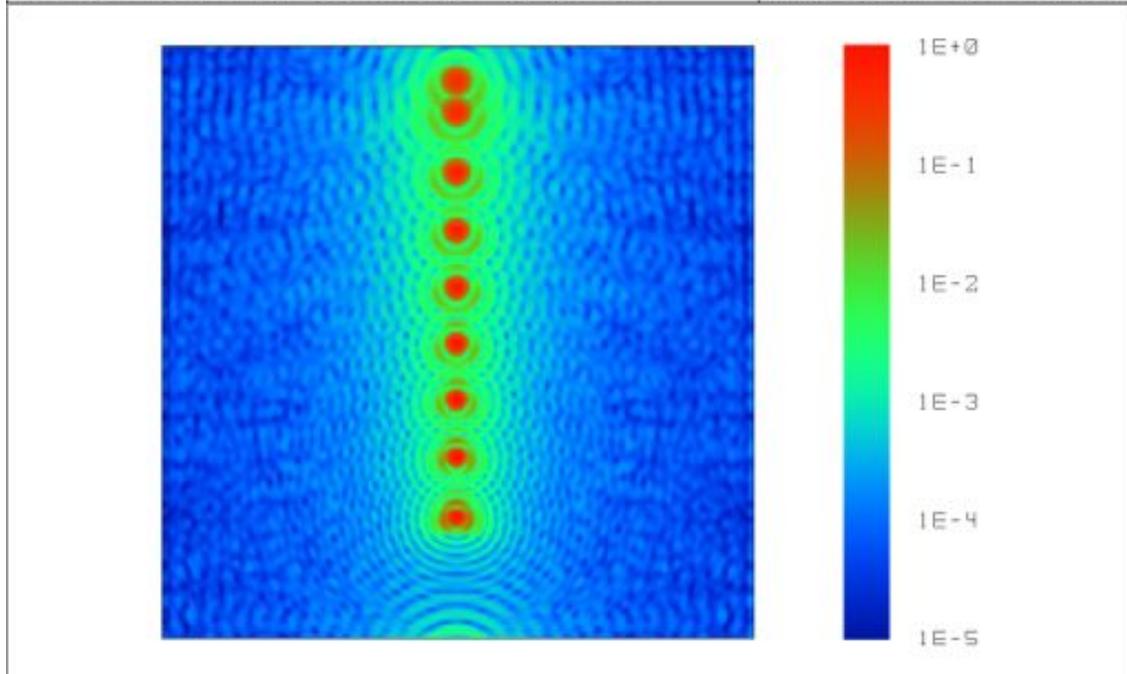




POLYCHROMATIC LOG FFT PSF

DIDP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006  
 1.0500 TO 1.0200  $\mu\text{m}$  AT 0.0000, 4.3000 MM.  
 SIDE IS 663.55  $\mu\text{m}$ .  
 SURFACE: IMAGE (DETECTOR )  
 REFERENCE COORDINATES: 0.00000E+000, -1.08899E+001

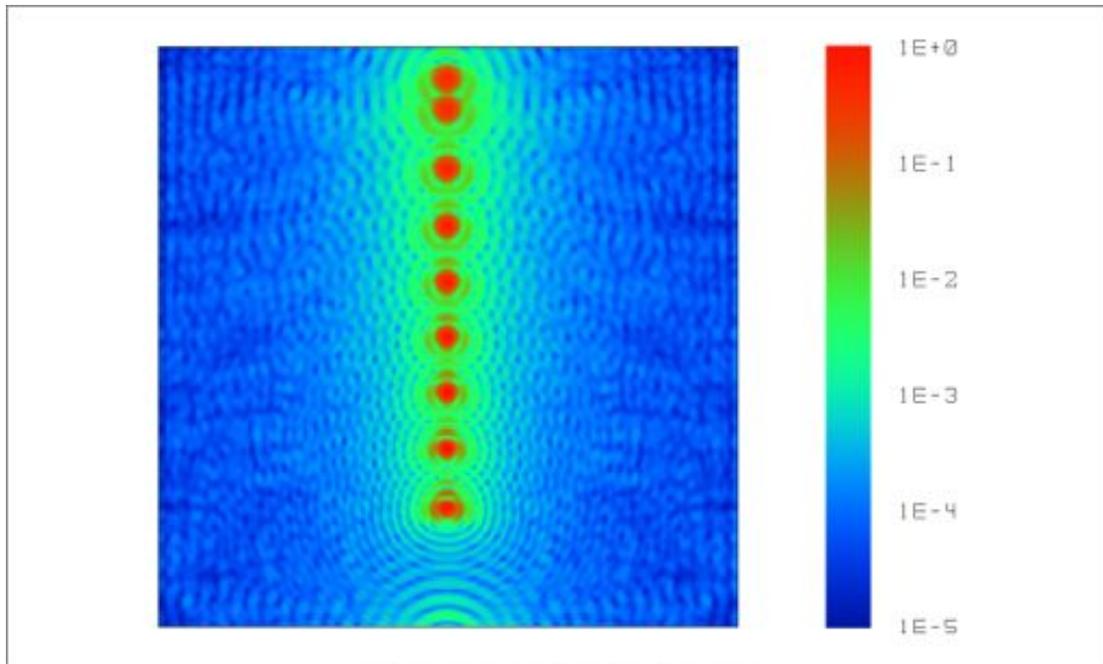
P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2



POLYCHROMATIC LOG FFT PSF

DIDP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006  
 1.0500 TO 1.0200  $\mu\text{m}$  AT 0.0000, 6.1000 MM.  
 SIDE IS 664.52  $\mu\text{m}$ .  
 SURFACE: IMAGE (DETECTOR )  
 REFERENCE COORDINATES: 0.00000E+000, -1.54645E+001

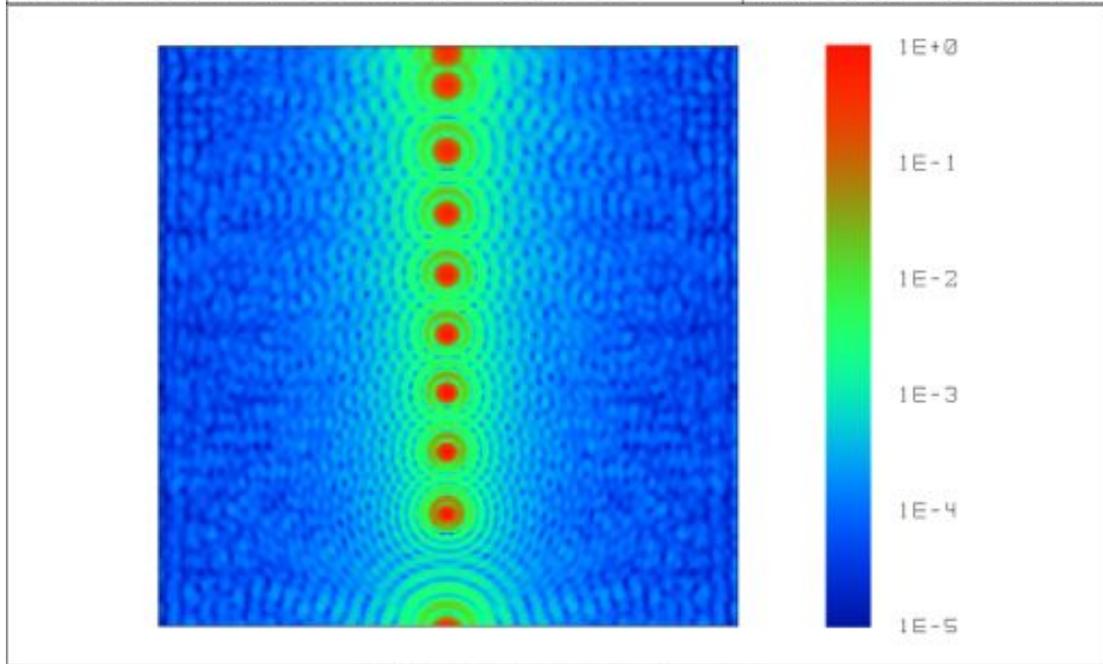
P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2



POLYCHROMATIC LOG FFT PSF

DIDP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006  
 1.0500 TO 1.8000  $\mu\text{m}$  AT 0.0000, 7.5000 MM.  
 SIDE IS 665.55  $\mu\text{m}$ .  
 SURFACE: IMAGE (DETECTOR )  
 REFERENCE COORDINATES: 0.00000E+000, -1.90499E+001

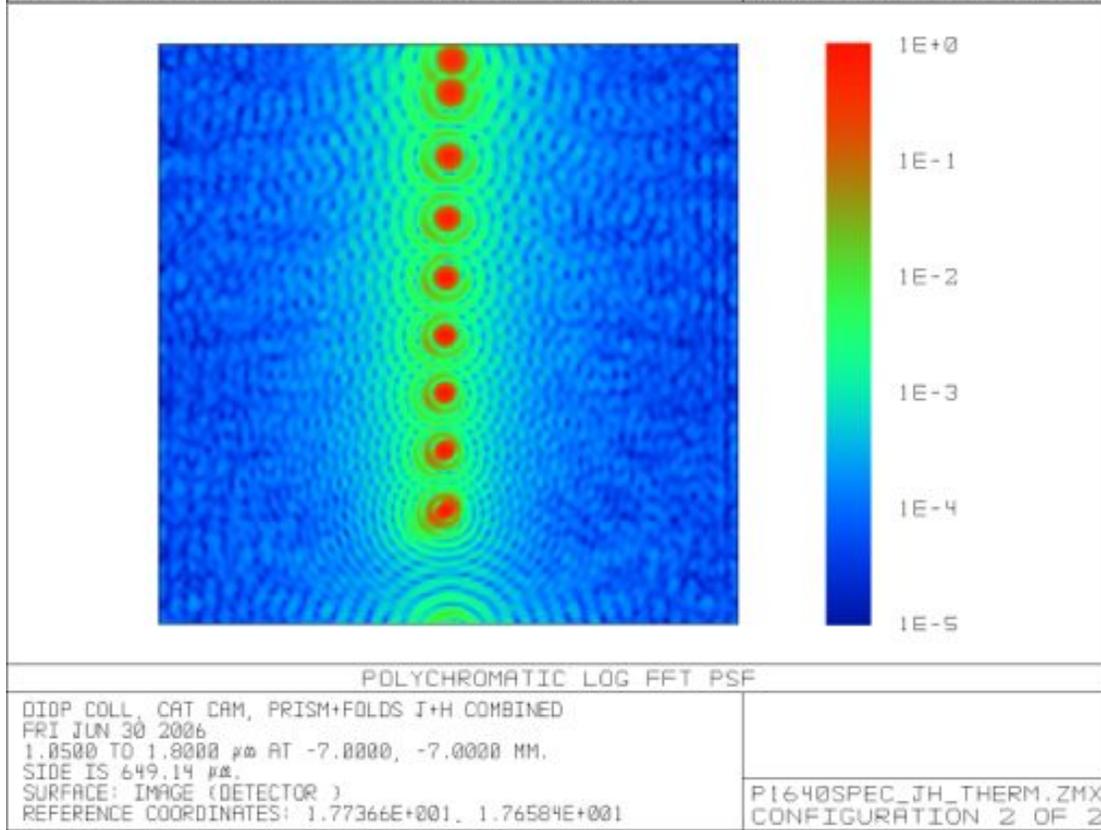
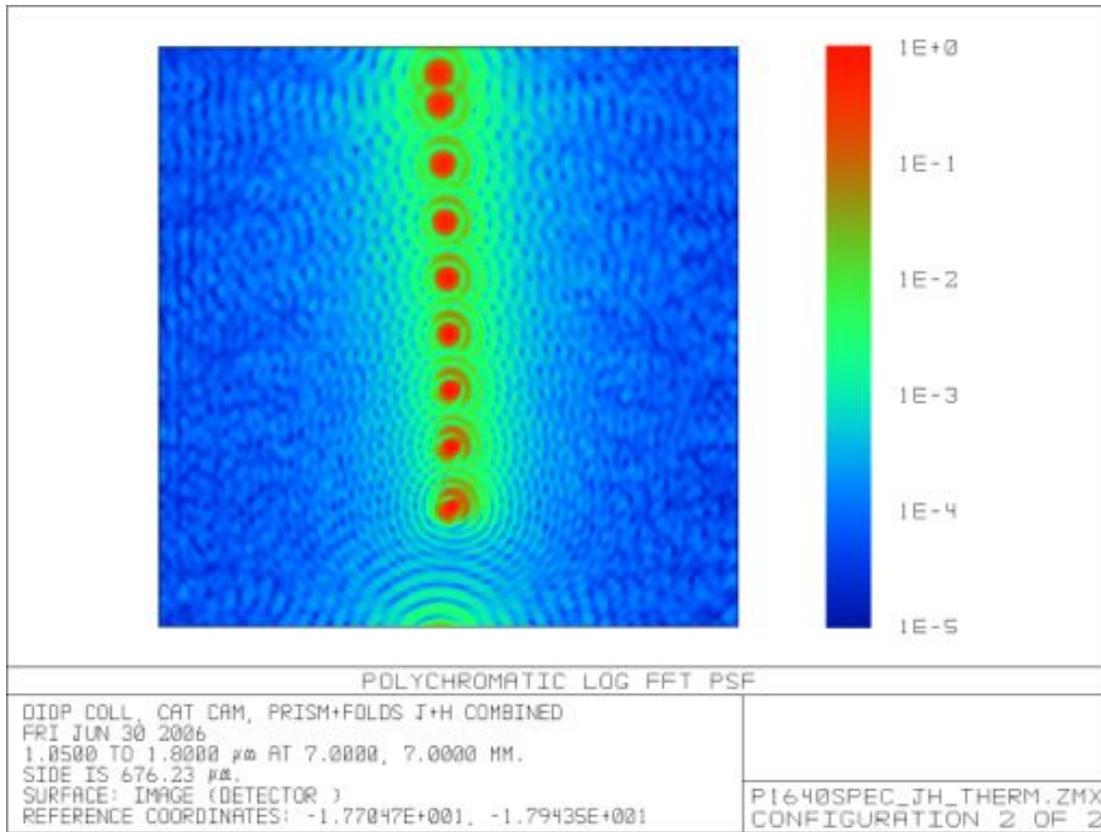
P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2

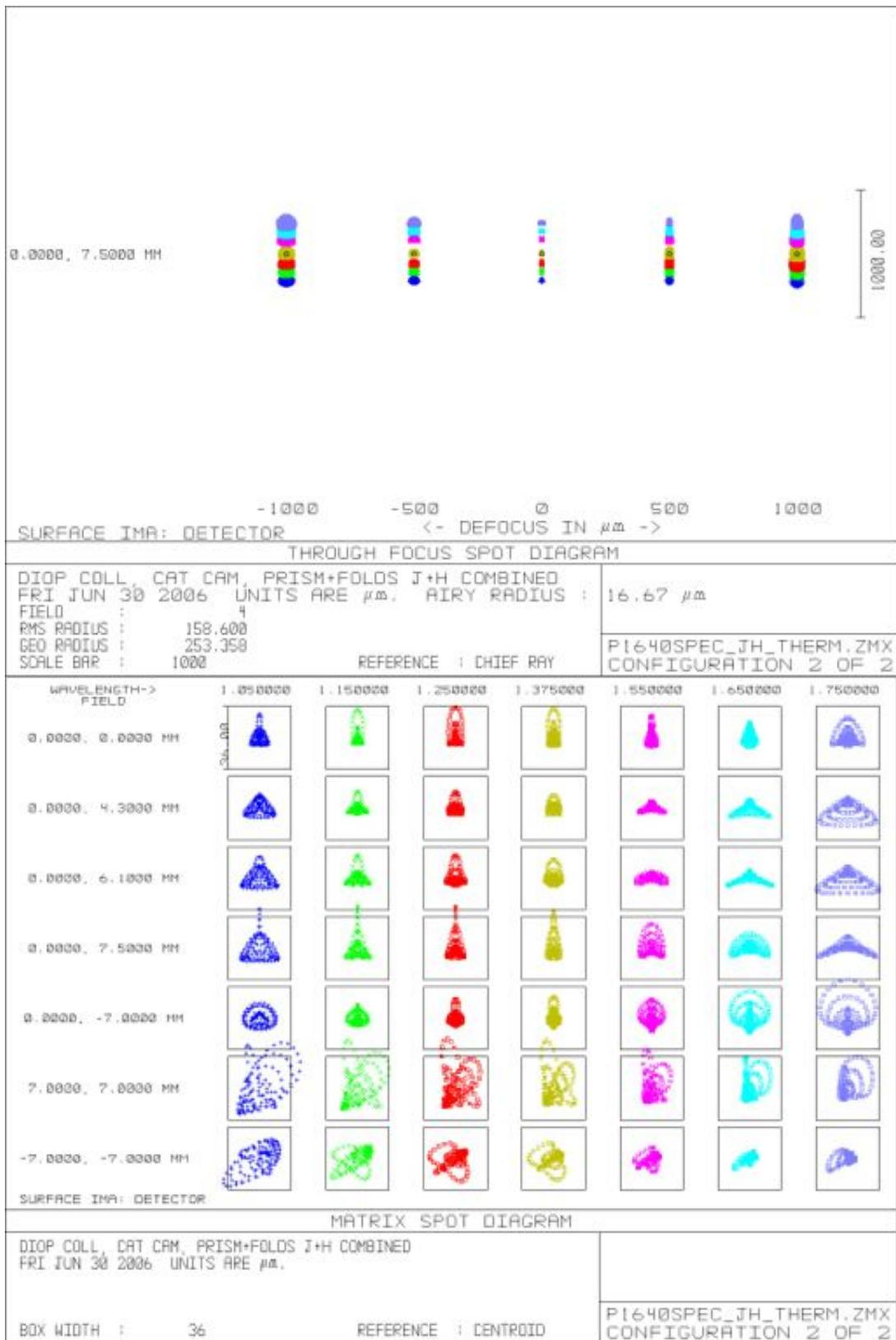


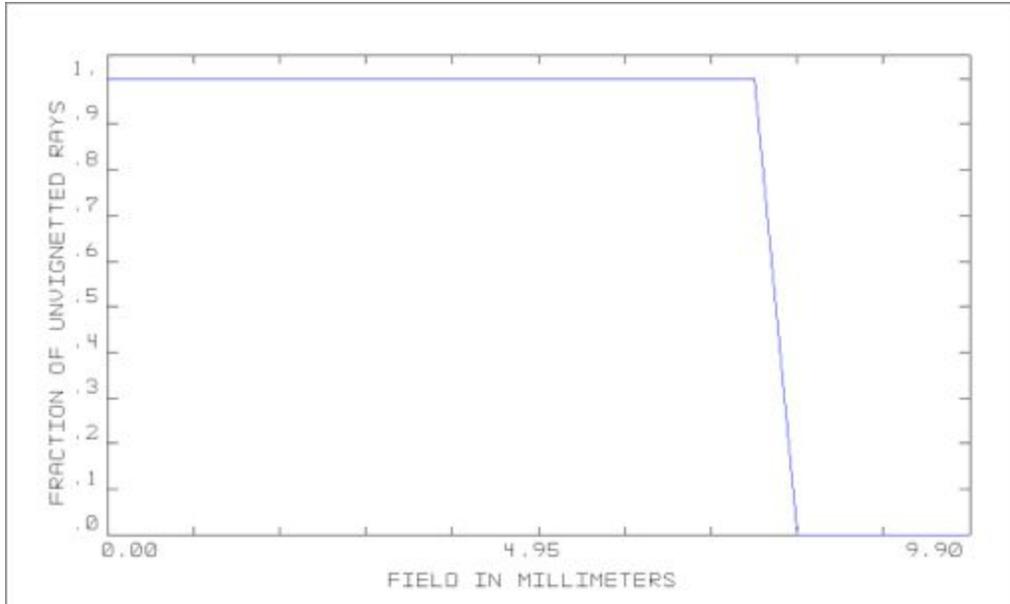
POLYCHROMATIC LOG FFT PSF

DIDP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006  
 1.0500 TO 1.8000  $\mu\text{m}$  AT 0.0000, -7.0000 MM.  
 SIDE IS 641.21  $\mu\text{m}$ .  
 SURFACE: IMAGE (DETECTOR )  
 REFERENCE COORDINATES: 0.00000E+000, 1.76023E+001

P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2



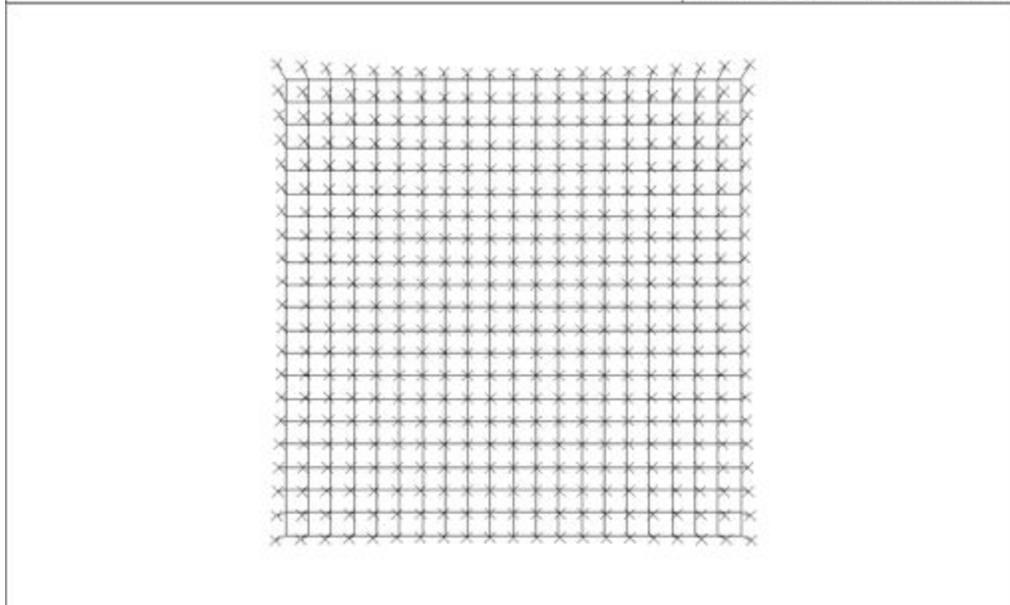




VIGNETTING DIAGRAM

DIOP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
FRI JUN 30 2006

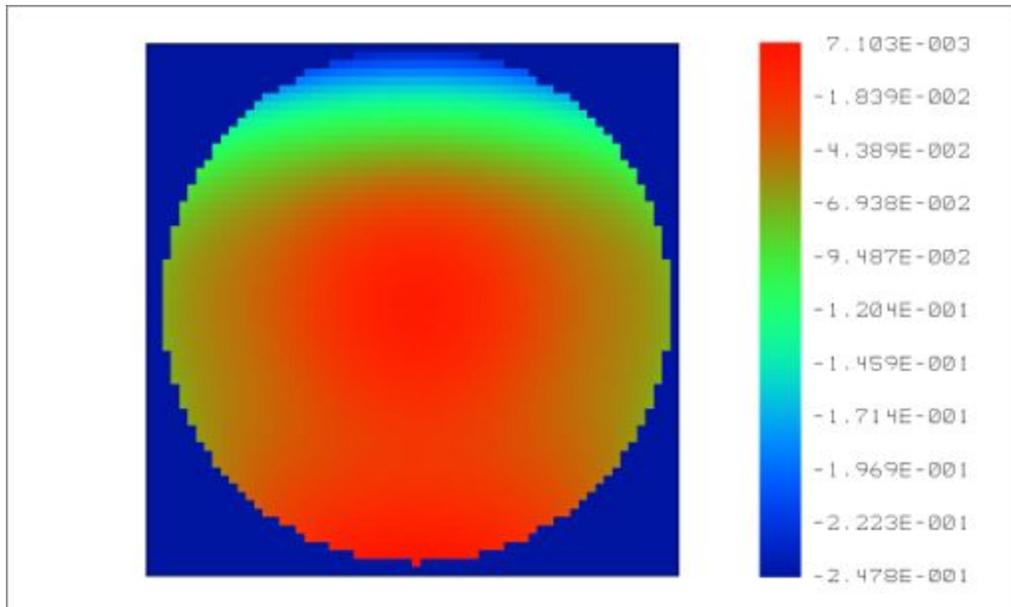
P1640SPEC\_JH\_THERM.ZMX  
CONFIGURATION 2 OF 2



GRID DISTORTION

DIOP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
FRI JUN 30 2006  
FIELD: 14.00 W 14.00 H MILLIMETERS  
IMAGE: 35.06 W 35.21 H MILLIMETERS  
MAXIMUM DISTORTION: 1.3684%  
SCALE: 4.000X, WAVELENGTH: 1.3500  $\mu$ M

P1640SPEC\_JH\_THERM.ZMX  
CONFIGURATION 2 OF 2



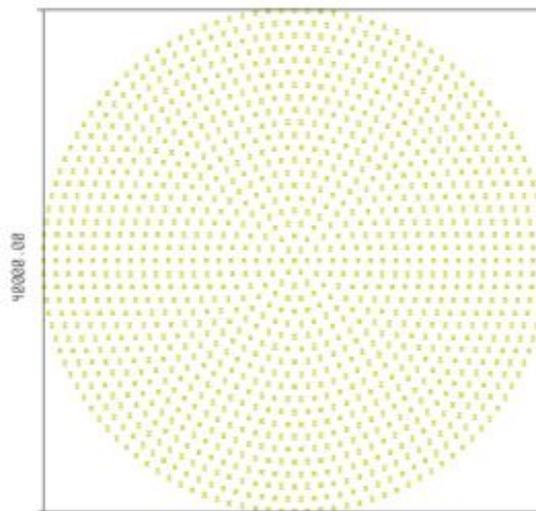
WAVEFRONT FUNCTION

DIOP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006  
 1.3500 μm AT 0.0000, 0.0000 MM  
 PEAK TO VALLEY = 0.2549 WAVES, RMS = 0.0434 WAVES.  
 SURFACE: IMAGE (DETECTOR)  
 EXIT PUPIL DIAMETER: 1.7999E+001 MILLIMETERS

P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2

OBJ: 0.0000, 0.0000 MM

+ 1.3500



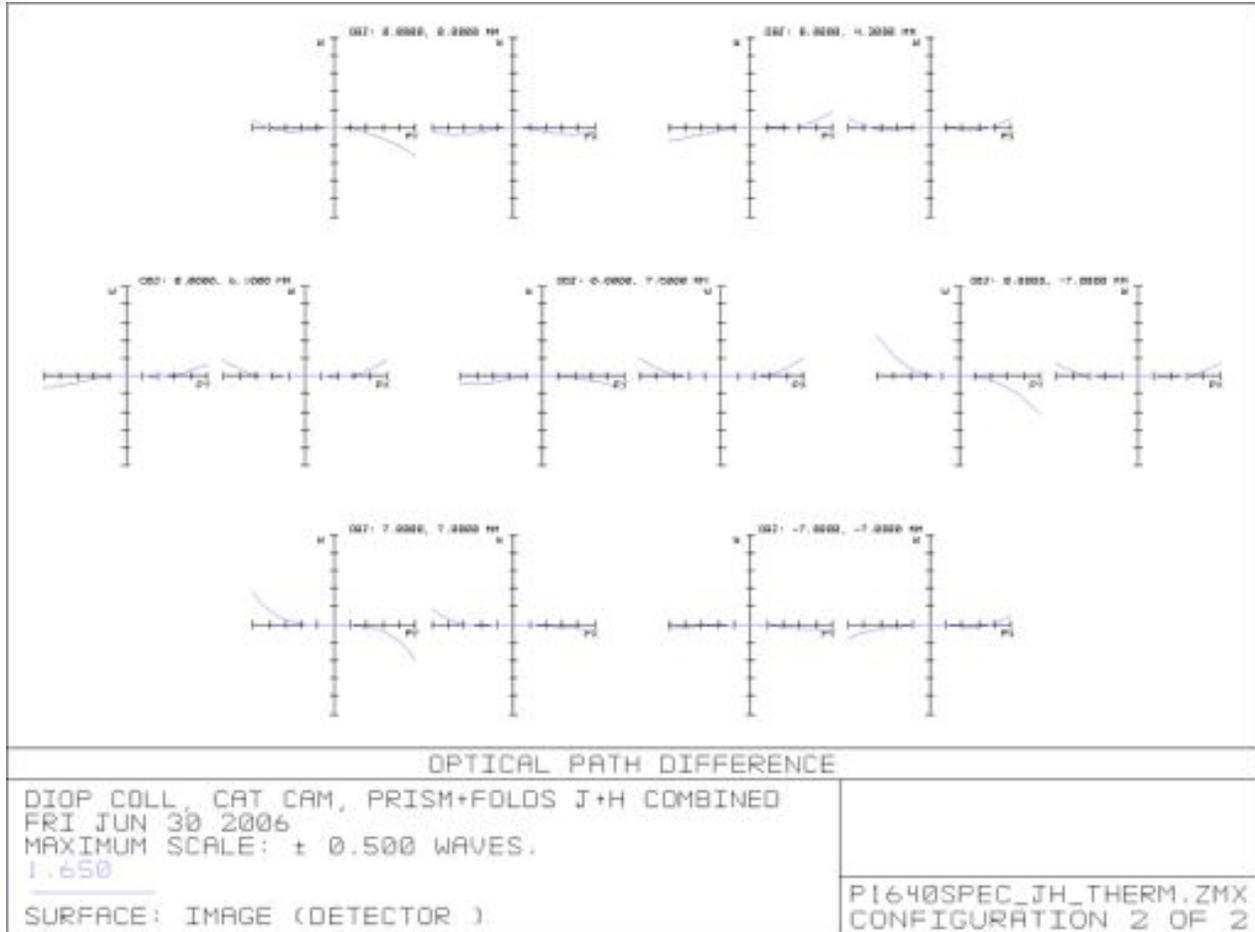
SURFACE 14: PRISM

IMA: 0.000, 0.000 MM

SPOT DIAGRAM

DIOP COLL, CAT CAM, PRISM+FOLDS J+H COMBINED  
 FRI JUN 30 2006 UNITS ARE μm.  
 FIELD : 1  
 RMS RADIUS : 1.5E+004  
 GEO RADIUS : 2.0E+004  
 BOX WIDTH : 4E+004  
 REFERENCE : CHIEF RAY

P1640SPEC\_JH\_THERM.ZMX  
 CONFIGURATION 2 OF 2



### 2.2.5. Detector System

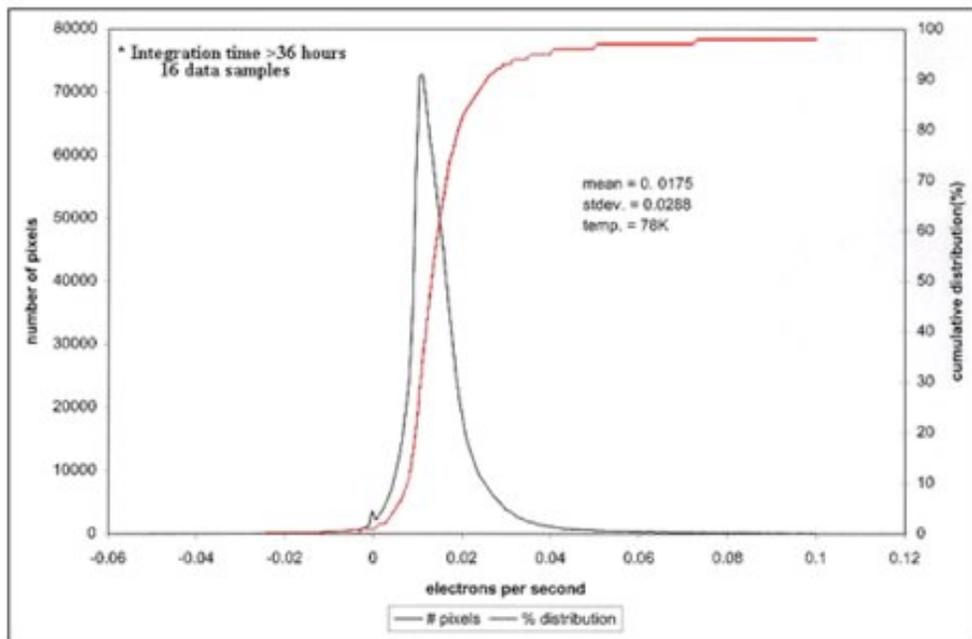
The heart of the detector system is a Rockwell Hawaii-II 2048x2048 pixel HgCdTe infrared array operating at cryogenic temperatures. The detector control uses a Generation III infrared array controller designed and built by Astronomical Research Cameras, Inc. (ARC) and configured to our Hawaii 2 chip. We also have a dedicated ARC power supply to go with this.

#### 2.2.5.1. Hawaii-II HgCdTe Array Specifications

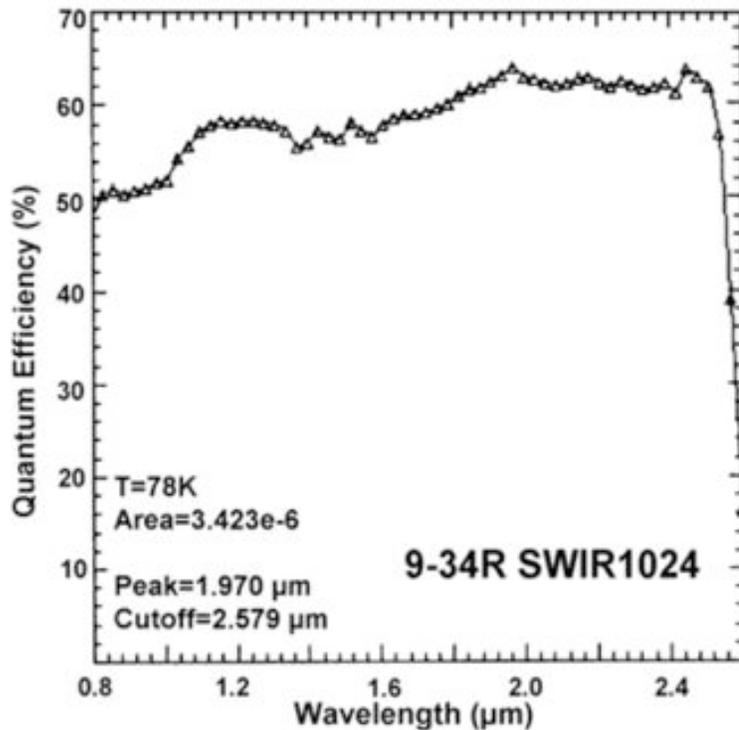
The information in this section was taken from the Gemini NIFS System Design Note 8.00 (dated April, 5<sup>th</sup>, 2000), entitled “NIFS Science Detector Trade-offs” by Peter J. McGregor. Although many of the passages in here refer to the earlier-generation HAWAII-1 arrays, the characteristics of the HAWAII-2 are very similar.

The HAWAII-2 HgCdTe array is an evolution of the successful 1024x1024 HAWAII-1 array. It uses PACE technology in which the HgCdTe detector material is deposited on a sapphire substrate. The 2048 x 2048 HAWAII-2, 18  $\mu\text{m}$  pixel arrays use similar technology to the 1024 x 1024 HAWAII-1 arrays. Both devices have a 2.5  $\mu\text{m}$  wavelength cutoff. They are expected to have similar performance with a single double-correlated sample read noise of  $\sim 9$

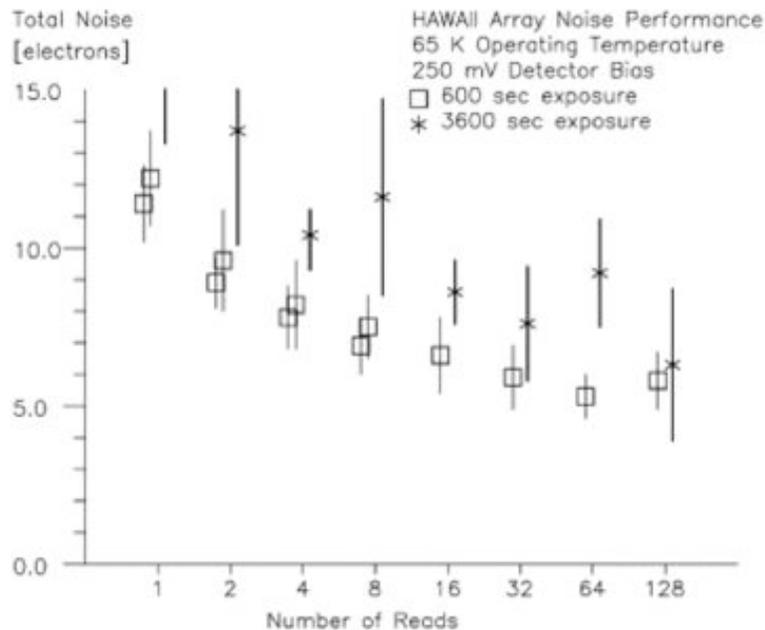
e. Read noises of  $\sim 4 e$  are likely using eight double-correlated (i.e., Fowler) samples. The dark current performance of the HAWAII-1 array is not well documented, due partly to the difficulty of measuring extremely low dark currents. Finger et al. (1998) report a mean dark current of  $< 30 e/hr$  ( $< 0.0083 e/s$ ) for a HAWAII-1 array operated at 78 K. This very low measurement is limited by electrical drifts in the data system. The Rockwell Science Center WWW pages show a dark current distribution with a mode of  $\sim 0.01 e/s/pixel$  for a HAWAII-1 array at an operating temperature of 78 K. Kozlowski et al. (1998) plot a different dark current distribution for a HAWAII-1 array operated at 78 K. This has a mode of  $\sim 0.026 e/s/pixel$  and a high dark current tail extending to  $\sim 0.15 e/s/pixel$ . Bailey et al. (1998) quote a mean dark current of  $0.05 e/s/pixel$  with  $> 99.66\%$  of pixels having  $< 1 e/s$  dark current for a HAWAII-1 array operated at 77 K and 0.5 V reverse bias. Mackay et al. (1998) report a mean dark current at 90-110 K for three of their HAWAII-1 arrays of  $\sim 0.1 e/s/pixel$  and  $\sim 2 e/s/pixel$  for an earlier fourth array. They note that for their devices  $\sim 10\%$  of all pixels have dark currents  $> 5$  times the mean,  $\sim 4\%$  have dark currents  $> 10$  times the mean, and  $\sim 1\%$  have dark currents  $> 20$  times the quoted mean value. These hot pixels behave in a predictable and repeatable way. The latter two high dark current measurements are partly due to the higher detector reverse bias voltage or higher operating temperature used. We conclude that HAWAII-1 arrays are capable of achieving modal dark currents as low as  $\sim 0.01 e/s/pixel$  when operated below 70 K and with reverse bias voltages  $< 200 mV$ , but that the dark current distribution has a tail extending to  $> 0.1 e/s/pixel$ . The node capacitance is  $\sim 40 fF$  at this reverse bias (Hodapp et al. 1996), so the well depth is  $\sim 50,000 e$ . PACE technology devices have fast output amplifiers permitting sample times of  $\sim 5 \mu s/pixel$ , but they suffer from declining quantum efficiency at wavelengths shortward of  $\sim 1.3 \mu m$  ( $QE \sim 60\%$  declining to  $< 50\%$ ) and significant persistence effects due to lattice mismatch between the HgCdTe detector and its sapphire substrate. Problems with amplifier glow in HAWAII-1 devices are expected to be solved in the HAWAII-2 devices, but this is yet to be verified.



**Figure 85. Dark current distribution for Hawaii-1 array.**



**Figure 86. Quantum efficiency function for HAWAII-1 detector.**



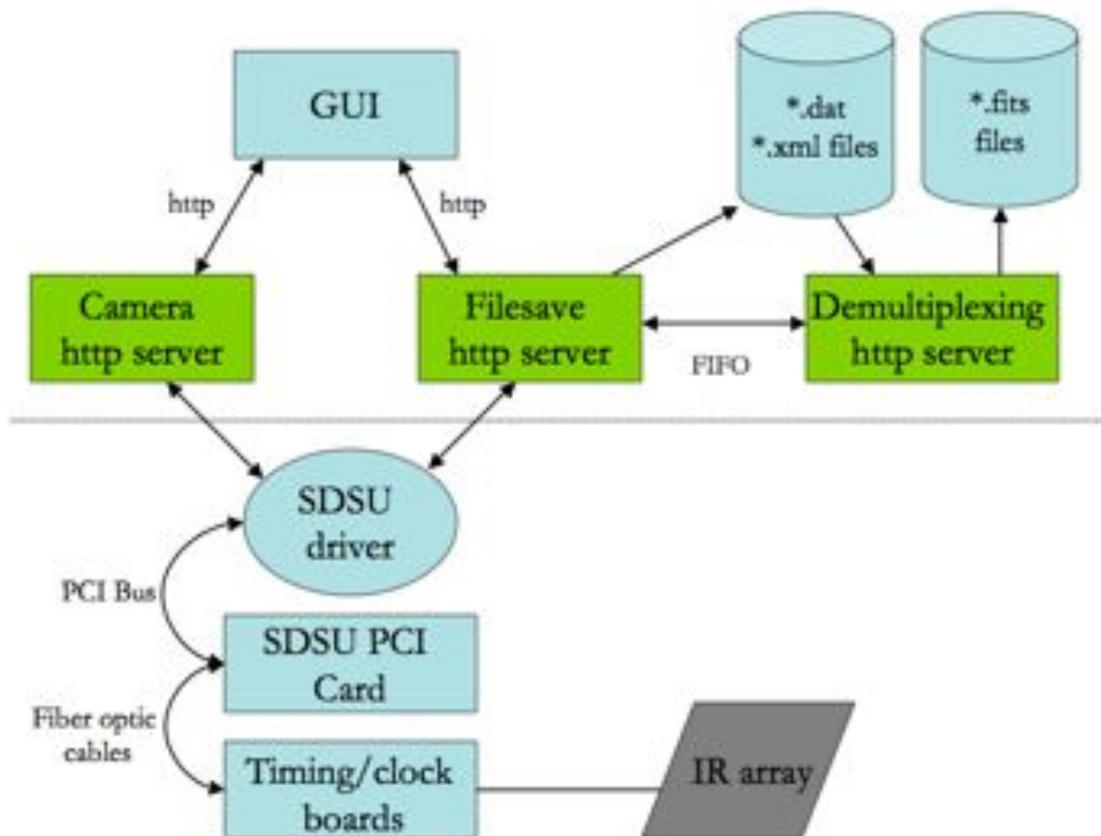
**Figure 87. Read noise for a HAWAII-1 array measured at 65K with 250 mV bias as a function of number of correlated double samples.**

The rate of ionizing events per pixel for the HAWAII-2 array with 18  $\mu\text{m}$  pixels will be more than a factor of two lower than for the 27  $\mu\text{m}$  pixel ALLADIN 1024 $\times$ 1024 InSb arrays

used in NIRI and GNIRS. Mackay et al. (1998) quote cosmic ray detection rates with their HAWAII-1 arrays of  $\sim 1$  event per square centimeter per minute, corresponding to  $\sim 815$  events detected by a HAWAII-2 array in a 3600 s integration.

### 2.2.5.2. Detector System Control

In order to maintain the greatest amount of flexibility and portability, our collaborators at the Astronomical Technology Centre in Edinburgh have configured our detector system to communicate with the outside world using XML files that are transferred using http (Beard et al 2002). The http protocol was chosen to allow greater flexibility and stability when such a system is moved from a particular institution or telescope. The XML files include all of the necessary parameters for a particular observation (exposure time, number of reads, etc). The system can perform Non-destructive reads (NDR) as well as Correlated Double Sampling (CDS). The flow of the user commands is shown schematically in the figure below. The user sends the appropriate configuration XML files via http to a set of three separate, but connected servers setup on our Data Acquisition Computer that organize the camera operations, the filesaving, and the detector de-multiplexing. The user can directly communicate with the Camera and Filesave servers, but the Filesave server is the only module that will communicate with the de-multiplexing server.



**Figure 88. Schematic of the detector data handling. XML command files are moved between three independent servers (green boxes) in the data acquisition computer and the SDSU controller.**

We communicate directly to our Camera and Filesave servers using customized LabVIEW software. These servers communicate with the SDSU detector controller, which in turn, organizes the reading of the infrared array through the timing and clock boards. When an exposure is complete, the data files are stored in a raw data format, and the demultiplexing http server converts these into FITS files.

### 2.2.5.3. Tutorial for Controlling the Camera

The following is a single HTML page written by Stewart McLay ([sam@roe.ac.uk](mailto:sam@roe.ac.uk)) to provide a simple tutorial on how to interface with the P1640 camera controller software system. The camera controller software system has two HTTP server processes that run continuously listening for commands on HTTP ports. These processes are called *camera* and *filesave*. The *camera* server process is the main thread of control that handles commands for downloading and running applications on the SDSU camera controller timing board. The *filesave* server process handles the data acquisition from the SDSU camera controller and storing the data to disk.

```
$ camera -p 7063
```

```
$ filesave -p 7063
```

## Initialise camera and filesave server

### Reset hardware

#### 1) Reset PCI card (software reset) command to camera server

HTTP command: <http://195.194.120.66:7063/exec?RST>

#### 2) Reset Timing board (hardware reset) command to camera sever

HTTP command: <http://195.194.120.66:7063/exec?RCO>

## Load telescope configuration

#### 3) Configure camera server telescope settings

HTTP command: [http://195.194.120.66:7063/config?uk\\_atc.xml](http://195.194.120.66:7063/config?uk_atc.xml)

#### 4) Configure filesave server telescope settings

HTTP command: [http://195.194.120.66:5417/config?uk\\_atc.xml](http://195.194.120.66:5417/config?uk_atc.xml)

## Load instrument configuration

#### 5) Configure camera server instrument settings

HTTP command: <http://195.194.120.66:7063/config?ultracam.xml>

#### 6) Configure filesave server instrument settings

HTTP command: <http://195.194.120.66:5417/config?ultracam.xml>

## Power on camera controller

---

## **Load power on application**

### **1) Load power on application on camera server**

HTTP command: [http://195.194.120.66:7063/config?hawaii1rg\\_pon\\_app.xml](http://195.194.120.66:7063/config?hawaii1rg_pon_app.xml)

### **2) Load power on application on filesave server**

HTTP command: [http://195.194.120.66:5417/config?hawaii1rg\\_pon\\_app.xml](http://195.194.120.66:5417/config?hawaii1rg_pon_app.xml)

## **Power on camera controller**

### **3) Execute application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?GO>

## **Power off camera controller**

## **Load power off application**

### **1) Load power off application on camera server**

HTTP command: [http://195.194.120.66:7063/config?hawaii1rg\\_pof\\_app.xml](http://195.194.120.66:7063/config?hawaii1rg_pof_app.xml)

### **2) Load power off application on filesave server**

HTTP command: [http://195.194.120.66:5417/config?hawaii1rg\\_pof\\_app.xml](http://195.194.120.66:5417/config?hawaii1rg_pof_app.xml)

## **Power off camera controller**

### **3) Execute application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?GO>

## **Execute dummy application**

## **Load dummy application**

### **1) Load dummy application on camera server**

HTTP command: [http://195.194.120.66:7063/config?hawaii1rg\\_dummy\\_app.xml](http://195.194.120.66:7063/config?hawaii1rg_dummy_app.xml)

### **2) Load dummy application on filesave server**

HTTP command: [http://195.194.120.66:5417/config?hawaii1rg\\_dummy\\_app.xml](http://195.194.120.66:5417/config?hawaii1rg_dummy_app.xml)

## **Run dummy application**

### **3) Execute application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?GO>

## **Execute Non-Destructive Readout (NDR) application**

## **Load NDR application**

---

**1) Load NDR application on camera server**

HTTP command: [http://195.194.120.66:7063/config?hawaii1rg\\_ndr\\_app.xml](http://195.194.120.66:7063/config?hawaii1rg_ndr_app.xml)

**2) Load NDR application on filesave server**

HTTP command: [http://195.194.120.66:5417/config?hawaii1rg\\_ndr\\_app.xml](http://195.194.120.66:5417/config?hawaii1rg_ndr_app.xml)

**Run NDR application****3) Execute application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?GO>

**General Commands****Read timing board at X memory at address 0x200 command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?RDM,X,0x200>

**Write value 0x1234 to timing board X memory at address 0x200 command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?WRM,X,0x200,0x1234>

**Execute application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?GO>

**Stop application command to camera server**

HTTP command: <http://195.194.120.66:7063/exec?ST>

**Status command to camera server**

HTTP command: <http://195.194.120.66:7063/status>

**Status command to filesave server**

HTTP command: <http://195.194.120.66:5417/status>

**File status command to filesave server**

HTTP command: <http://195.194.120.66:5417/fstatus>

**Get application file name list command to camera server**

HTTP command: <http://195.194.120.66:7063/list>

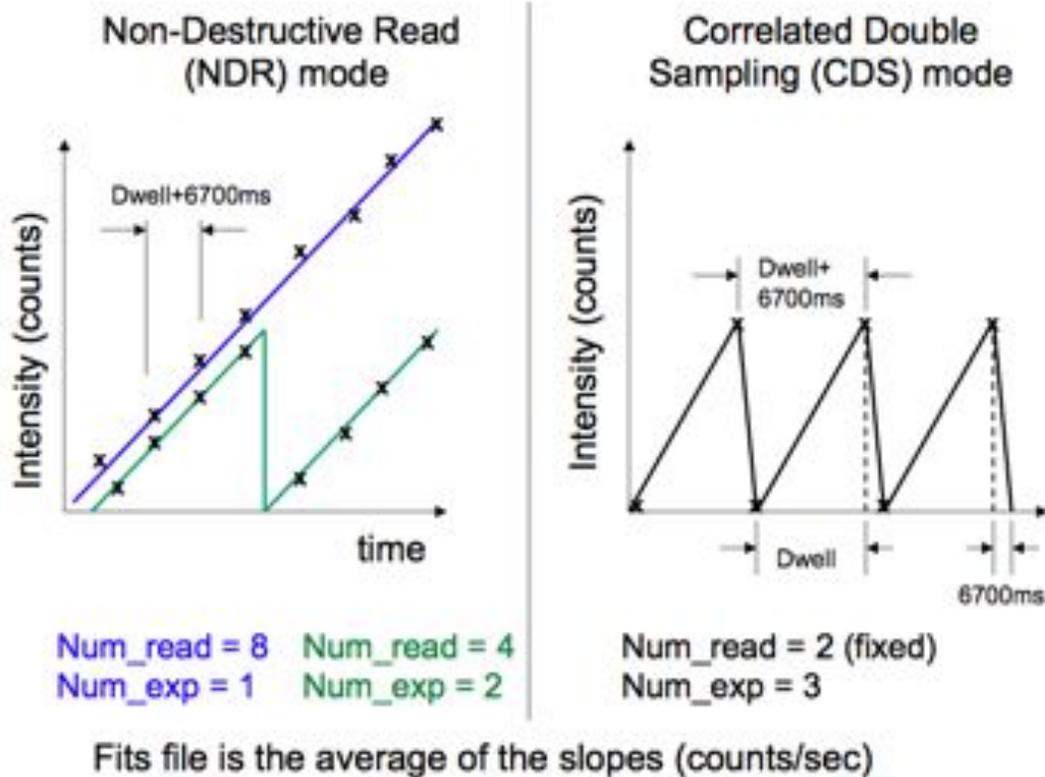
**Get dummy application file command to camera server**

HTTP command: [http://195.194.120.66:7063/get?filename=hawaii1rg\\_dummy\\_app.xml](http://195.194.120.66:7063/get?filename=hawaii1rg_dummy_app.xml)

**Get NDR application file command to camera server**

HTTP command: [http://195.194.120.66:7063/get?filename=hawaii1rg\\_ndr\\_app.xml](http://195.194.120.66:7063/get?filename=hawaii1rg_ndr_app.xml)

---



**Figure 89. Two schematic drawings showing the Non-destructive Reads (NDR) and the Correlated Double Sampling (CDS) modes of detector readout.**

This is the algorithm for the NDR slope used in the demux task.

$$m = \frac{\sum_{i=1}^n V_i \{i - \frac{(n+1)}{2}\}}{dt \times \frac{n}{12} (n^2 - 1)}$$

where  $V_i$  is the voltage of the sample  $i$ ,  $n$  is the total number of samples and  $dt$  is the time interval between the samples.

(Ref: SPIE Vol. 1235 Instrumentation in Astronomy VII (1990))

**Figure 90. Formula used for NDR slope in the de-multiplexing software. This is not well understood.**



**Figure 91. The SDSU controller (gold box) and power supply (grey box) used for P1640.**



**Figure 92. The power off (left) and power on (right) lighting configurations on the SDSU controller.**

#### **2.2.5.4. Printed Circuit Board**

The detector is housed in a black Zero-Insertion Force (ZIF) socket which is mounted on a custom printed circuit board shown in the drawing below. The rounded corner of the board was determined in order to prevent collision with the radiation shield. In addition a copper block (see drawing below) has been soldered to the back of of the ZIF socket to act as a good thermal cooling pathway. This block also serves as the primary mounting mechanism for the

detector. A single aluminum plate (“Copper Block holder” in the drawing below) is used to mount this copper block to the detector mount via four M5 screws.

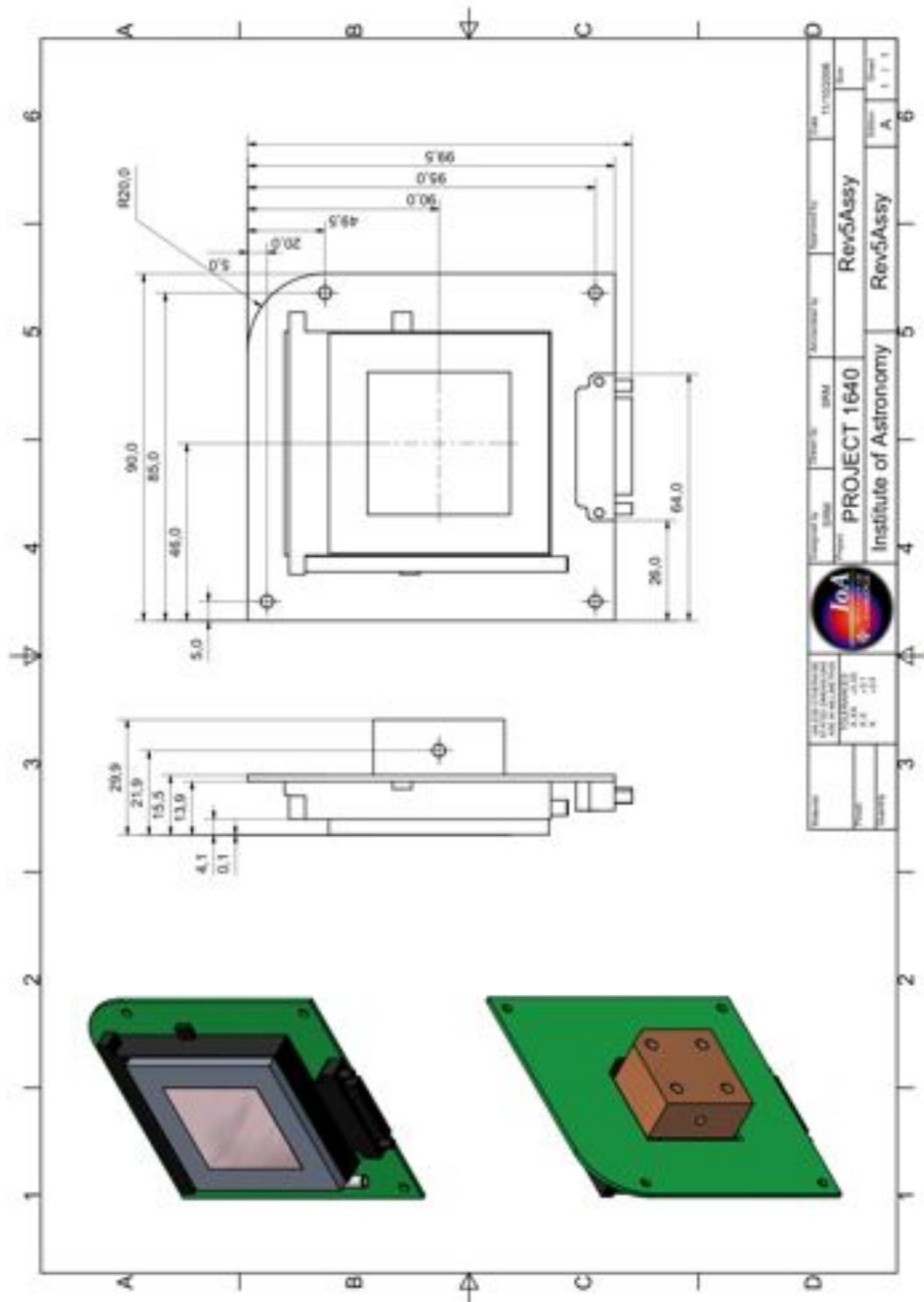
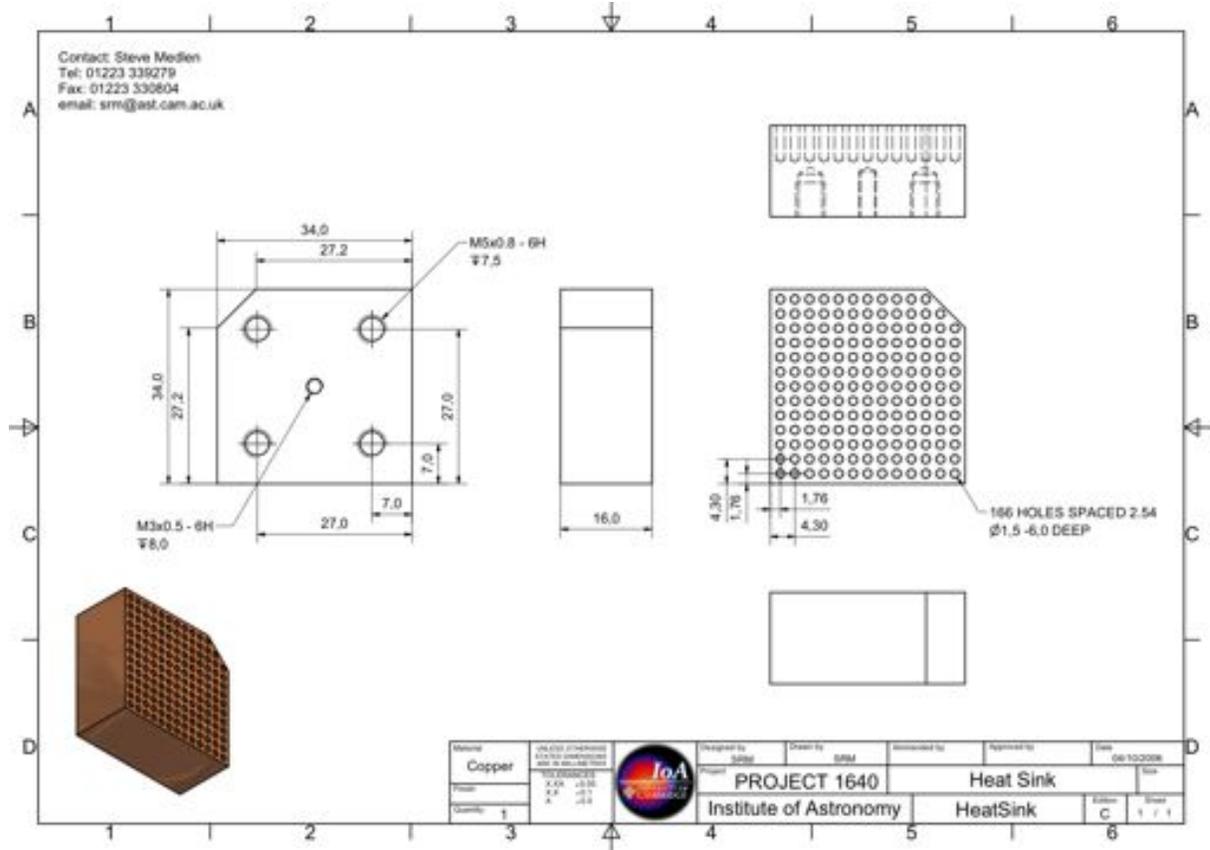


Figure 93. Design drawings for the P1640 Printed Circuit Board.



**Figure 94. This copper block serves as the primary detector heat sink and is soldered to the back of the ZIF socket on the PCB. Note the tapped hole for the temperature sensor mounted in an M3 screw.**





**Figure 96. The PCB front (left) and back (right) showing the copper block heat sink. The four M5 screws secure the entire PCB to the plate in the back of the detector mount (see drawing of copper block holder below).**

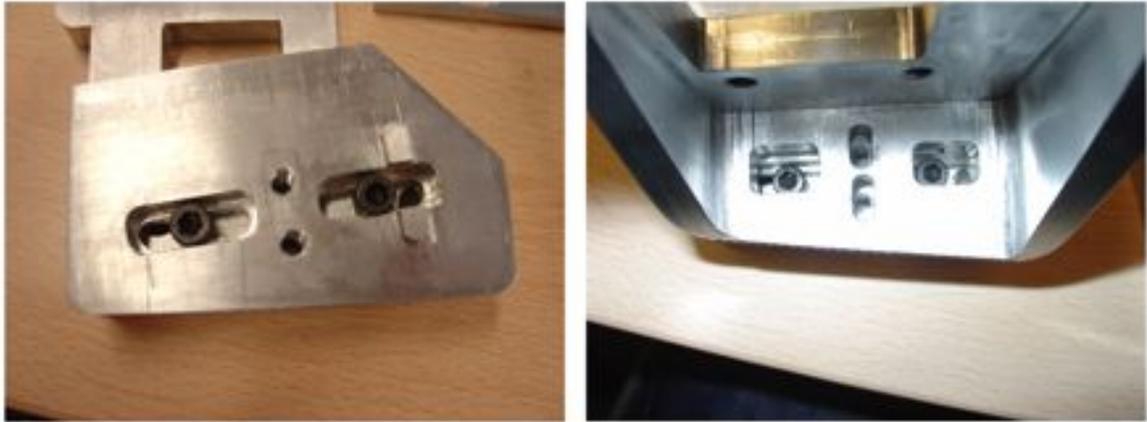
#### 2.2.5.5. Detector mount and detector cabling

The printed circuit board (PCB) assembly is mounted onto the upper portion of the detector frame via the PCB's copper block and the aluminum plate shown below called "Copper block holder". This copper block holder is bolted via four  $\frac{1}{4}$ -20 screws in slots which allow the aluminum plate, and hence the detector, to slide vertically up and down.



**Figure 97. Left: The PCB with test chip carrier. The detector cabling travels down through a trough in the detector mount plate, through the optics baseplate to the vacuum feed through socket. Right: the field lens with cell retainer mounted in front of the PCB.**

In addition, this upper detector frame piece is capable of "x-y" movement in the plane parallel to the optics baseplate. This is accomplished via an intermediate plate shown in the photo below. This intermediate plate has screws in slots to allow the side movement, as well as a rail to guide the upper detector frame for the forward movement. These movements can happen independent of each other as large holes provide access to these screws.



**Figure 98. Left: the middle mount plate moves left to right. Note the fin on the right which guides the upper detector frame. Right: The detector frame piece moves parallel to the beam path and can be moved to adjust the detector focus.**

The detector cabling which comes out of the plug at the bottom of the PCB travels straight down through a groove cut into the detector mount base (see photo below). This cabling travels down through the main optics baseplate via a semi-circular hole (see drawings of dewar baseplate) and out through a hole in the radiation shield. These cables are soldered to a 41-pin Amphenol vacuum feed-through socket (P/N 602GB-07H20-41PN, Mil-C-26482 specification), which is o-ring mounted to a round Aluminum plate bolted to the dewar.

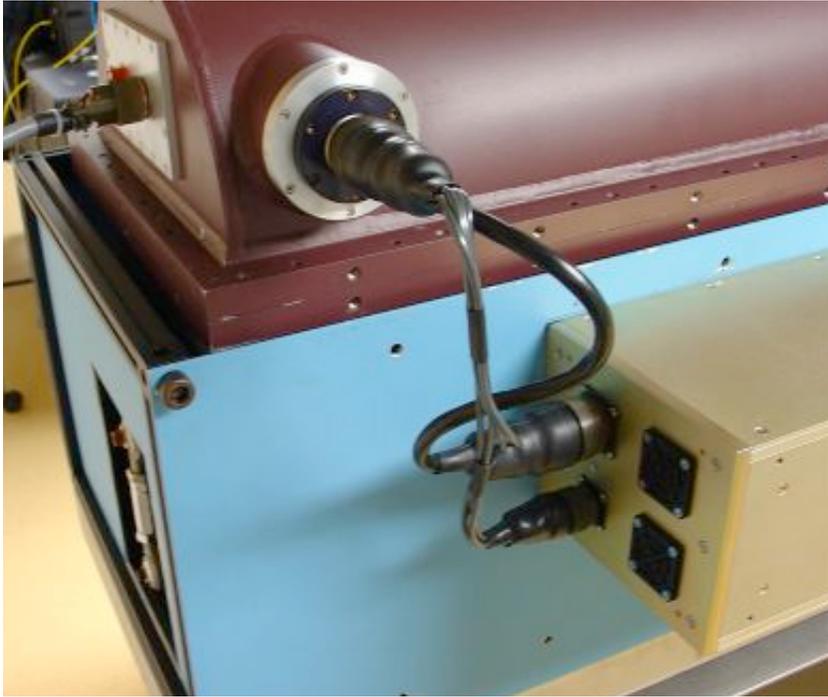
The cabling for the detector has a single Military type connector on one end and two military type connectors that are plugged into the detector electronics box (see photo below). The detector electronics box is connected to its power supply via a single multi-pin military-type connector.



**Figure 99. The Amphenol vacuum feed through socket. The aluminum portion shown on the right is the surface making contact with the o-ring on the**

---

**aluminum dewar plate. The black housing clamps this aluminum piece to the dewar ensuring a good seal.**



**Figure 100. Detector Cabling. The dewar vacuum feed through port has a single military type connector, while the detector controller box has two military connectors.**

---

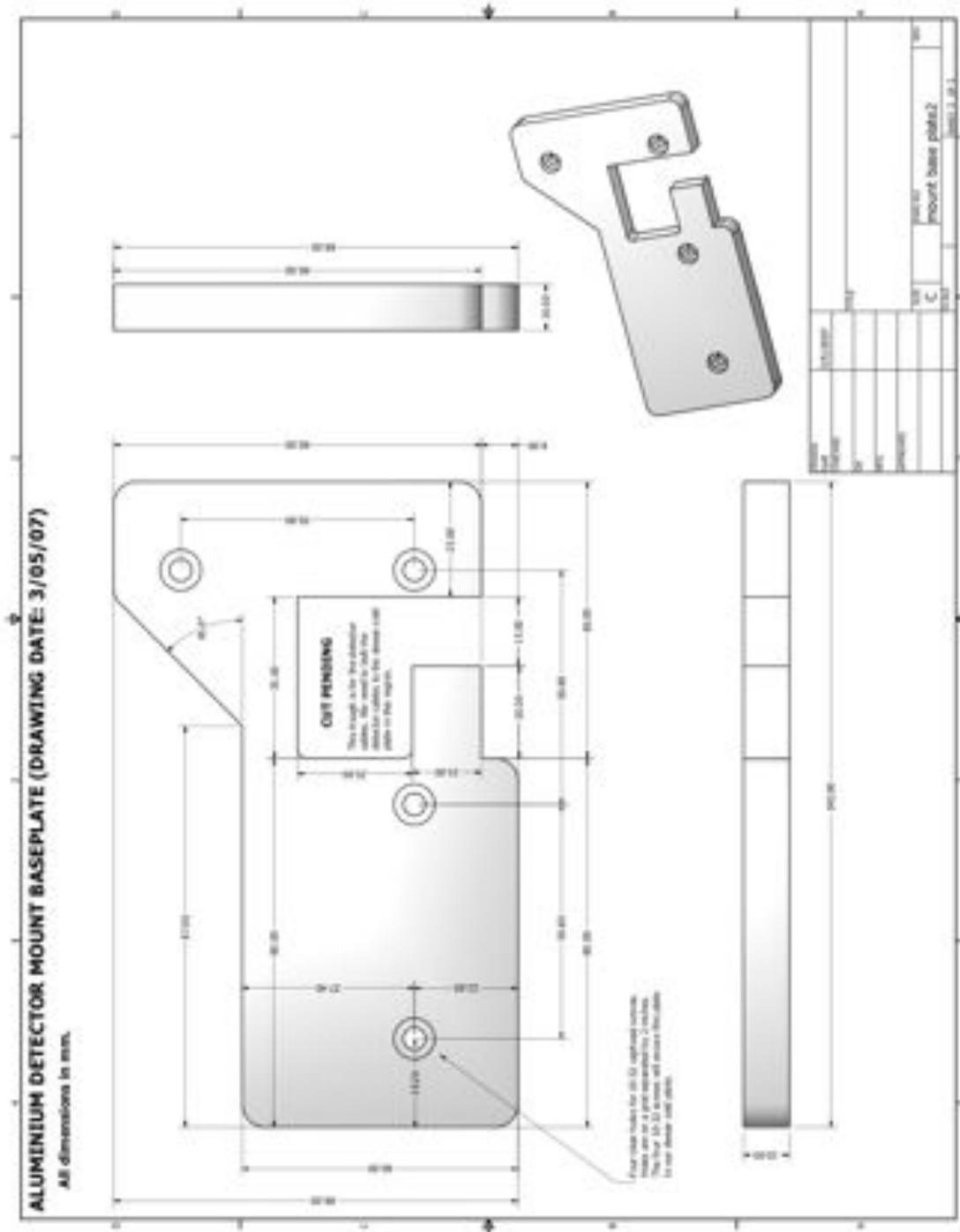


Figure 101. Design drawing for the detector mount baseplate

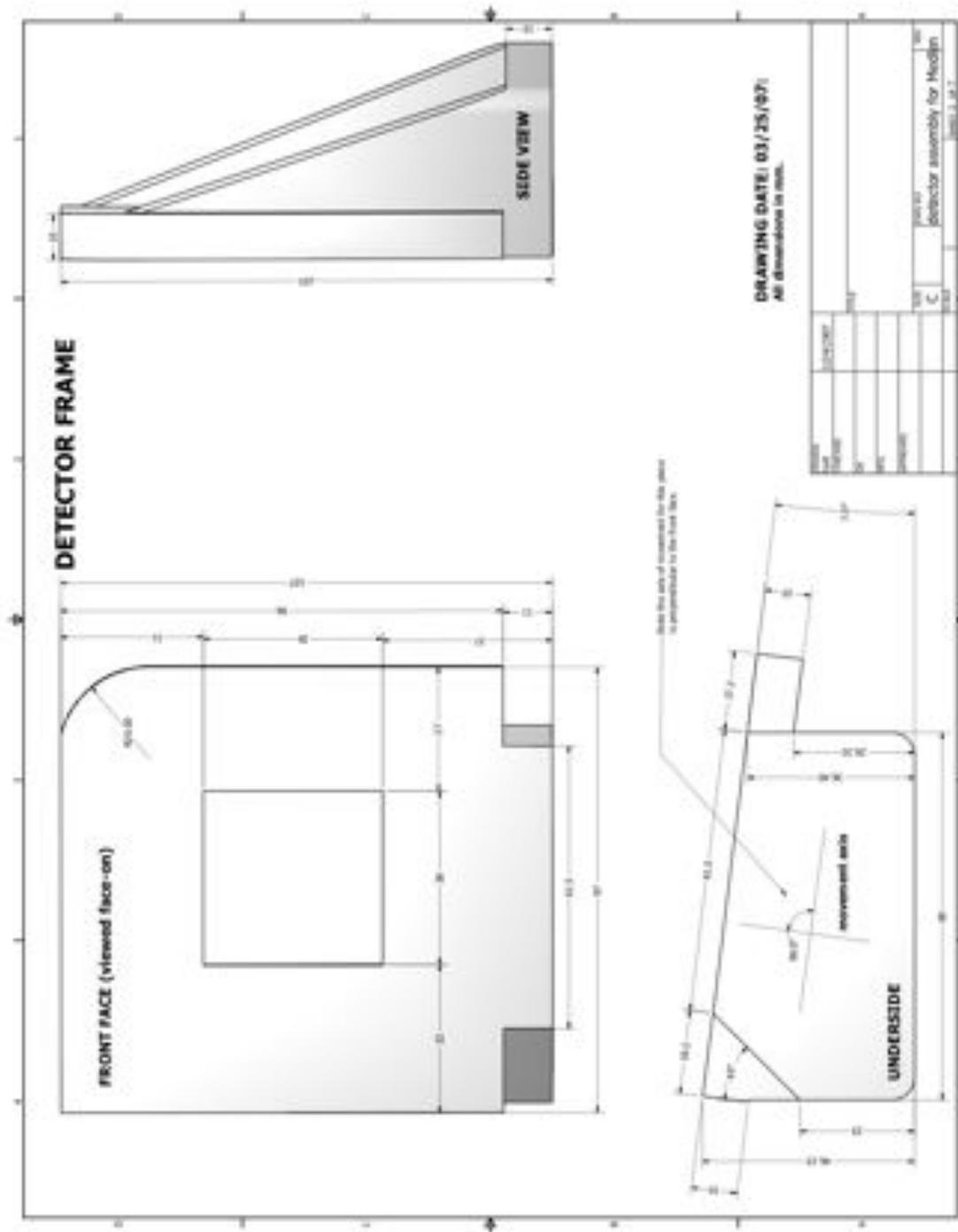


Figure 102. Design drawing for the detector frame. The copper block slides into the square region in the frame.





### **2.2.5.6. Detector Removal and Insertion**

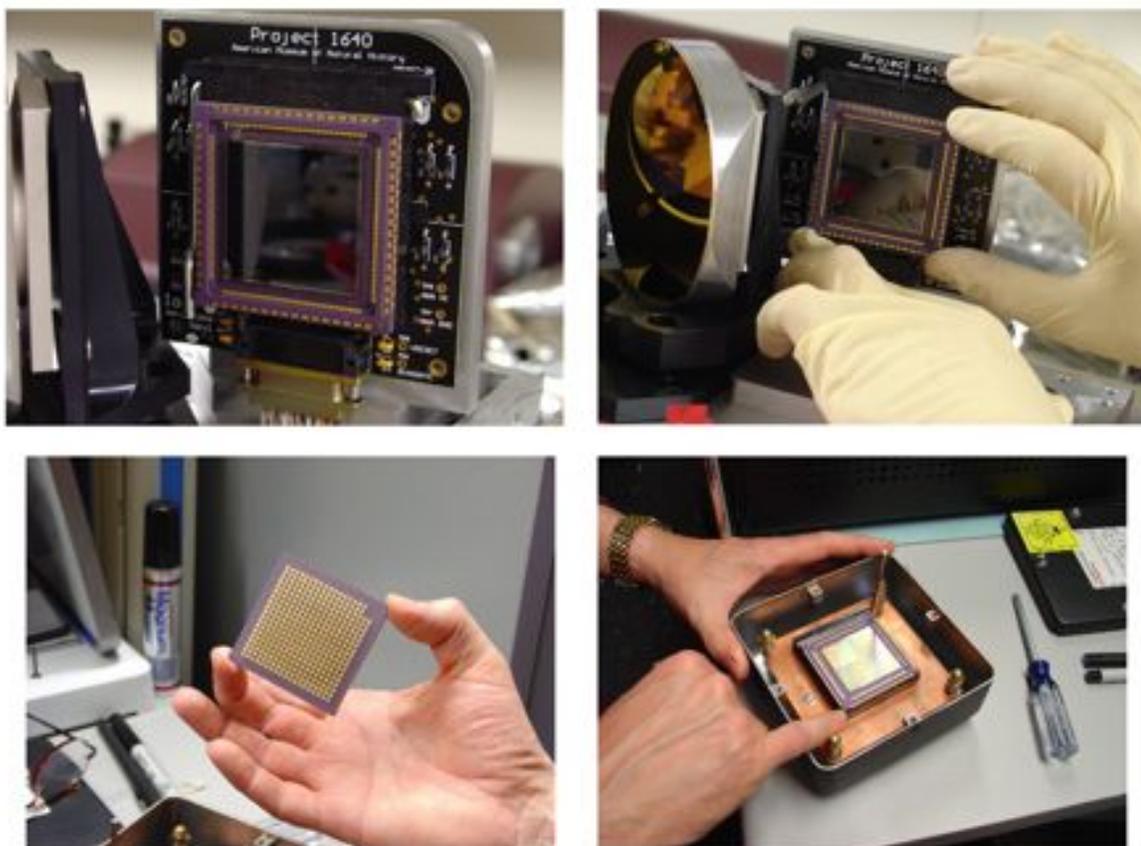
To remove the detector chip from its mount on the PCB, extreme care must be taken not to impart any electrical shocks to the array, but also to ensure the chip does not fall since its mounted vertically.

1) First, lift the aluminum lever on the left side of the ZIF (Zero-Insertion Force) socket while holding the array in place only touching at the corners of the ceramic portion of the chip carrier (see photo below). Take great care that one of your fingers does not make any contact with the extremely fine gold wires going between the gold pads on the ceramic chip carrier and to the chip itself. Any contact could sever a wire, compromising the entire detector. Once the lever is horizontal the chip is free and can fall out of place.

2) Remove the detector holding it at the corners as in the picture below.

3) The detector can be stored in its transport box as shown in the figure below. This is simply a ZIF socket installed on a spring-mounted copper plate. Place the detector in place in the ZIF socket, making sure that all the pins on the back of the array fit squarely into the holes in the ZIF socket. The correct orientation is noted by a “missing” corner of pins on the back of the array (see photo below). This corner should be placed at the corner that is closest to where the lever hinges (the upper left corner if viewed face-on).

---



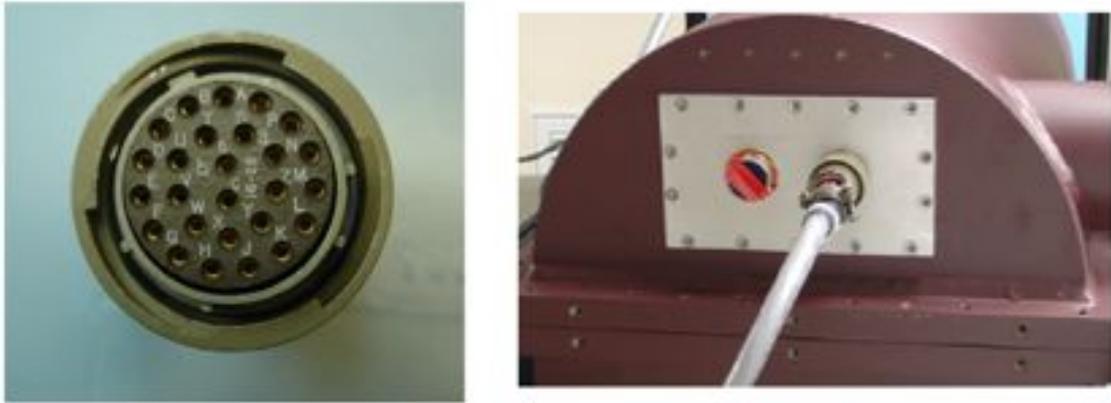
**Figure 105. Several steps showing the removal of the Hawaii 2K detector from its ZIF socket.**

### 2.2.5.7. Temperature Control

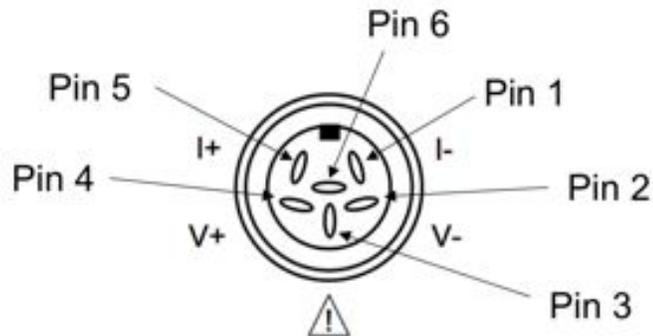
The temperature sensing and control in the IFU is controlled via two Silicon diode temperature sensors, and a rack mounted Lakeshore 331S temperature controlling unit. One sensor is located in the center of the copper block soldered to the back of the printed circuit board. In addition, we have two 2.5  $\Omega$  resistors to provide heating to the system.

Part Description	Qty	Vendor	Part Number
Temperature sensor	2	Lakeshore	DT-670-SD
Wiring leads	2	Lakeshore	SMOD-4-DT32-4
Temperature Controller	1	Lakeshore	331S
Cryogenic Wire	1	Lakeshore	WHD-30-100
2.5 $\Omega$ aluminum-housed resistors	2	Digi -Key	TMC10-2.5-ND
Dewar mounted vacuum Feed Thru Connectors	4	Detorionics	DTIH-16-26PN DTIH-16-26PN
Cable mounted feed thru mating plugs	4	Detorionics	MS3116F-16-26S
10m cabling	2	Anthony Industries	Custom

**Temperature sensors:** The sensors are two Lakeshore DT-670-SD Silicon Diodes mounted in a M3 screw (see drawings below). This particular series of sensors work from 1.4K – 500K, and have 12mK calibrated accuracy at cryogenic temperatures. In addition, we use a custom Lakeshore SMOD-4-DT32-4 wiring lead configuration going to the four wires on the diodes. This corresponds to two Voltage inputs (V+, V-) and two Current inputs (I+, I-). We have four feet of wiring on each sensor. These wire leads are soldered to a single Detronics P/N DTIH-16-26 vacuum feed-thru connector mounted on the dewar wall. The other is spare. These connectors have been mounted via epoxy onto an aluminum plate. This plate is o-ring sealed on the dewar wall via 14 10-32 screws.



**Figure 106. The temperature sensor cabling. Left: The key pattern on the connector. Right: The cabled connected. We currently don't use one plug.**



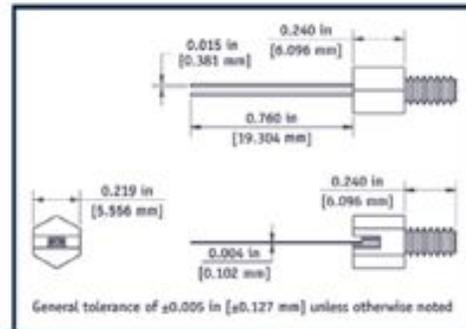
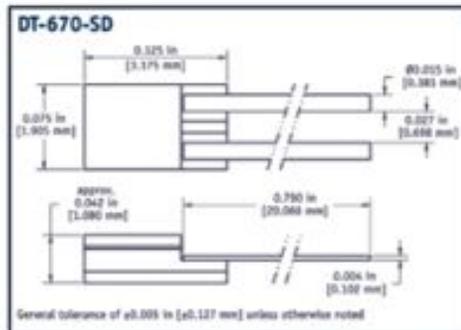
Pin	Symbol	Description
1	I-	- Current <span style="color: green;">Green</span>
2	V-	- Voltage <span style="color: red;">Red</span>
3	⚠	+1 mA – Model 330 Configuration Shield – Model 340 Configuration
4	V+	+ Voltage <span style="color: black;">Black</span>
5	I+	+ Current <span style="color: black;">Black</span>
6	None	Shield

**Figure 107. Detail on the input plug to the Lakeshore 331 Temperature controller. The input to the controller is a six pin connector with a pattern shown above. The wires in the cable corresponding to these pins are colored as shown above in the table.**

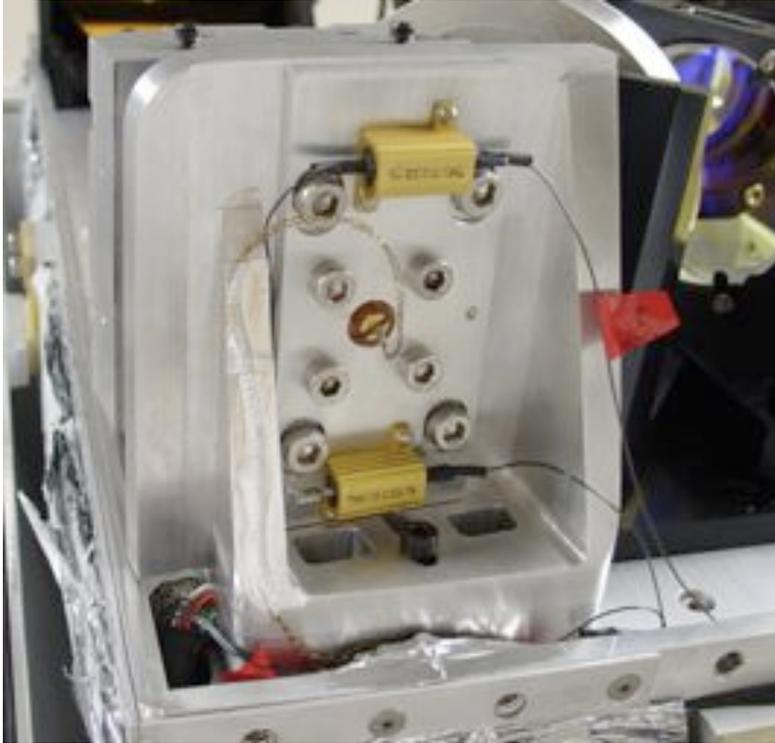
**Table 7. The pins in the Detronics plugs are wired to the temperature sensor wires as shown below.**

Temp Controller Sensor A (Cold Plate)	Pin
V- (green)	C (capital, not lower case!)
I- (green)	N
V+ (gold)	E
I+ (gold)	V
Temp Controller Sensor B (Detector)	
V- lead (green)	b
I- lead (green)	J
V+ lead (gold)	L
I+ lead (gold)	u
Resistor wiring	
(Two resistors connected in series)	C (lower case, not capital!)

G



**Figure 108. The Silicone diode temperature sensor (upper left). This diodes is housed in a M3 screw housing as shown in the upper right and lower image.**



**Figure 109. The back of the detector mount showing the resistors connected to the back plate, and the temperature sensor screwed into the copper block in the PCB. The four 1/4-20 screws fix the plate to the detector frame, the smaller screws to the copper block.**

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### 2.3. Wave Front Calibration System

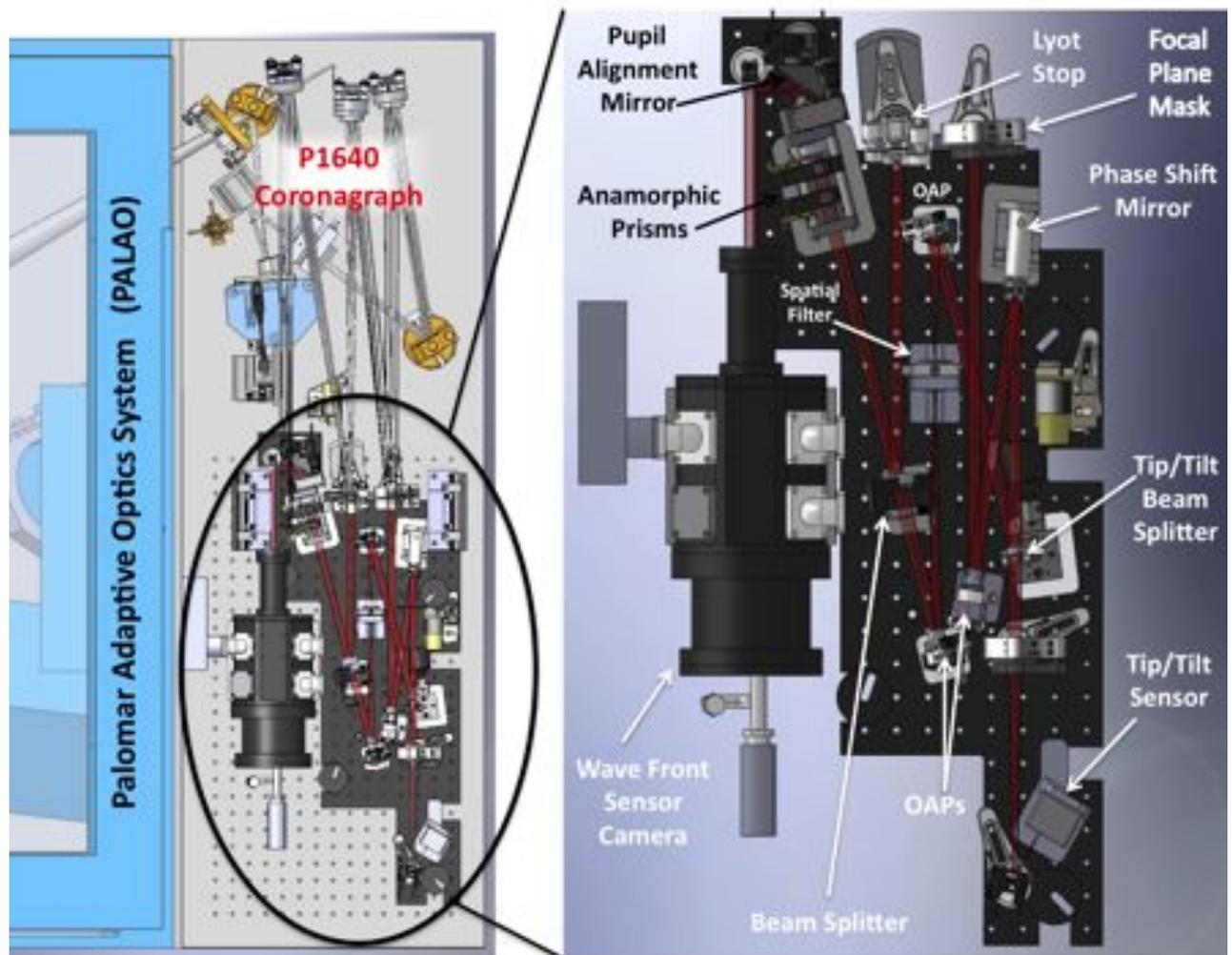
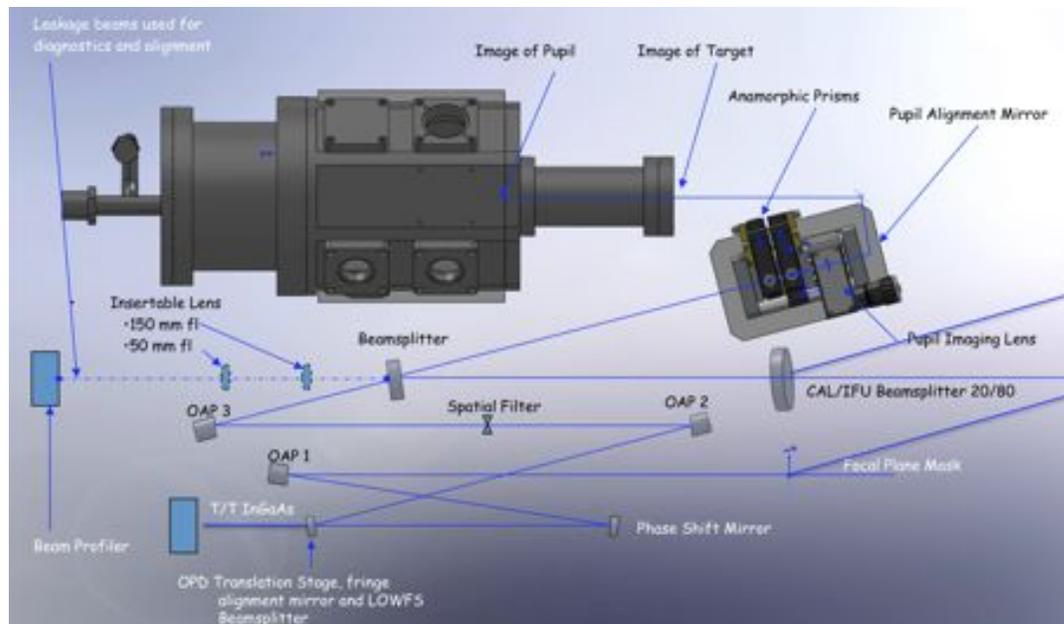
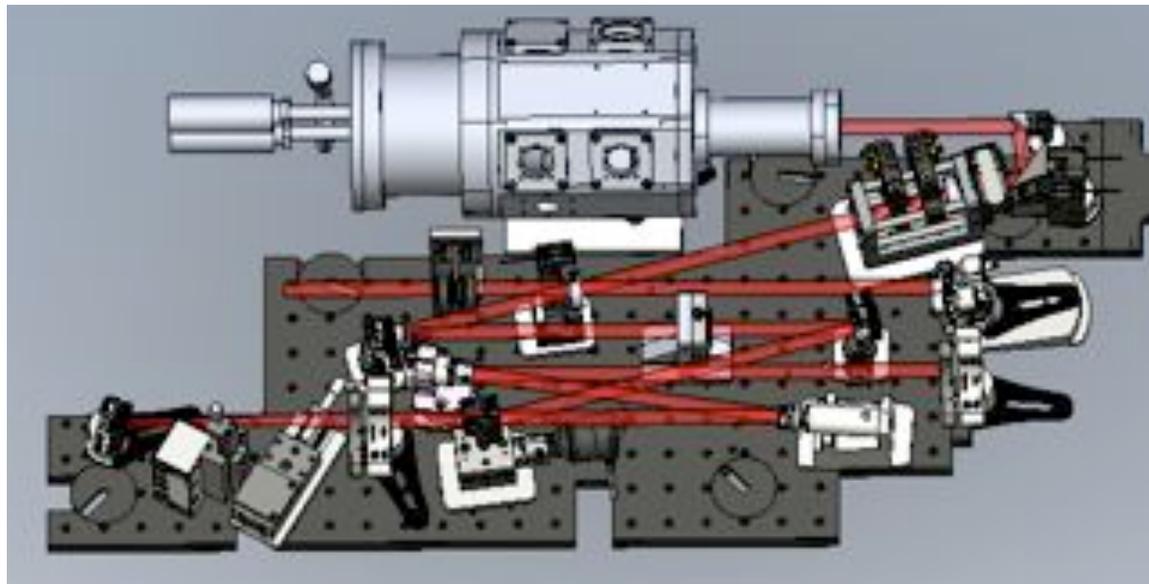


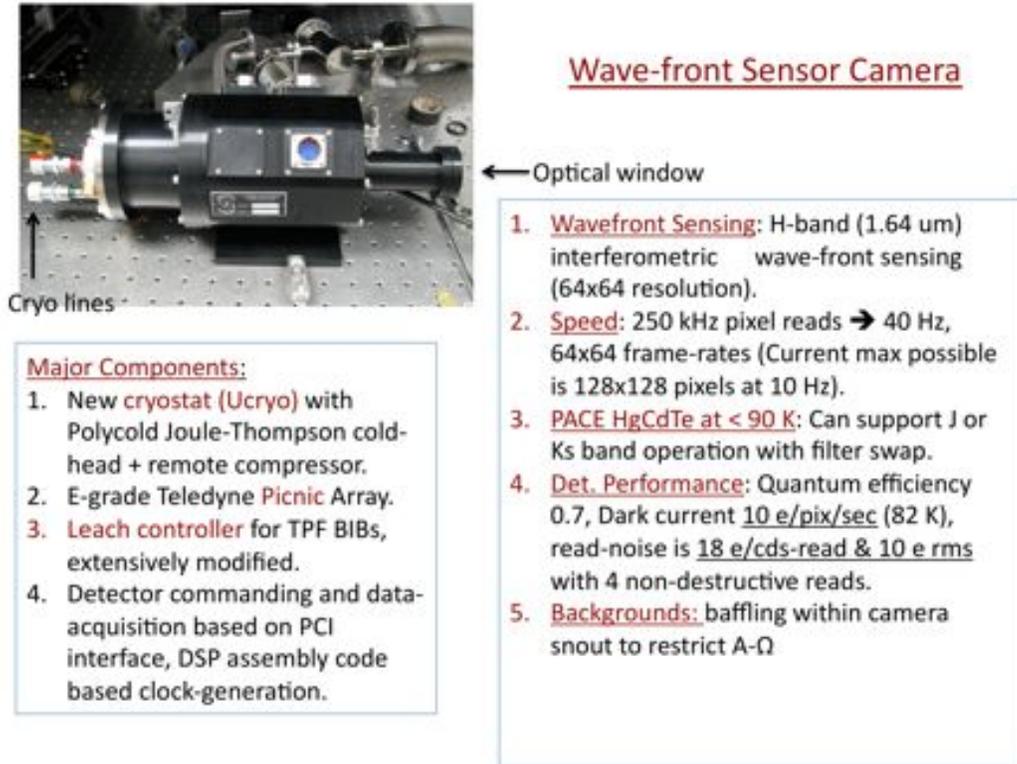
Figure 110. Detail for the P1640 Wave front calibration system.



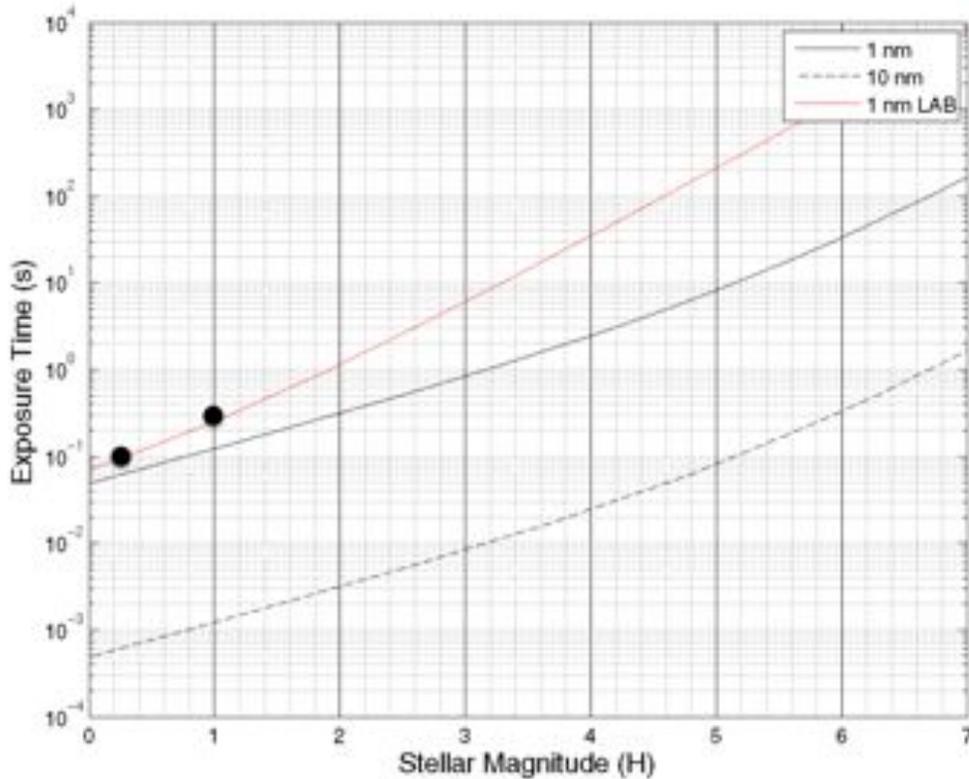
**Figure 111. Cal optics in detail with mounts removed (Image courtesy of GV).**



**Figure 112. Another image of the Cal System courtesy of LCR.**



**Figure 113. Cal system camera specs courtesy of GV.**

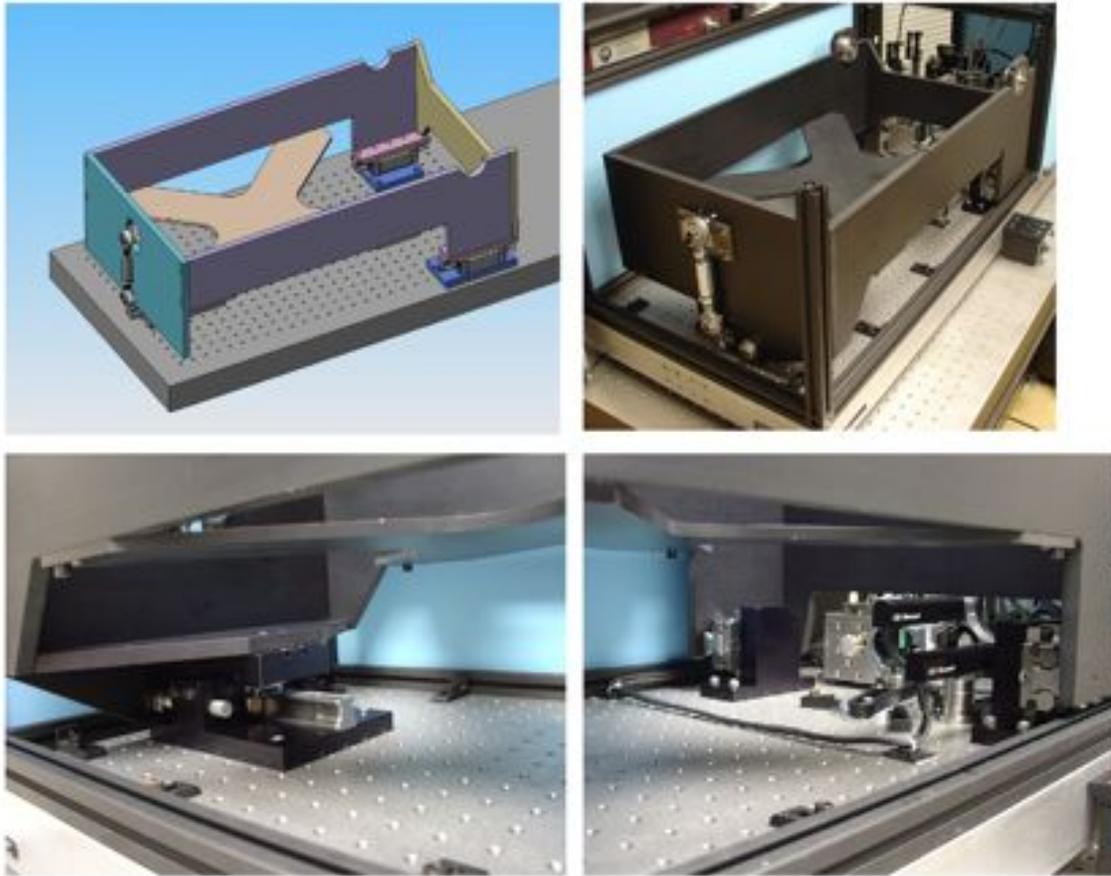


**Figure 114. Initial exposure time estimates for the CAL system courtesy of GV.**

## 2.4. Ancillary Components

### 2.4.1. Dewar Support/Focus Mechanism

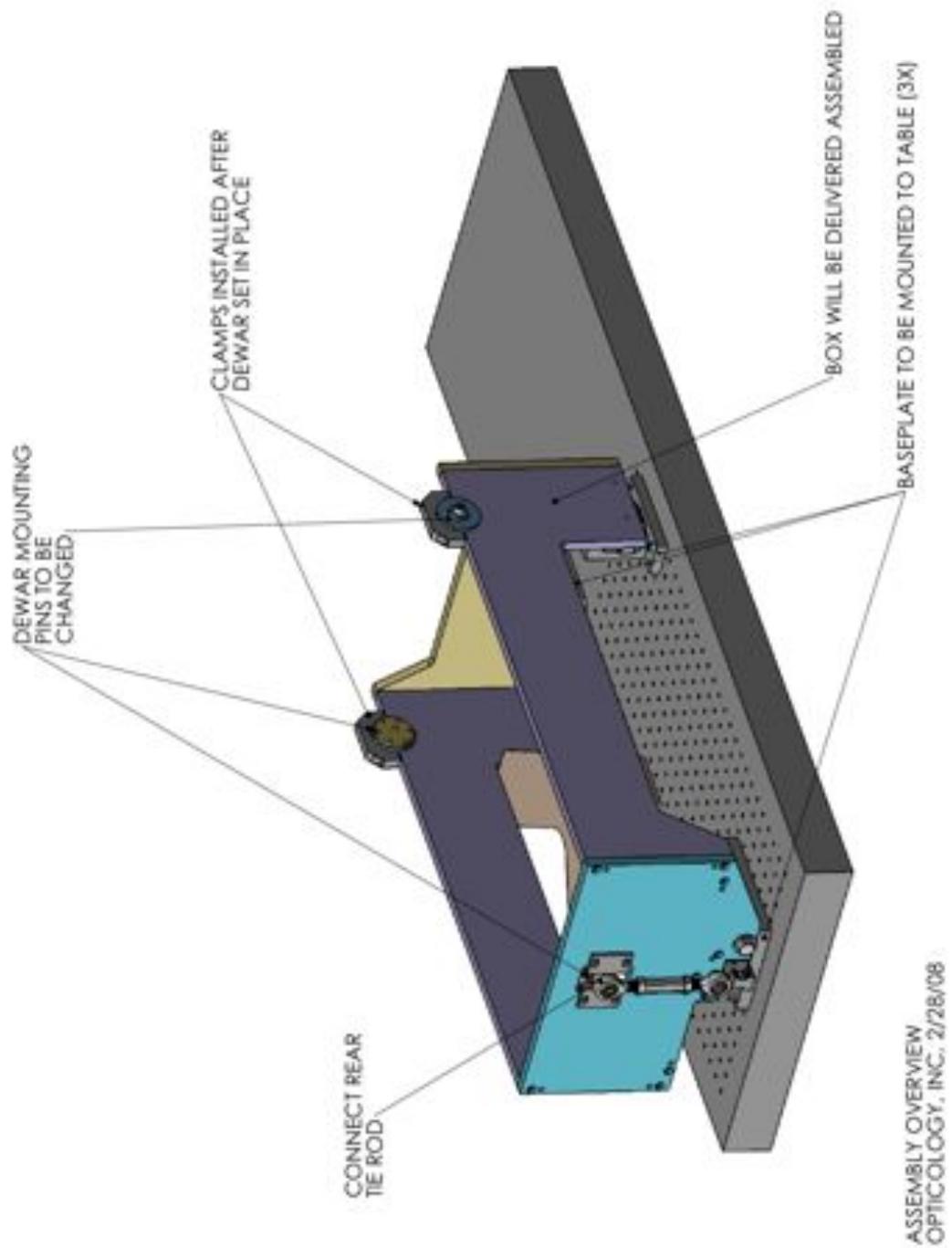
To maintain dewar stability while minimizing flexure during telescope slewing, have have developed a custom dewar handling bracket and manufactured by Opticology in New York City. Our dewar has three mounting pins, two towards the front, and one on the rear face, which are used to attach to our mounting bracket. The entire bracket assembly is mounted on flexure-resistant rails which allows 20-30mm of focus movement using a fine-thread screw. This mounting bracket also allows a +/-10 degree tilt using a screw-jack mechanism at the rear of the dewar, allowing the entire dewar to pivot on its front two mounting pins by applying a vertical movement at the rear pin.



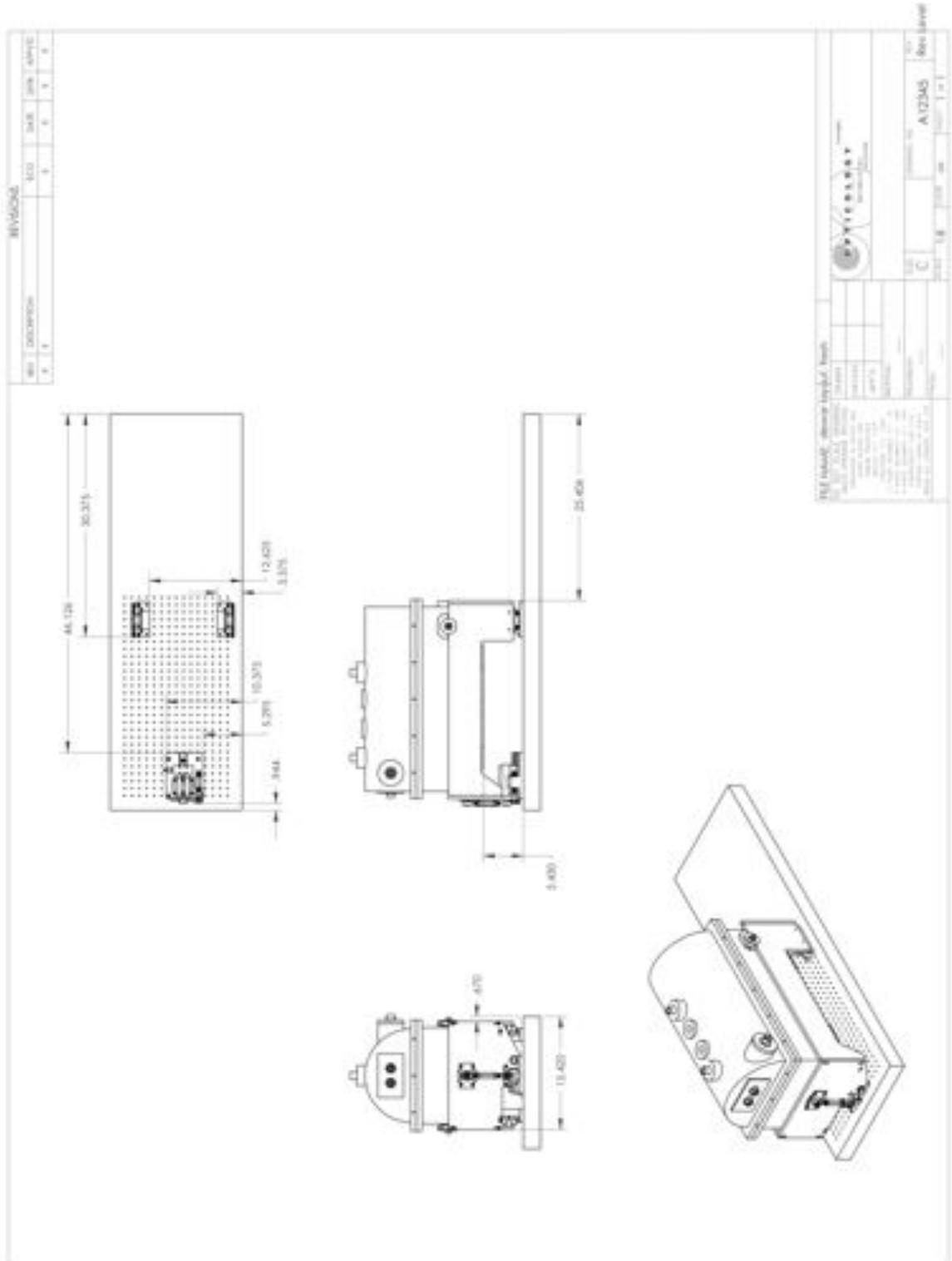
**Figure 115. The detector focus and support mechanism. The entire assembly can provide a +/- 10 degree tilt via the screw jack mechanism in the rear, pivoting on the front two pins. The entire mechanism is mounted on low flexure rails mounted in runner blocks.**

**Table 8. Parts list for the dewar handling mechanism rail systems.**

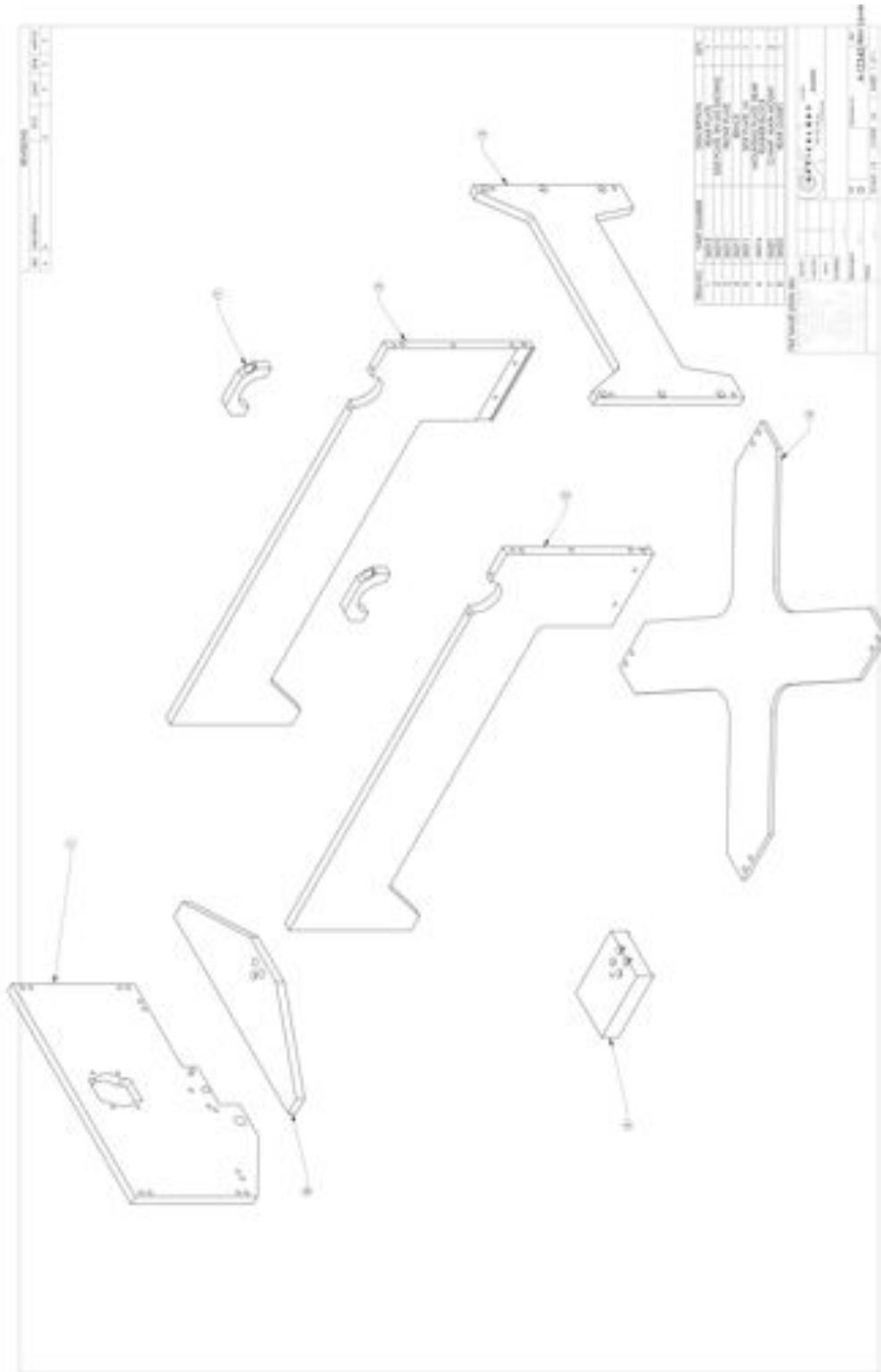
<b>Description</b>	<b>Qty</b>	<b>Vendor</b>	<b>Part number</b>
Ball rail (176mm long)	1	Rexroth Bosch	R160520231
Ball rail (116mm long)	2	Rexroth Bosch	R160520231
Ball carriage (“ball block”), size 25, 8% preload, “H” accuracy.	3	Rexroth Bosch	R165122320
Clamp	1	Rexroth Bosch	R161924282
Clamp spacer	1	Rexroth Bosch	R161924285



**Figure 116. Description for mounting the dewar into its handling mechanism.**



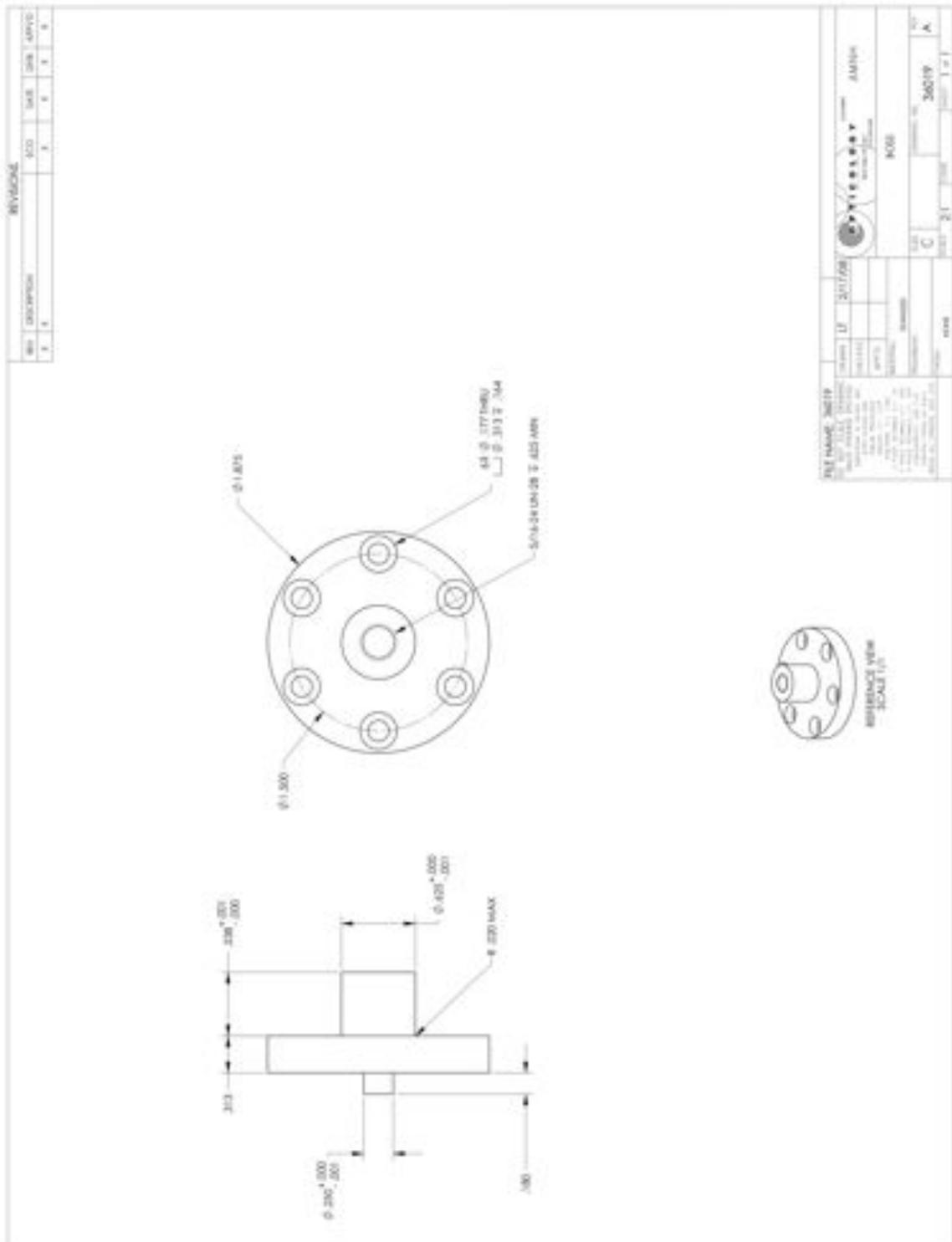
**Figure 117. Design drawings of the dewar support and focus mechanism.**



**Figure 118. Design drawings for the carriage portion of the dewar focus assembly.**

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**Figure 120. The two front dewar mounting pins are identical and shown in this design drawing. These are mounted directly on the dewar.**

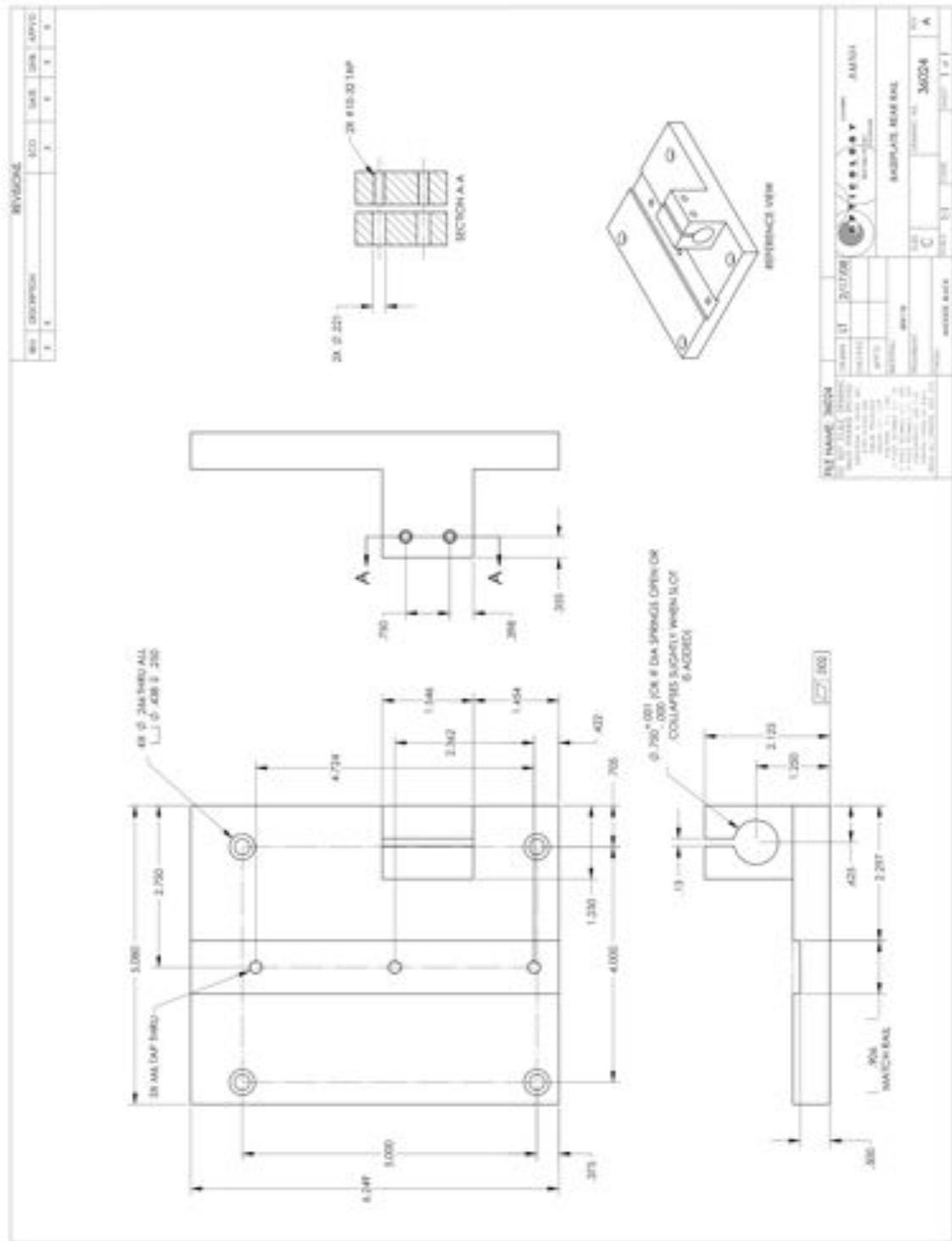


Figure 121. This baseplate for the rear rail is bolted directly to the Thorlabs baseplate for the instrument. The longer rail is bolted to this baseplate via three M6 screws. The focussing screw is not shown in this drawing.





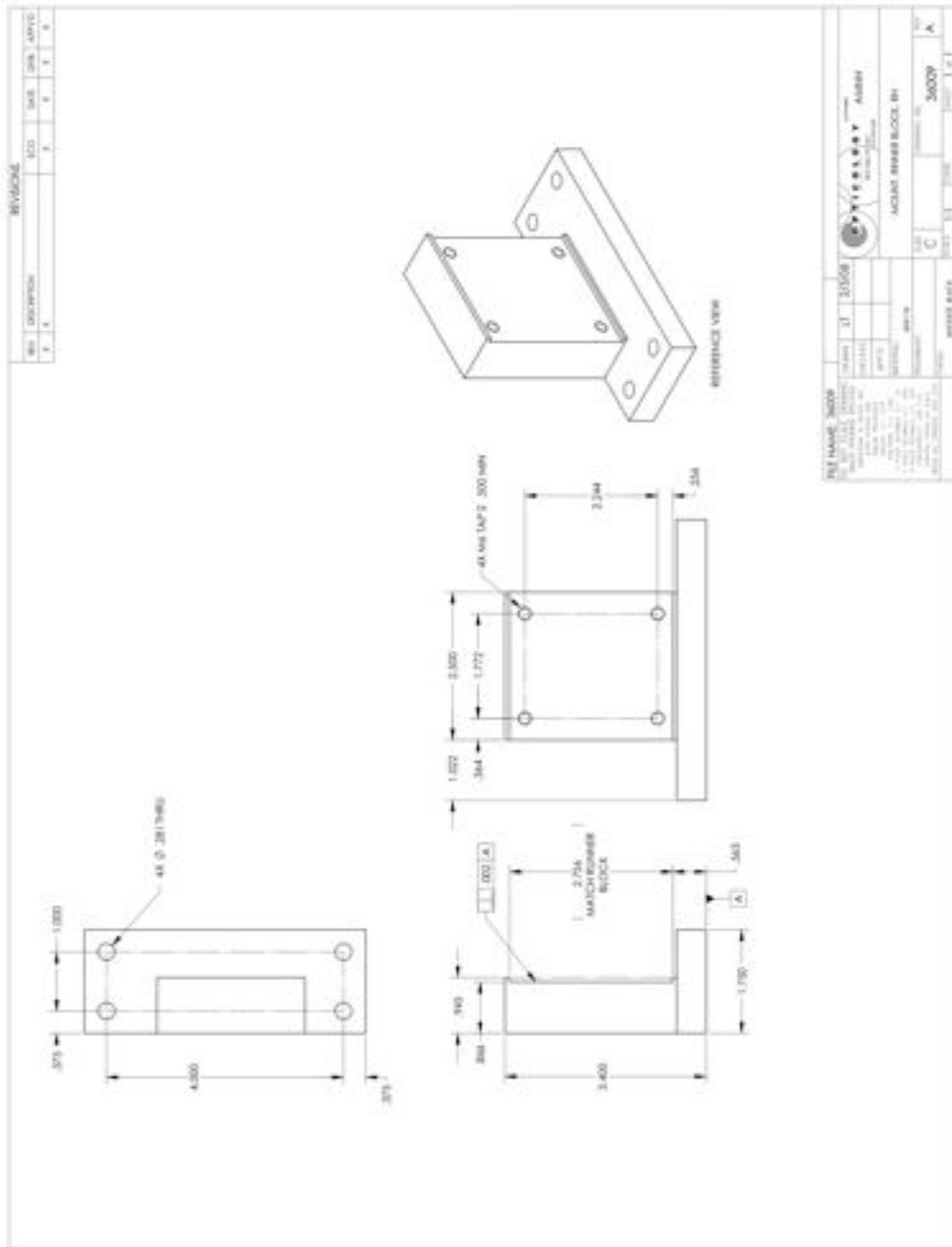


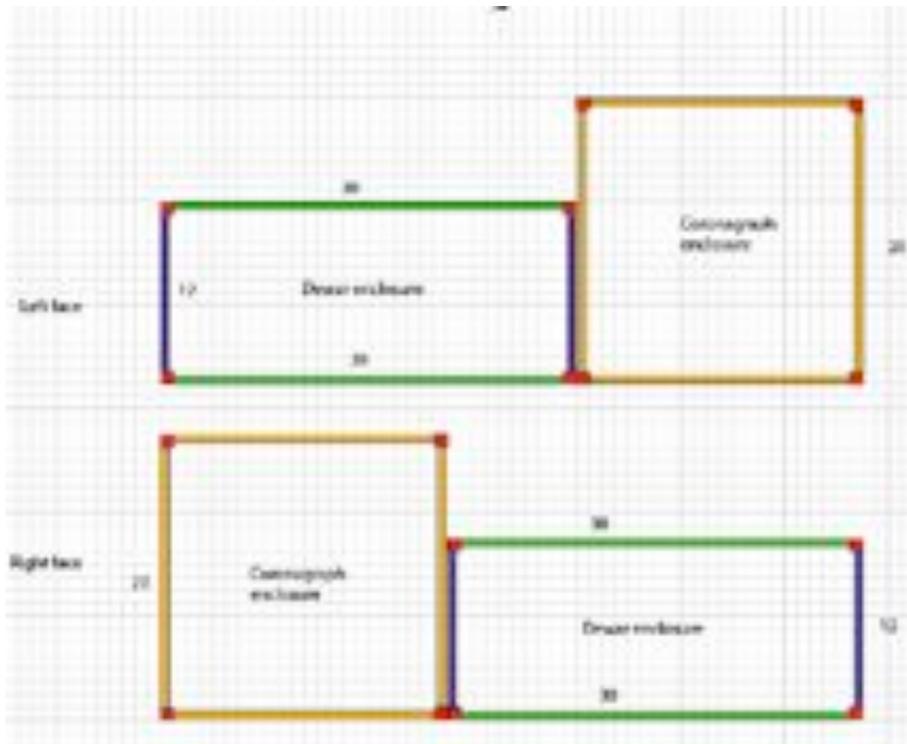
Figure 124. Similar to the above drawing. This mount is bolted to the right hand runner block.

### 2.4.2. System Enclosure

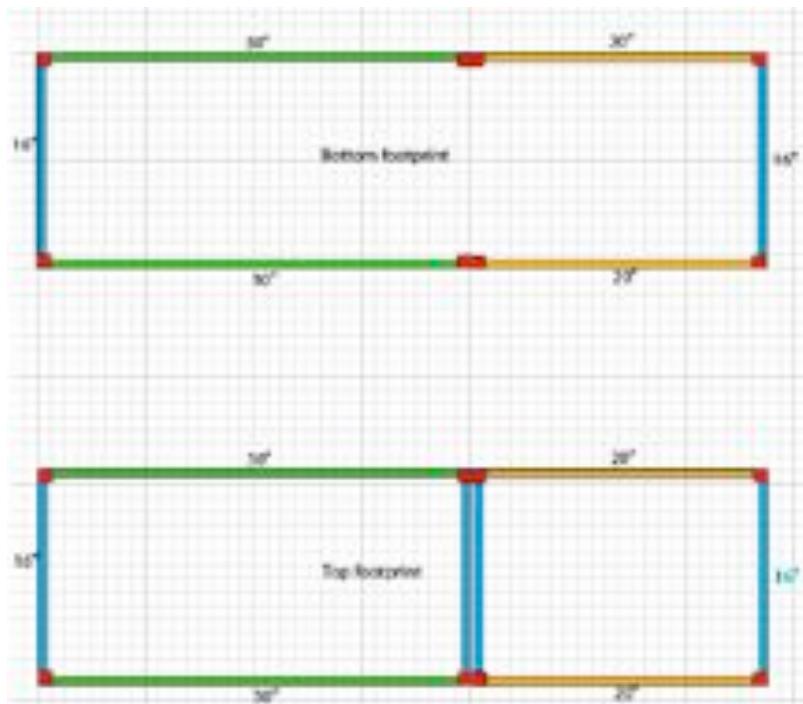
The enclosure for the system (IFU+ coronagraph) is comprised of 1/8" thick painted Aluminum panels secured by standard optical table rails. The enclosure is comprised of two segments (see drawing below). The first is a rectangular cube shape enclosed on three sides (back, left and right) forming a skirt around the IFU dewar. The second is a rectangular cube shape enclosed on four sides (front, left, right and top), housing primarily the coronagraph. The enclosure rails will be constructed from Thorlabs components; XE25 rails and RM1G construction cubes. Drawings of the panels are included below.

**Table 9. Parts list for system enclosure.**

Component	Qty	Description
XE25L12	4	12 inch rail
XE25L20	8	20 inch rail
XE25L30	4	30 inch rail
XE25L16 custom	7	16 inch custom rail
RM1G	16	corner construction cubes
XE25T4	2	T-nuts for attachment of braces to rails



**Figure 125. Side views of the P1640 enclosure rail structure.**



**Figure 126. Top view of the rail structure.**

A picture of the secured railings are shown below. The railings are secured to the table via standard Newport optical table clamps. An XE25T4 T-nut and an 8-32 screw is required to secure the clamp to the rail, while the clamp is secured to the table via a  $\frac{1}{4}$ -20 screw.



**Figure 127. Left: the enclosure rails and corner blocks for the enclosure. Right: The rails are clamped to the workplate via standard optical bench clamps using a T-nut in the rail.**

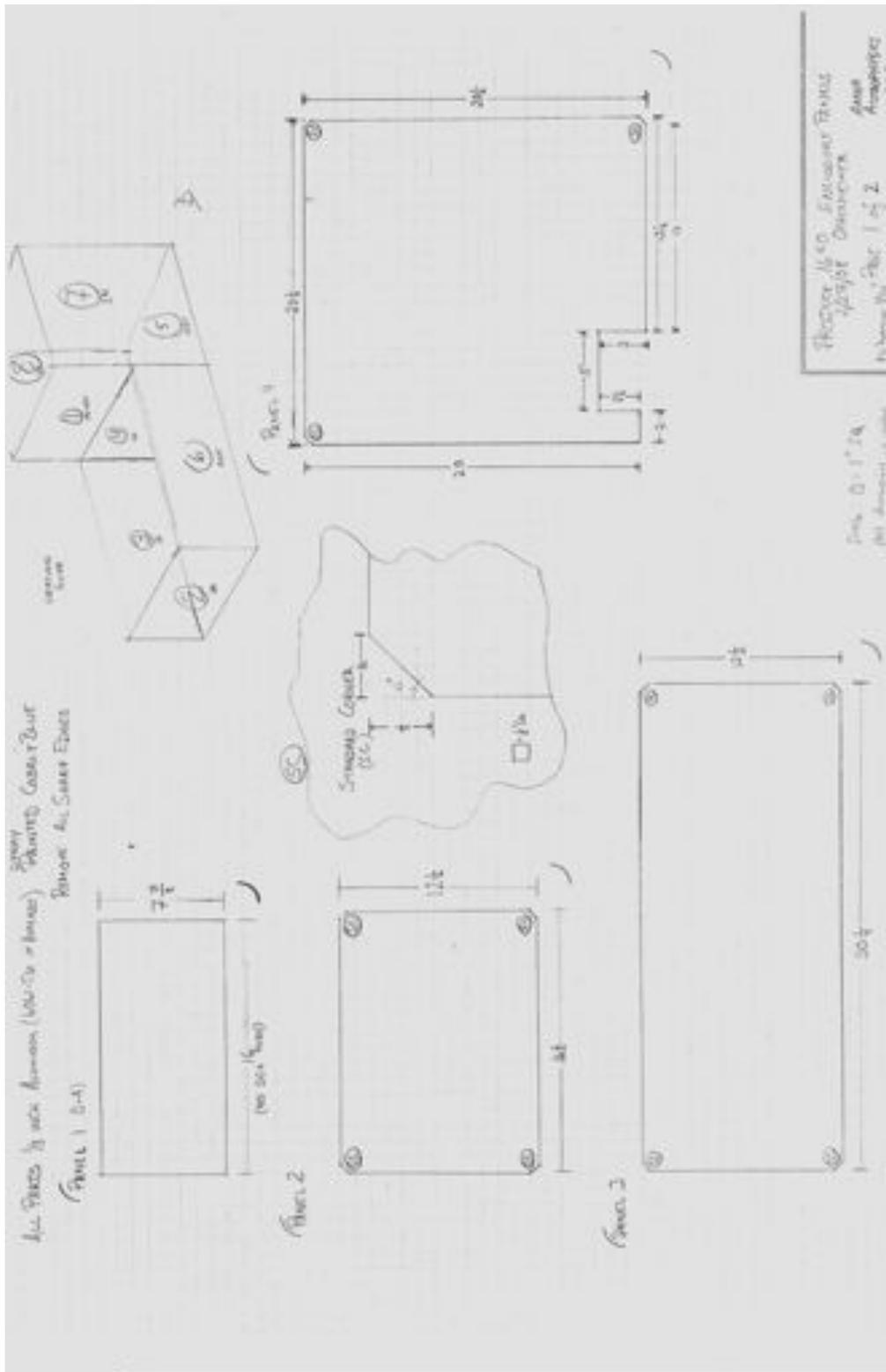


Figure 128. Design drawings for the enclosure panels.

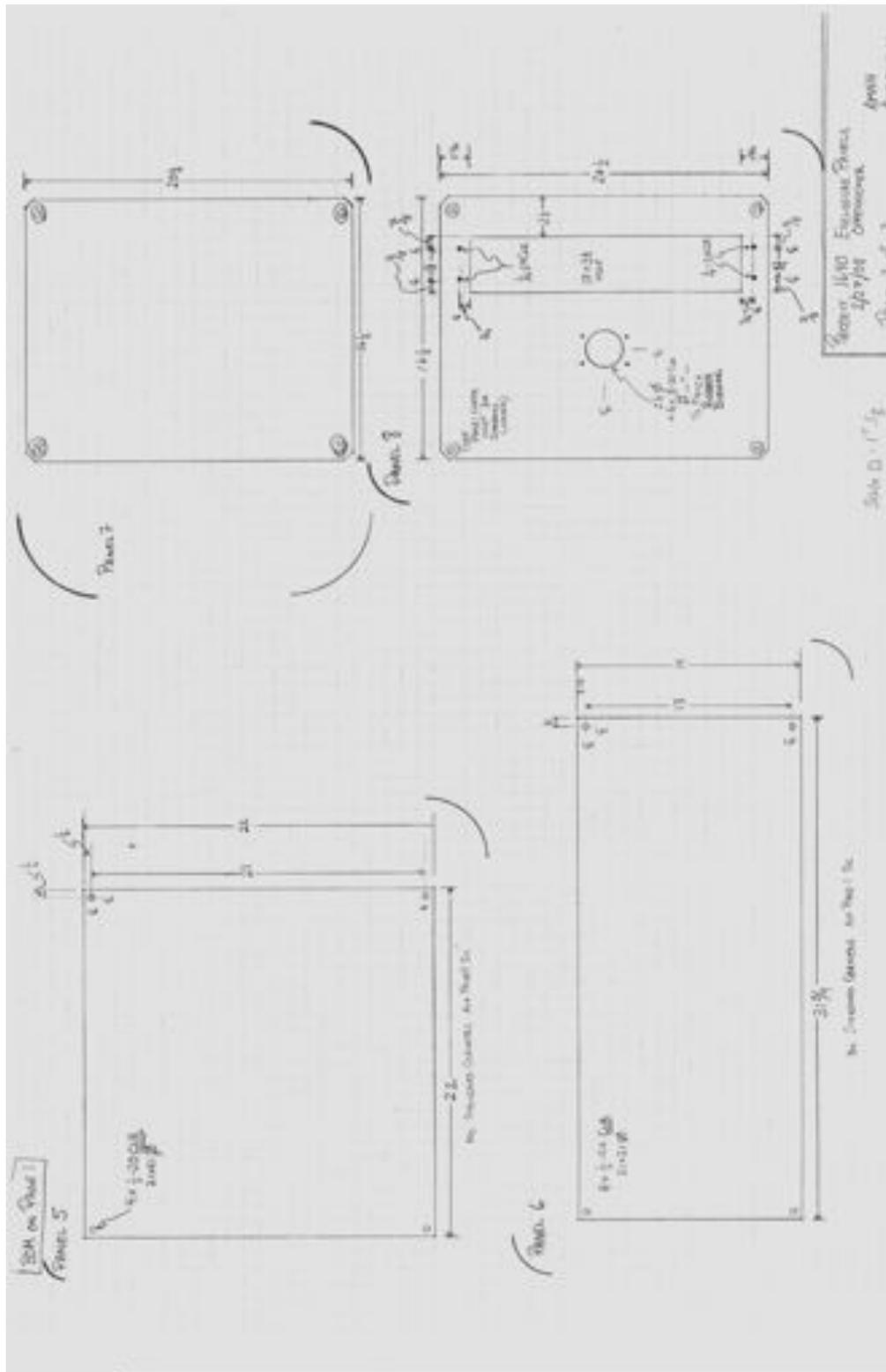


Figure 129. Design drawings for the enclosure panels, cont.

2.4.3. System Cabling Design

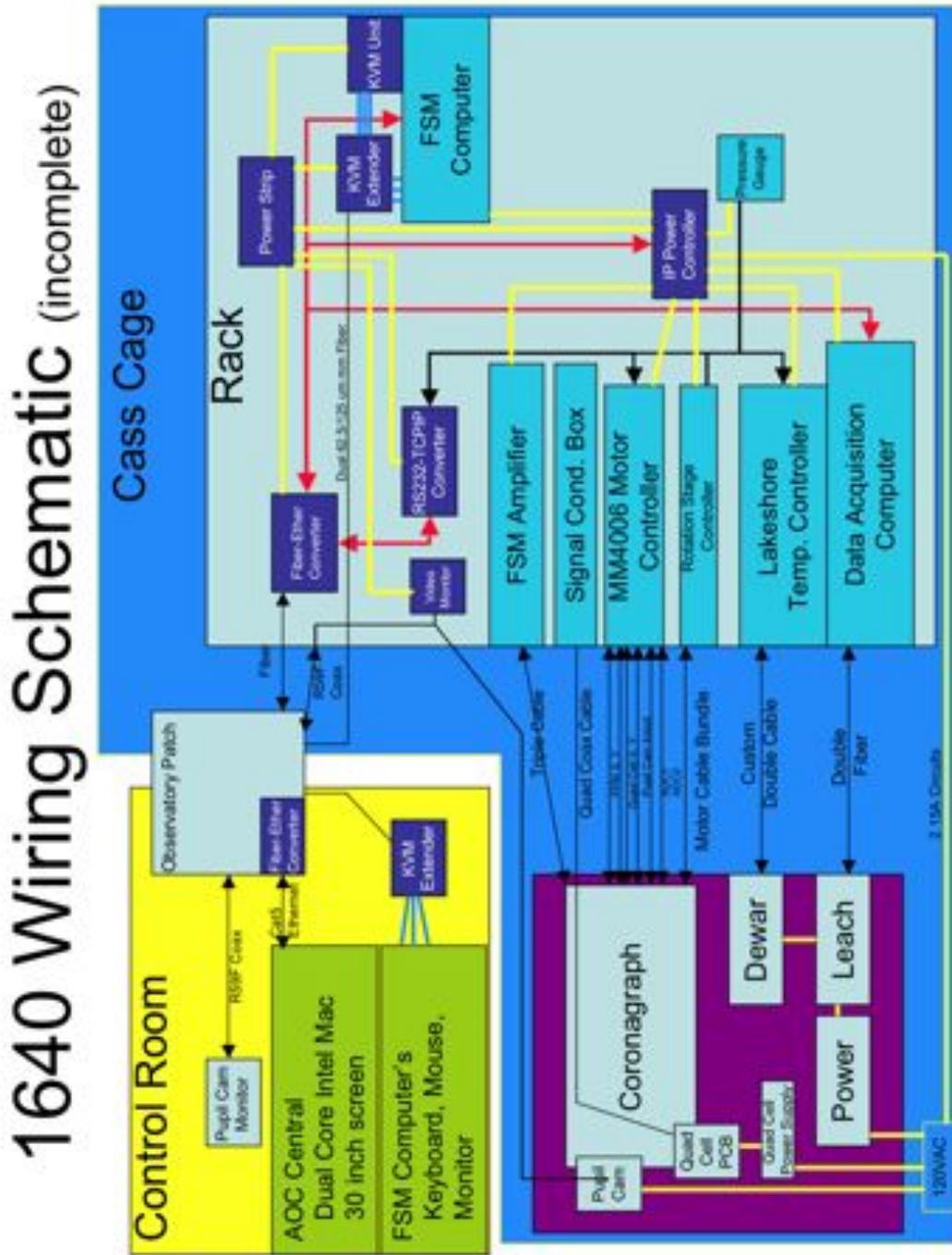


Figure 130. Internal wiring schematic

# Project 1640 Control Room Cabling

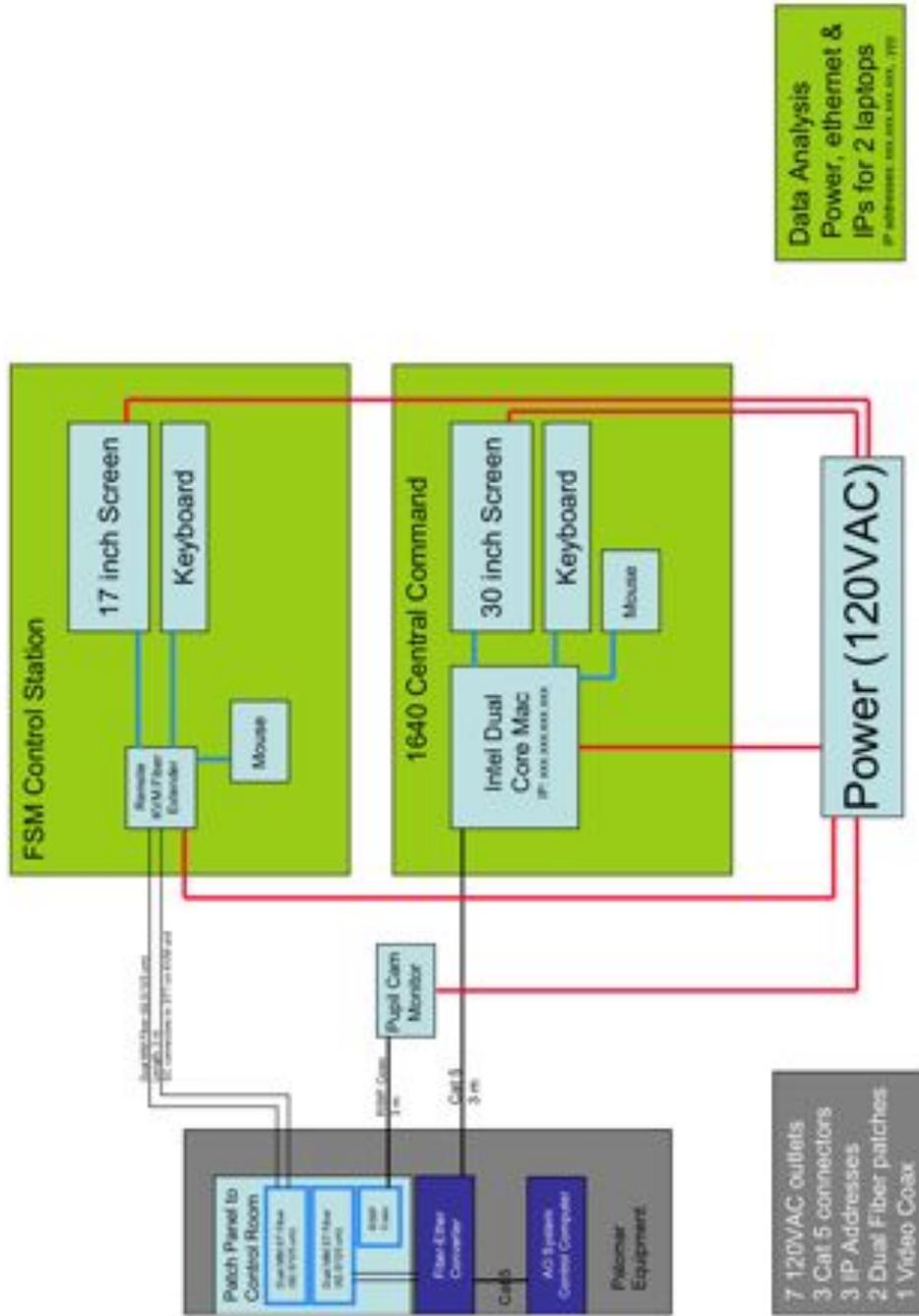
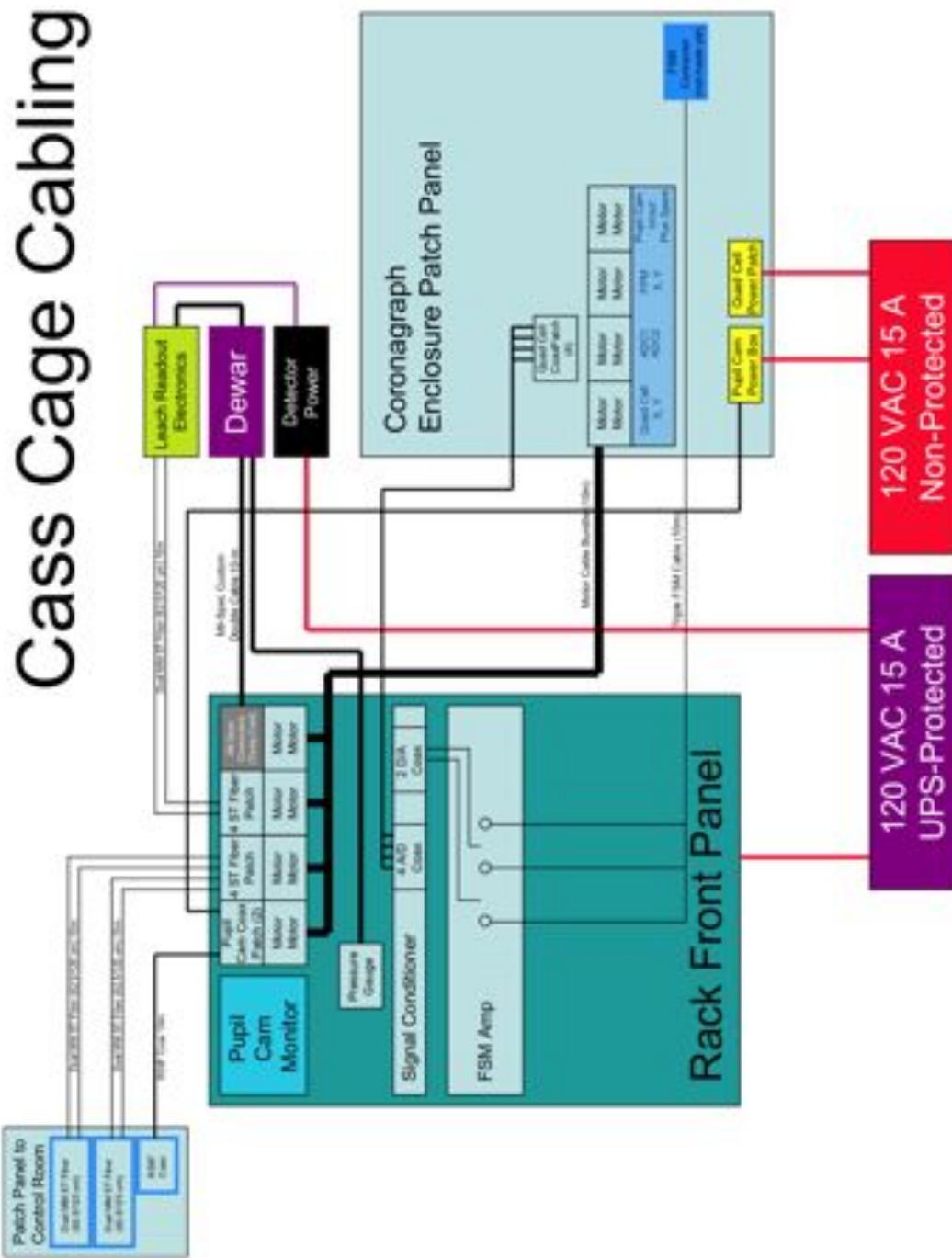


Figure 131. Control Room Cabling



**Figure 132. Cass Cage Cabling.**

# Internal Rack Cabling

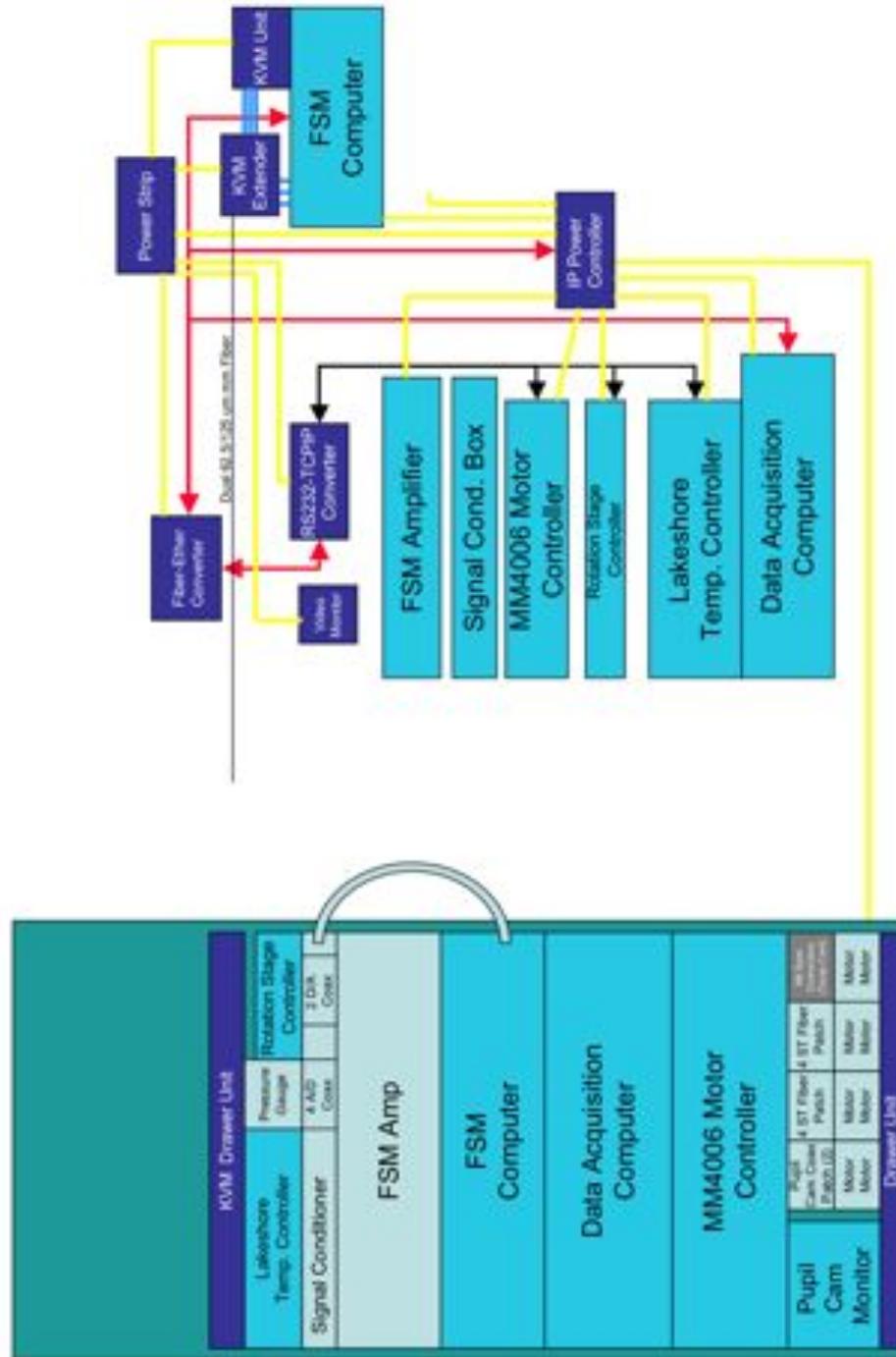
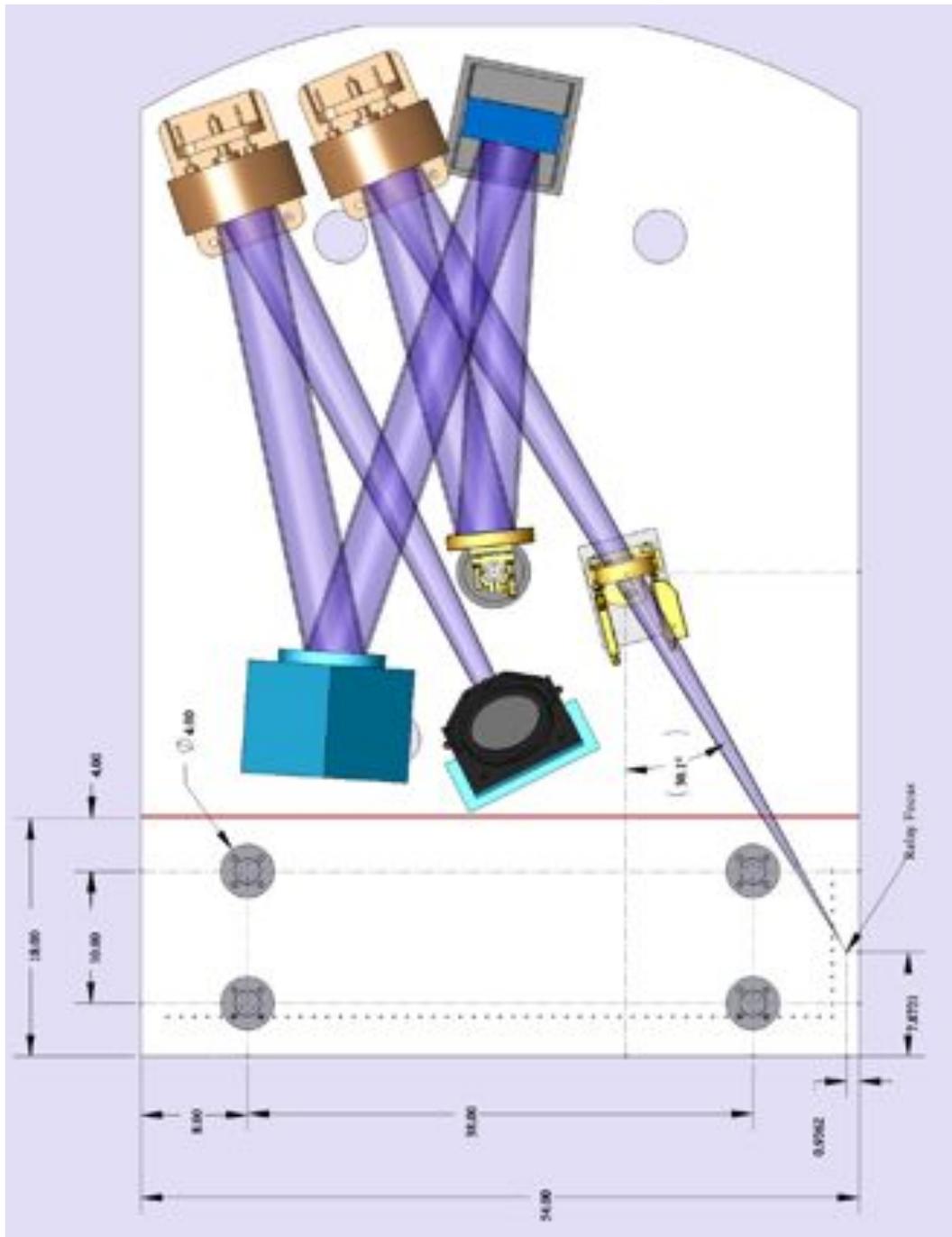


Figure 133. P1640 Internal Rack Cabling.

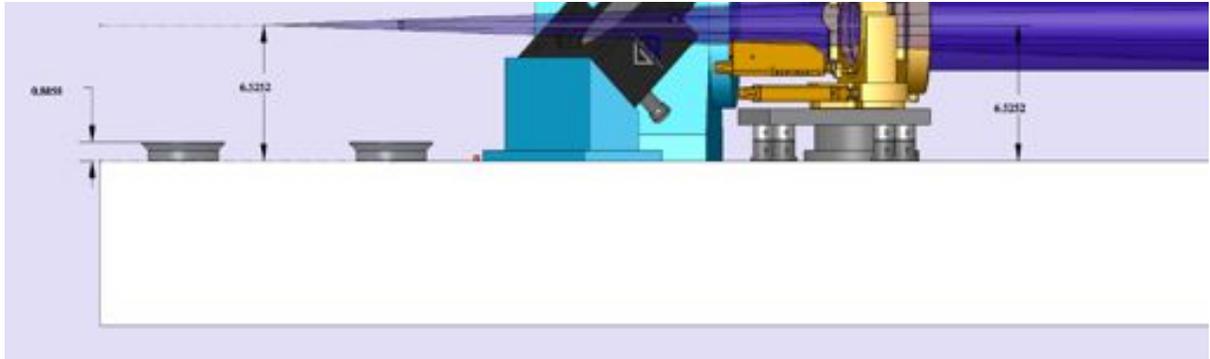
#### **2.4.4. Interface with Palomar AO system**

This section describes the design for mounting to the PALAO bench. Our entire coronagraph+IFU package is mounted on a single Thorlabs custom breadboard 18" x 54" x 2.4" in size. One side of our breadboard has 1/4-20 tapped holes on a one inch grid, suitable for mounting the coronagraphic optics and the dewar mounting bracket. The other side of this breadboard contains four custom aluminum pucks for mounting the entire assembly to the Palomar AO system. The AO bench has an identical set of pucks attached in the same configuration. When the instrument is raised up to the bench, the four opposing sets of pucks are aligned and clamped together, with the dewar and coronagraphic optics hanging down. This procedure allows complete repeatability in each mounting.

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**Figure 134.** The AO bench layout with the placement of the four mounting pucks shown.



**Figure 135. Side view of the AO bench showing the AO beam height as well as the placement of the pucks.**

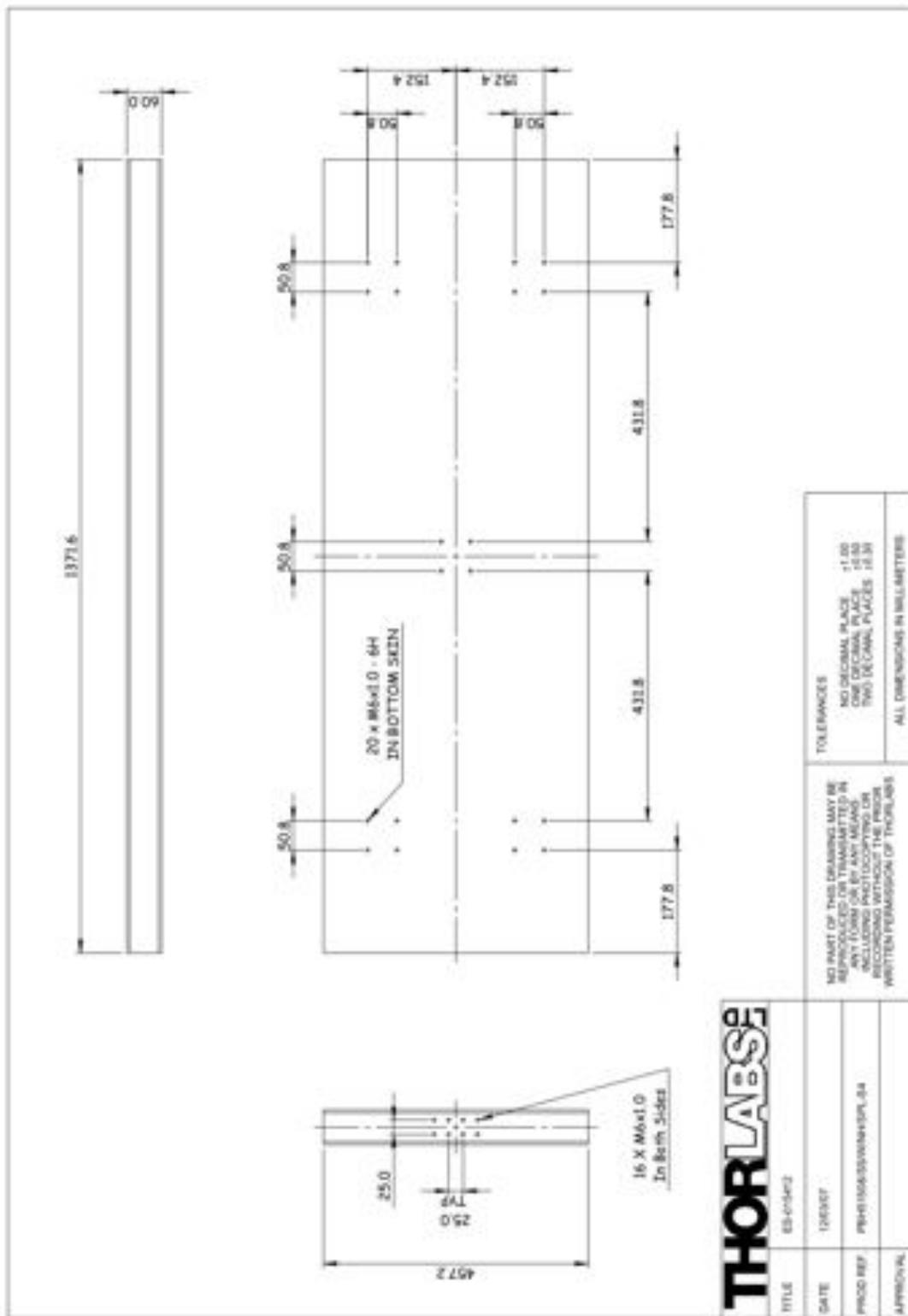


Figure 136. Custom optical breadboard from Thorlabs showing five locations for mounting pucks.

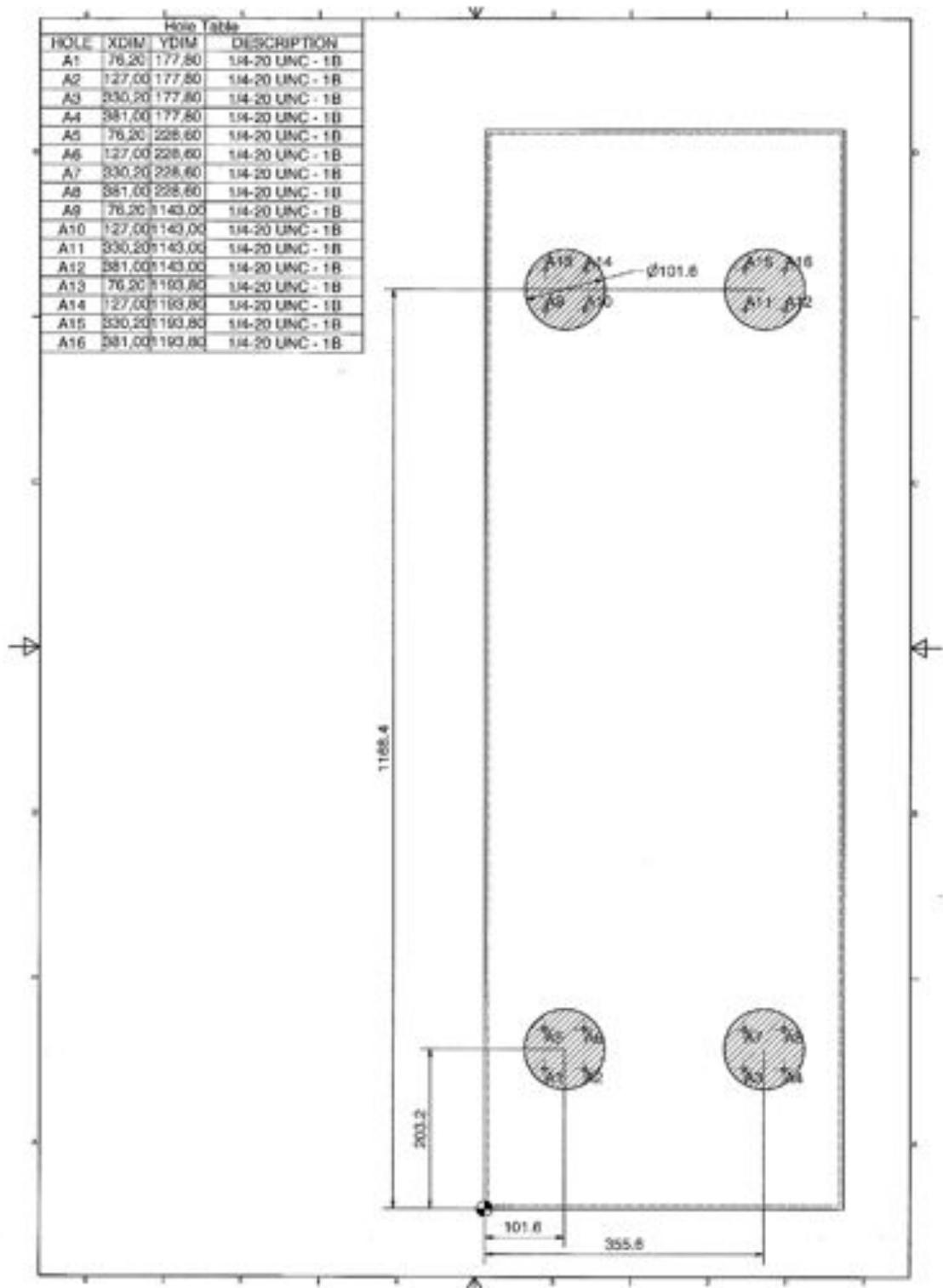
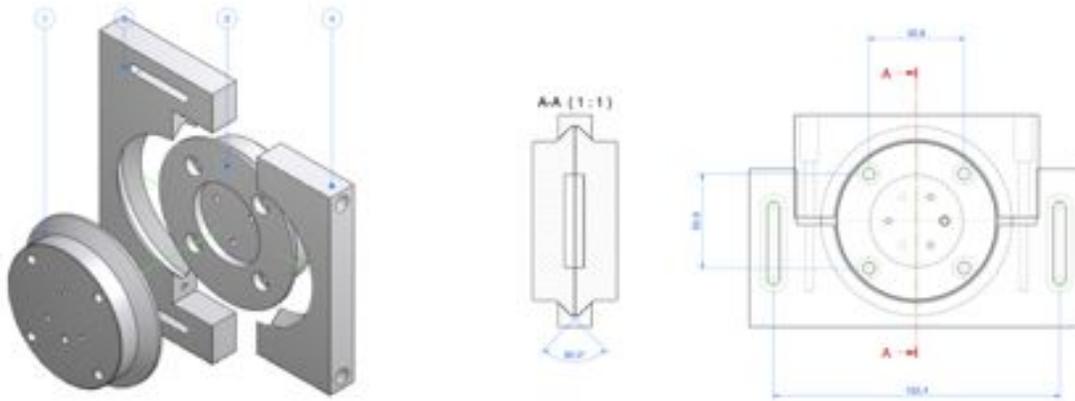


Figure 137. Placement of mounting pucks on underside of mounting plate.



**Figure 138. Design drawings for the puck mounting mechanisms. One puck is attached to the PALAO bench and the other to the P1640 bench. When these are adequately lined up, they may be clamped.**

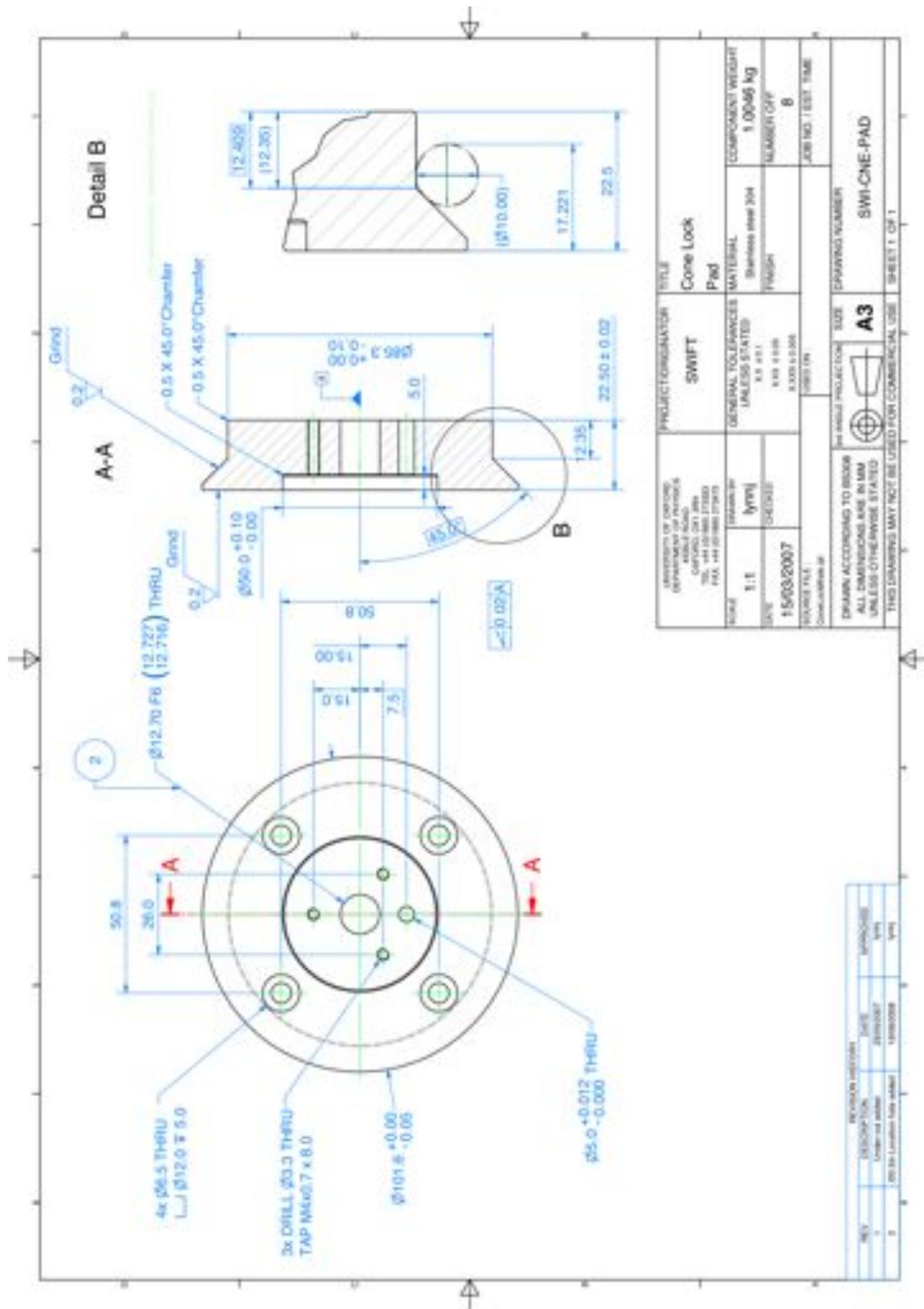
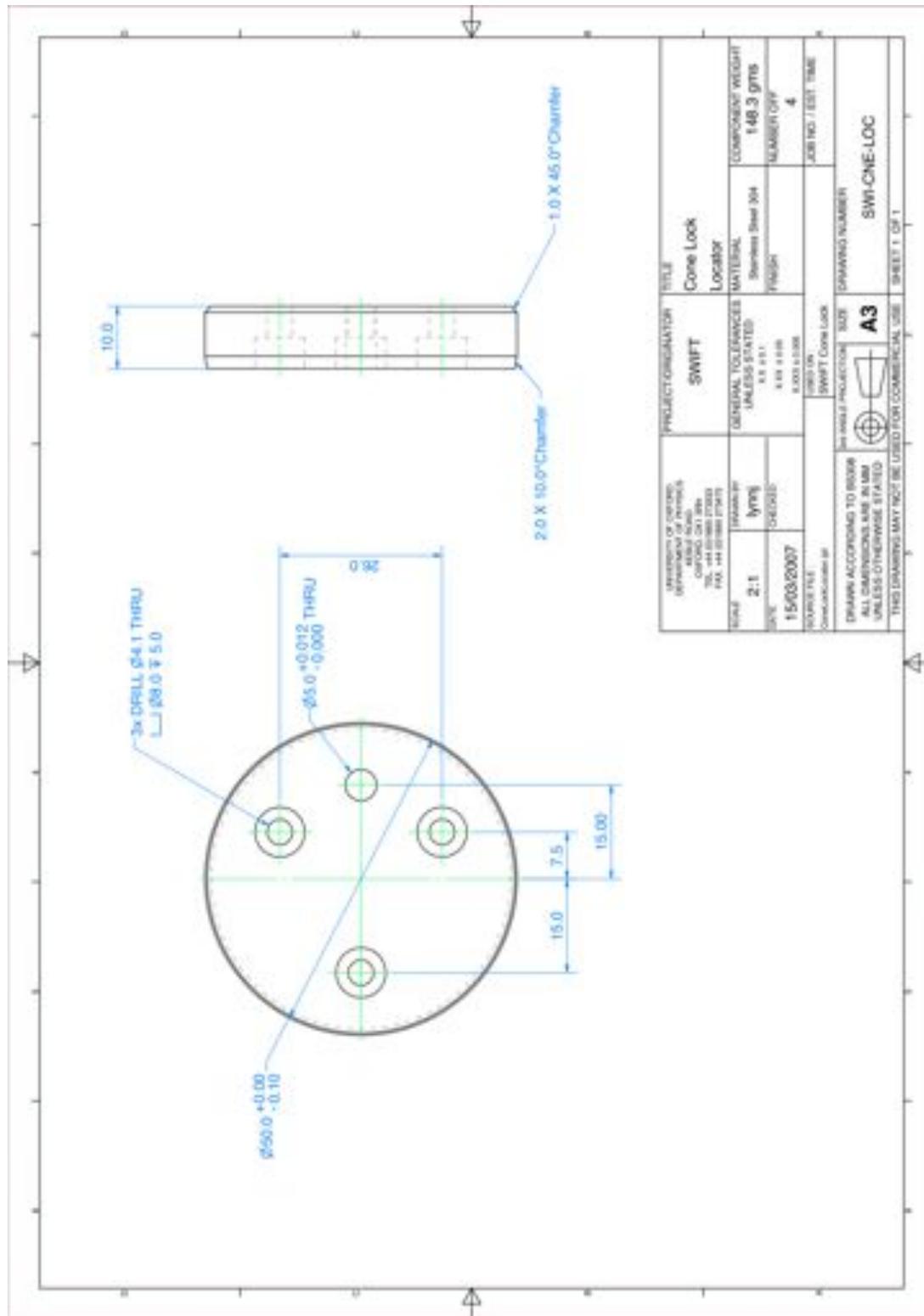


Figure 139. Machine drawings for the mounting pucks. All four pucks are identical.



**Figure 140. Machine drawing of the locator pad for each clamp. This pad serves as a "pilot" for each pad to ensure each clamp pair is aligned the same way each time the instrument is removed and replaced on the telescope.**



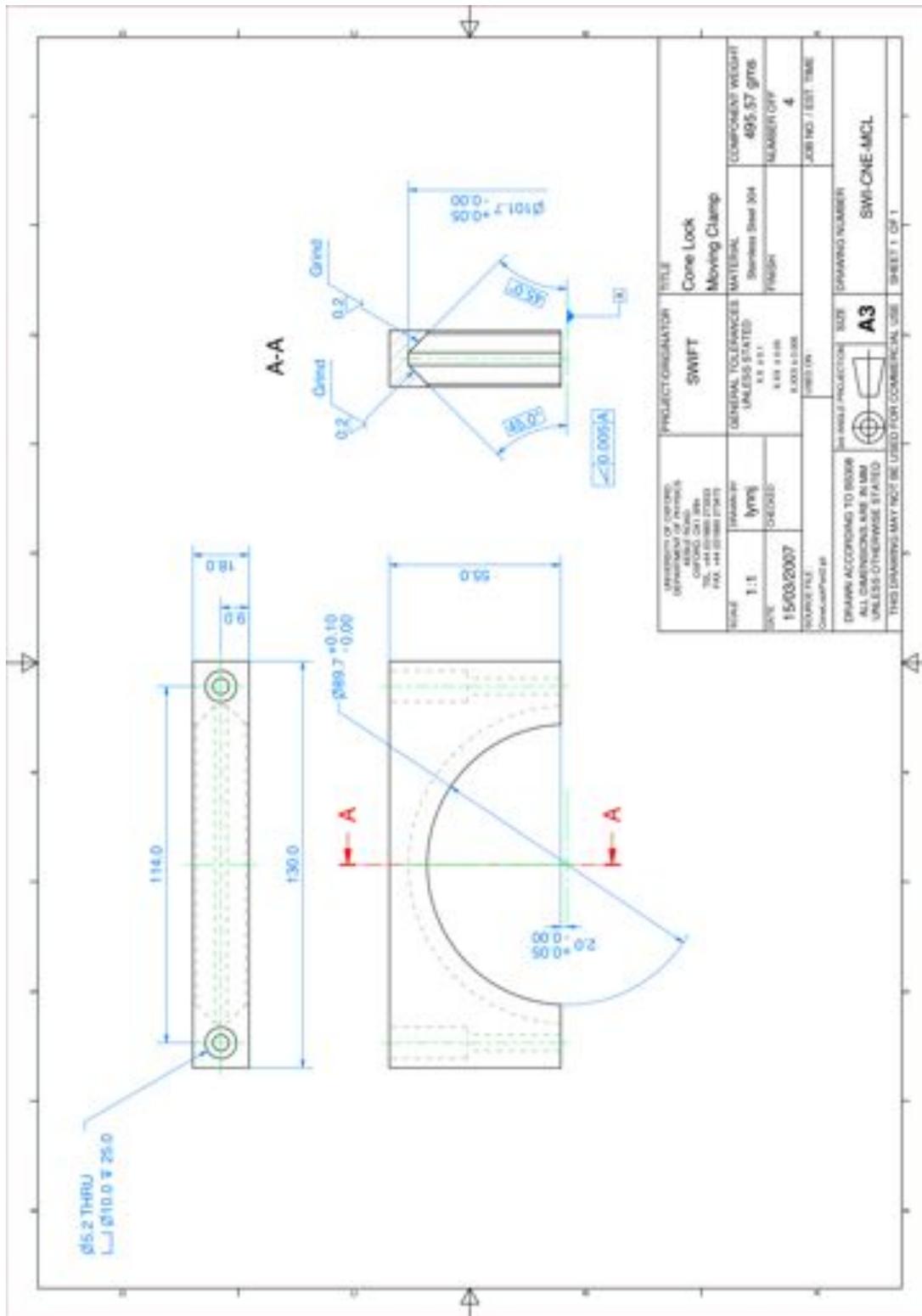


Figure 142. One half of each of the mounting clamps. This portion will move inward and secure the tow pads together as the clamp screws are tightened.

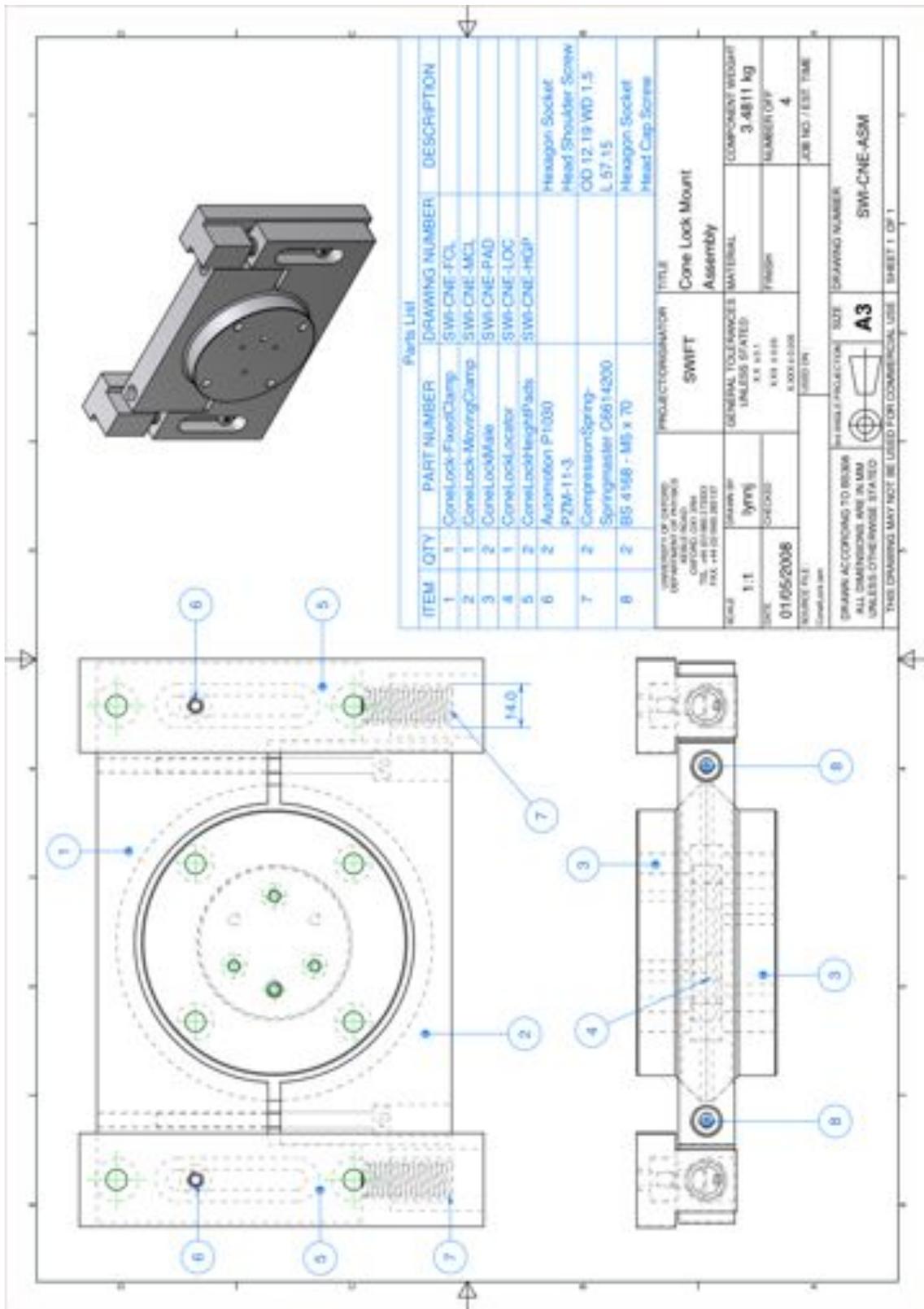


Figure 143. Revised version of mounting pucks including the cone lock height pads.

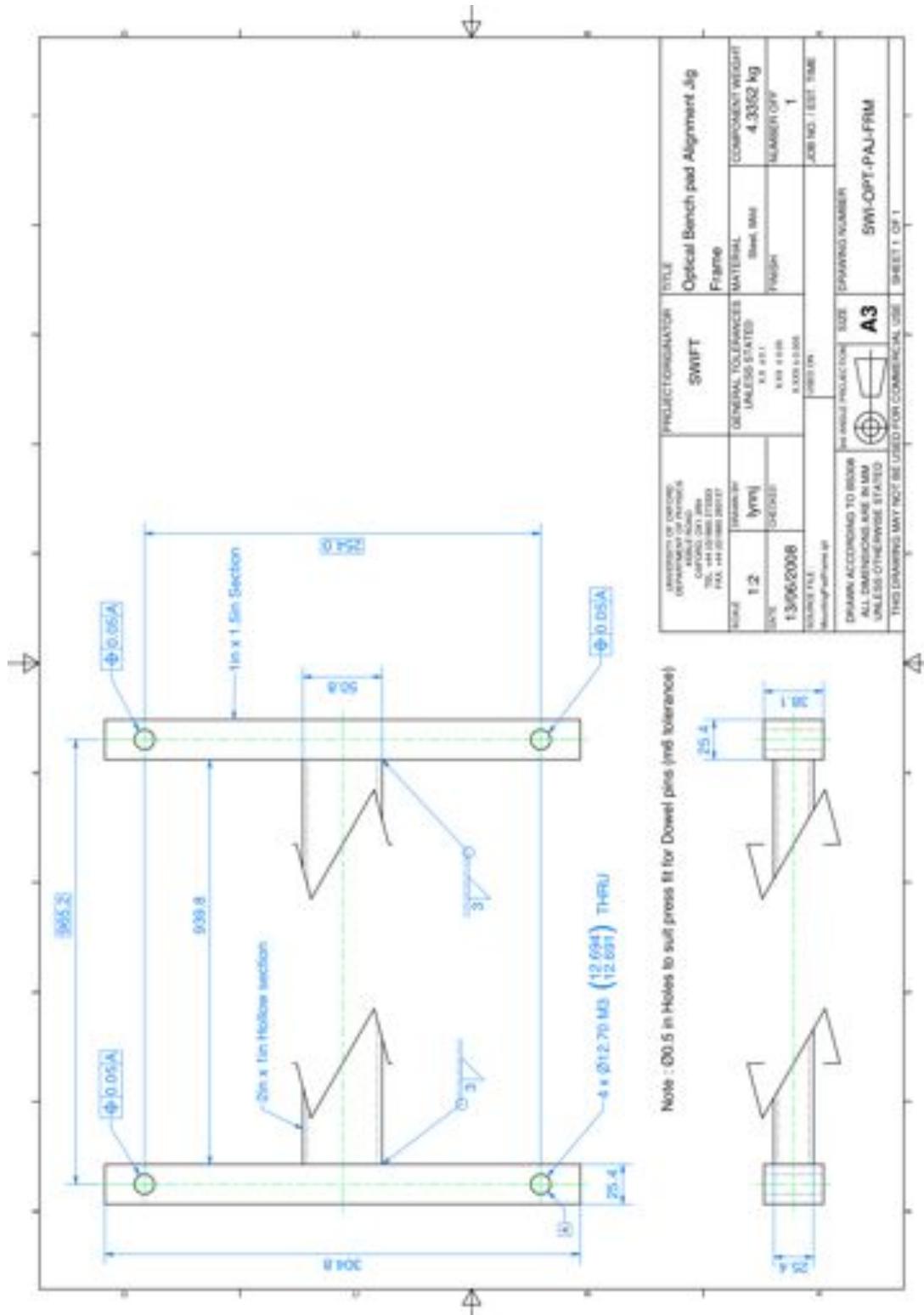


Figure 144. Machine drawings for the mounting puck alignment jig frame.

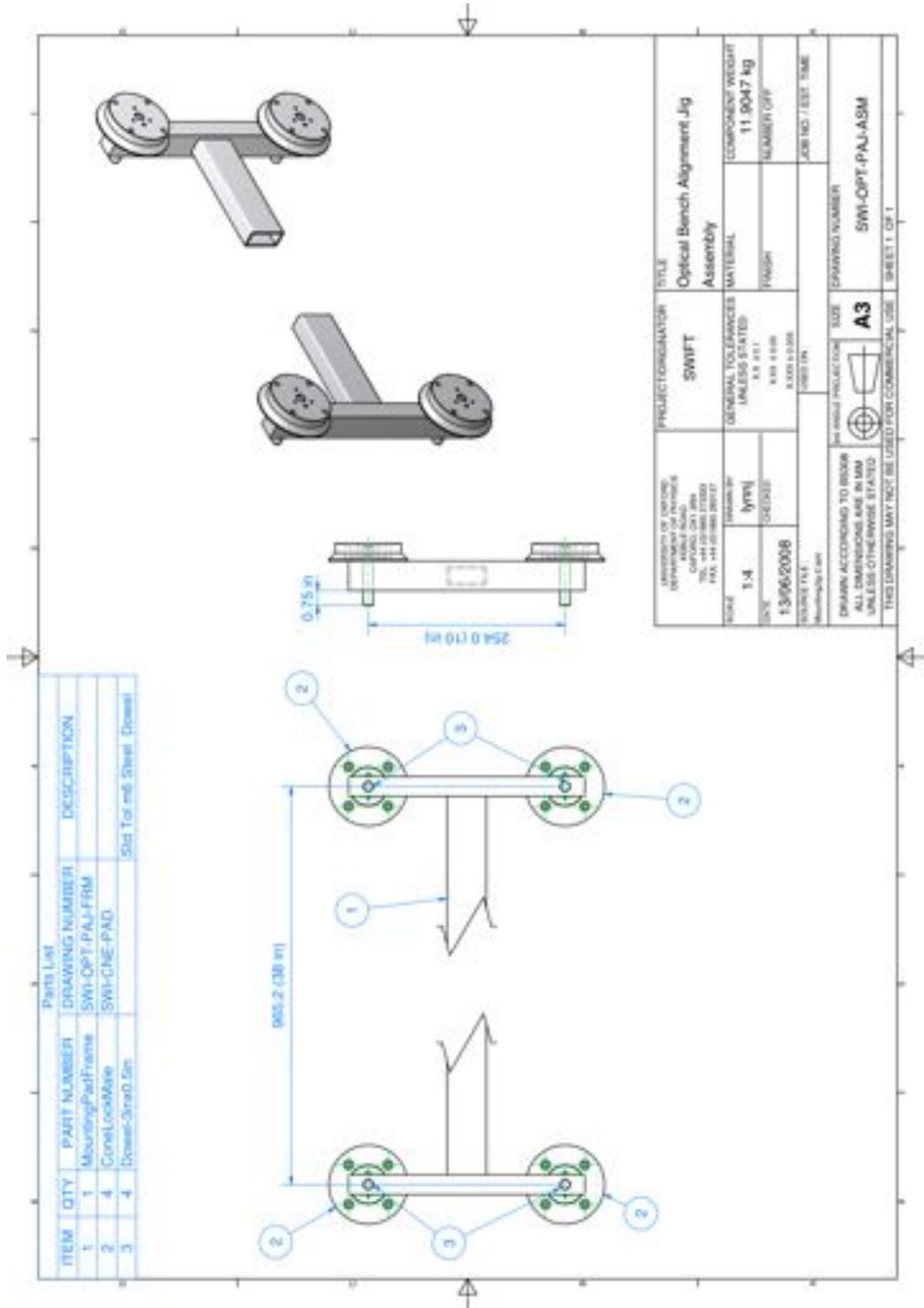


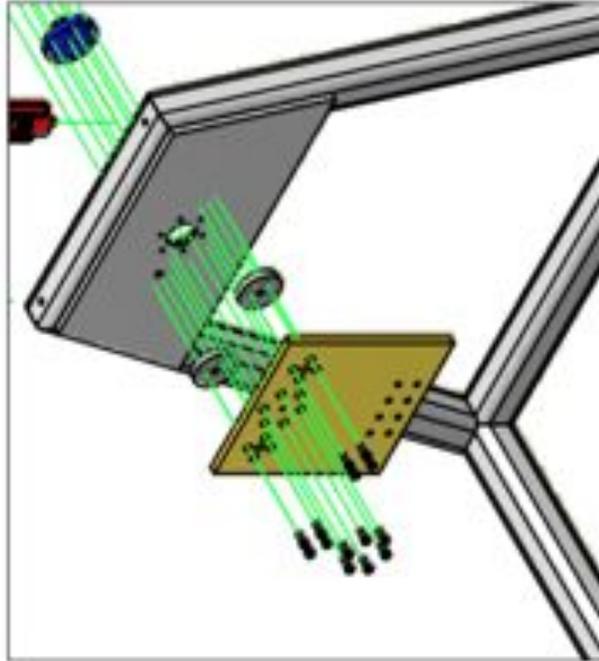
Figure 145. Machine drawing of alignment jig mechanism.

### 2.4.5. Handling Cart

We have developed a customized handling cart for smooth instrument transport. The cart design aids in the installation on the AO bench primarily via two features: 1) Six spring housings cushion the transport as well as provide differential compression (As the instrument is raised up on the Cassegrain elevator, the slightly uneven elevator floor often causes one portion of the instrument to reach the optical bench first. Compression in this region will allow the instrument to become parallel with the AO bench as the instrument is raised up. 2) Our cart has fine “x-y” adjustment to match our mounting pucks with the AO bench pucks. The instrument is mounted to the cart via two rotateable plates which share an axis. This allows the instrument to be rotated on this cart in a “spit” manner--essential for switching between the “optics down” configuration for mounting, and the “optics up” configuration for instrument maintenance. The instrument is mounted to these plates via eight M6 screws, which screw into 8 tapped holes on each side of our instrument baseplate. A locking pin on each end of the cart allows the instrument to be locked in the “optics up”, or “optics down”. The cart has a pump action hydraulic scissor jack mechanism for raising it.

The rolling cart portion (blue, yellow and green steel handle parts in the picture below) is a standard McMaster-Carr Light Duty Foot-Operated Mobile Lift Table. It has a 770lb weight capacity and is listed P/N 2779T45). The swivel casters are McMaster-Carr P/N 2779T994.

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**Figure 146. The handling cart partially extended and detail on the rotating mounting plates.**

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**Figure 147. Detail on the ball bearing track rails that allow the upper A-frame portion of the handling cart to move in the plane parallel to the floor (bottom). The x-y adjustments that facilitate this movement (top).**

---





**Figure 149. Design for either of the two rotating mounting plates on the handling cart. The instrument is mounted via the 8 M6-sized holes on each place. The 8 screws screw directly into the optics baseplate shown below.**



**Figure 150. Eight M6 holes in the workplate used for mounting the instrument on the handling cart.**



**Figure 151. The instrument on its handling cart. Note the placement of the shims between the cart mounting plate and the instrument itself.**

#### 2.4.6. Transport Crating

The Project 1640 Transport is handled by three crates with the dimensions given in the table below. The two largest crates for transporting the instrument and the electronics rack were built by SafeArt Transport in New York city. All crates are wooden and the two largest crates have an outer wooden structure. For weatherproofing, the insides are lined with Tyvek and the dewar joints are lined with a rubber gasket. Also, the paint adds a level of waterproofing. Each door on the larger crates are secured with bolts, and the floor is lined with masonite. There is a small ramp which can facilitate moving the instrumentation for both crates in and out of them. The ramp is stored in the larger crate. To load the largest crate, the IFU and coronagraph combination are be mounted on the handling cart and the cart rolled into place in the crate.

<b>Crate</b>	<b>Dimensions (inches)</b>	<b>Supplier</b>	<b>Contents</b>
1	79 x 42 x 62	Safe Art Transport	IFU+coronagraph mounted on handling cart.
2	35 x 37 x 61	Safe Art Transport	Electronics rack
3	26 x 29 x 22	AMNH	Miscellaneous



**Figure 152. The two large shipping crates for the Project (lavender) containing the instrument plus its cart, and the electronics rack, respectively. We use the larger of the unpainted crates for miscellaneous items.**

## **3. Operations**

### **3.1. Alignment**

#### **3.1.1. Coronagraph Alignment**

After the instrument is placed on the AO Bench:

- 1) Rotate bench so 1640 optics are vertical on the table (table underneath)
  - 2) Turn on stimulus with brightest source available (laser?). Turn on the entire 1640 system and put the tip/tilt mirror at the midrange (done by software automatically on running). Move all motors to nominal positions.
-

3) Before moving anything, try to tilt FM1 only, to see whether the beam can be directed to form a good image at the FPM. This is probably not possible. However, if the beam follows the path indicated in the Zemax and Inventor models, but is out of focus at the FPM, change the AO focus to see whether it can be brought into a good focus.

4) If this works, adjust FPM x and Y to direct the beam onto the lyot stop. Use Pupil Cam for fine alignment. Fine tune Lyot stop tip/tilt to center the beam on the final Sphere and the rejected light onto Pupil Cam lens. Tilt final sphere to center the beam on the dewar window beam cover (center of milled aluminum pattern). Take images to center up the focal plane mask on the detector's field of view, by only tilting the final sphere. Adjust focus of dewar until satisfied.

If OAP2 needs to be moved:

1) Most likely, the above will not work and both FM1 tip/tilt and the OAP1 need to be moved to get the beam going down OAP2's axis. The focus position after FM1 is as per the inventor drawing (close to hole, 10, 5? check), and the beam should be incident on OAP 1 at hole x, x, with a width of 4 mm. To proceed, remove the Apodizer. FM1's tilt is determined by placing the beam in the right location. Now, the only free parameter is OAP1 (tip/tilt and xy position on table). A slight misalignment of the OAP1 axis to the beam results in significant astigmatism. It must be positioned so that a good image is produced at the FPM. To do this, do not move the FSM, FM2 or OAP2. Simply move OAP1 to get a good image on FPM, well centered on the mask hole. This may take 3 weeks. It may be helpful to remove the ADC prisms during this process. If the stimulus phase diversity software works, it may provide superior metrics in placing OAP2. To achieve this, retroreflect the beam after the ADC prism assemblies to get a return beam back to the stimulus camera.

Final tweaks to the angle of OAP2 and 3 may be necessary to minimize aberrations.

Tip/Tilt optical path alignment: The lens should be well focused, but with the detector in the midrange nominal positions, the fold mirror may need to be adjusted.

## **3.2. Instrument Preparation and IFU Dewar Procedures (AMNH)**

### **3.2.1. Pump down procedure (AMNH)**

The Project 1640 dewar has a KF-25 vacuum seal-off valve connected to the underside ports next to the large tank fill hole. This fitting, which is angled off at a 45 degrees, can be connected to a KF-25 sized vacuum hose via a KF-25 o-ring and clamp. To secure this valve fitting on the dewar, place the fitting onto the dewar port and tighten the fitting via the 1 3/4" brass nut. **Caution: When tightening this nut, make sure not to apply too much torque as the fitting could be damaged.** Typically, the wrench for a 1 3/4" brass nut will be nearly three feet long. It is extremely easy with a wrench this large to apply too much torque and damage the seal-off valve fitting or the dewar port, or both.

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**Figure 153. The vacuum pump valve on the P1640 dewar.**

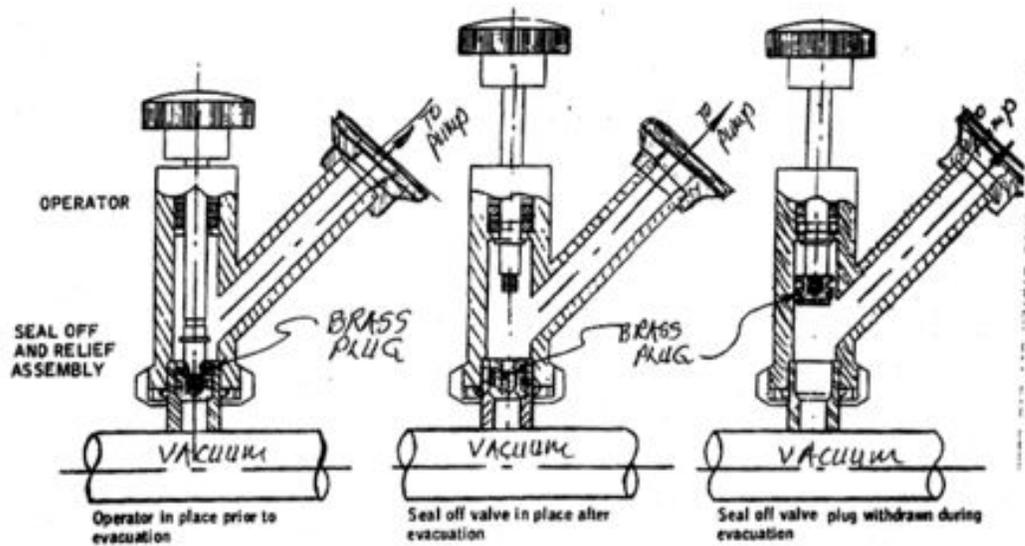


This valve can be opened and closed via a brass plug that fits into a socket in the dewar port (see drawing below). This plug can be taken in and out of its socket via a shaft with a black plastic knob on the end. This shaft can be disconnected from the plug by unscrewing it when the plug is in place. Note however, that to pull the plug in or out, the shaft does not need to be turned in any way.

**To evacuate:** Make sure the pump hose is clamped onto the KF-25 valve fitting with a suitable clamp and an O-ring greased with some vacuum grease. The stiffness of the vacuum pump hose has a tendency to exert some significant torque on the entire valve fitting. *Make sure the pump and hose is placed in such a way as to minimize the torque*

*on the fitting.* Starting with the plug in its dewar socket, make sure the shaft is screwed into this plug by giving the black handle several clockwise turns. When you have convinced yourself that the shaft and plug are connected, pull the shaft straight up (do not unscrew!). The dewar is now fully open. Start the pump, and only the roughing pump will be working initially. After several minutes the turbo pump will achieve a rotation of several hundred Hz. The dewar should be left on the pump for several hours. If a significant work has been done on the dewar, it should be left on the pump for a longer period. This is especially true if new volatile-producing substances (tape, ink, etc.) have been incorporated into the dewar, or if you suspect there may be fingerprints inside. After about 24 hours of pumping the dewar will achieve a pressure of around .2 mbar (.1 - .2 Torr). At these pressures, it is safe to begin putting Liquid

Nitrogen into the tanks.

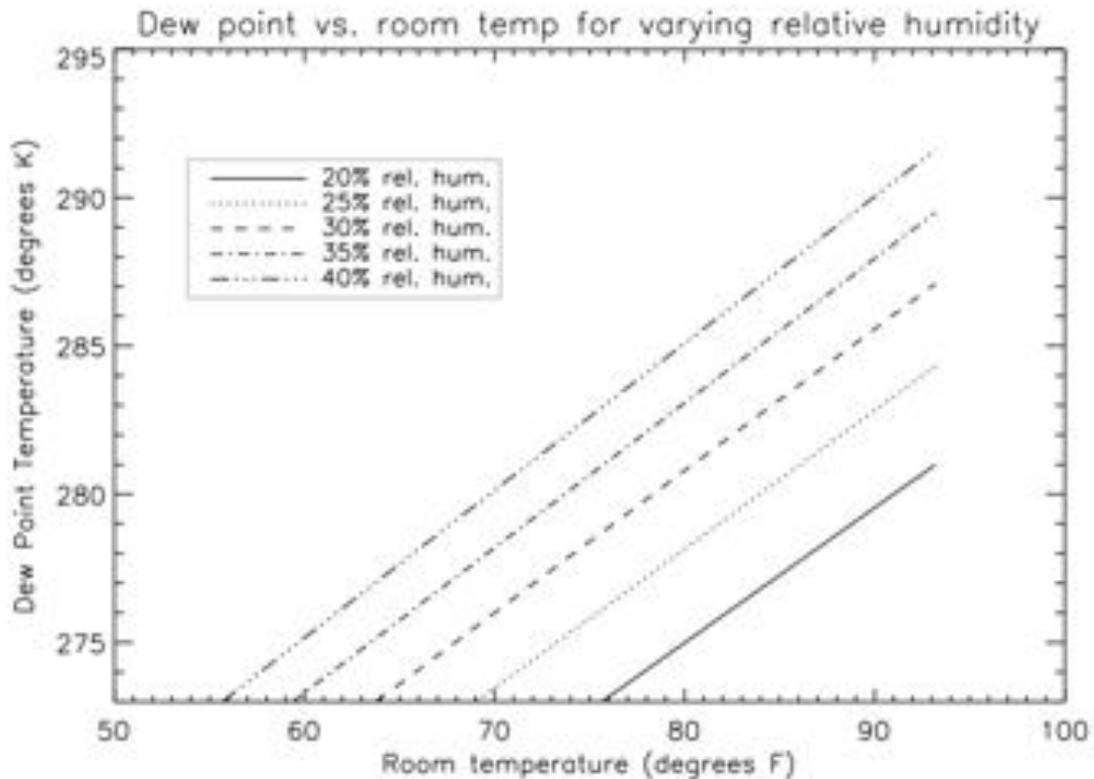


**Figure 154. Detail showing how the brass plug can be pulled in or out of the dewar.**

**Venting the dewar:** When you are pretty sure the dewar is not cold, stop. Check again. It is a good idea to have 2-3 checks (look at the temperatures sensor, ask people if there is any chance it is cold, look at the logbook, etc.) to make sure that the dewar is warm enough to be vented. *Venting room air into the dewar when it is cold, could form ices on the optics and detector, ruining the entire spectrograph.* The plot below shows the dew point (the combination of temperature and pressure at which condensation would form on the optics and detector) for various humidities and room temperatures. For example, the dew point (as read on the the temperature sensors) for a 75 degree day with 20% humidity will be 272K (i.e. the temperature sensors must read at least 272K before venting should begin). However, for a 75 degree day with 40% humidity the dew point is at about 283K. Note however, that these calculations should only be used as guides, so play it safe and let the dewar warm a bit more than these temperatures before venting.

Currently, the only way to vent the dewar with room air is to connect the vacuum pump, vacuum the hose, open the dewar, and slowly leak air into the hose and dewar. Connect the vacuum pump hose to the dewar valve fitting if it is not already connected. The dewar will be closed now. Verify this by making sure the brass plug is all the way down into its dewar socket. Also make sure that a vacuum gauge is connected to the vacuum pump via a "T" junction. Begin pumping down the pump hose, leaving the dewar closed. *Don't ever pull up the black handle unless you are sure there is a suitable vacuum in the pump hose.* It is still possible for a person to pull up the black handle even if the dewar is at a high vacuum and the hose has room pressure. Once the hose pressure has reached that of the dewar, it is okay to open the dewar by pulling up on the black handle. After you have done this, stop the pump and let the turbine slow down to less than 500 Hz. If you are certain the temperature of the dewar is suitable for venting, allow a little gas to leak into the pump hose. The AMNH pump has a small black knob near the base of the hose on the pump which allows some gas to leak into the hose and dewar. If gas is

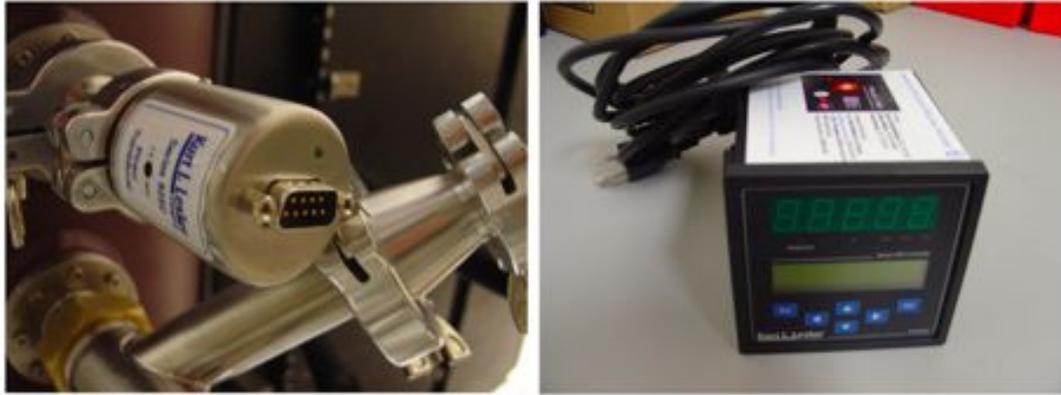
being transferred into the dewar, you will hear a hissing noise. When the hissing has stopped, both the dewar and hose are at room pressure.



**Figure 155. Dewpoint plot. Given a room temperature and humidity, the vertical axis represents the temperature at which dew will form on the optics or detector in the dewar (The temperature sensors list in degrees Kelvin).**

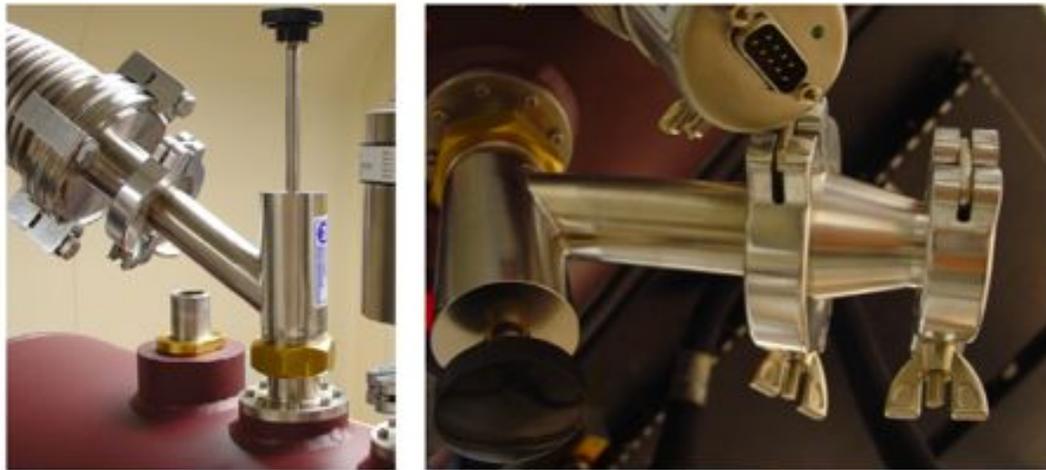
### 3.2.2. Pump down procedure (Palomar Mountain Crew)

- 1) First, hook up P1640 Lesker pressure gauge to the pressure sensor on the dewar (both shown in the photo below), and check the pressure. This gauge should be set to read in mbar, but scrolling through the electronic menus will allow you to adjust the settings (need more info here).

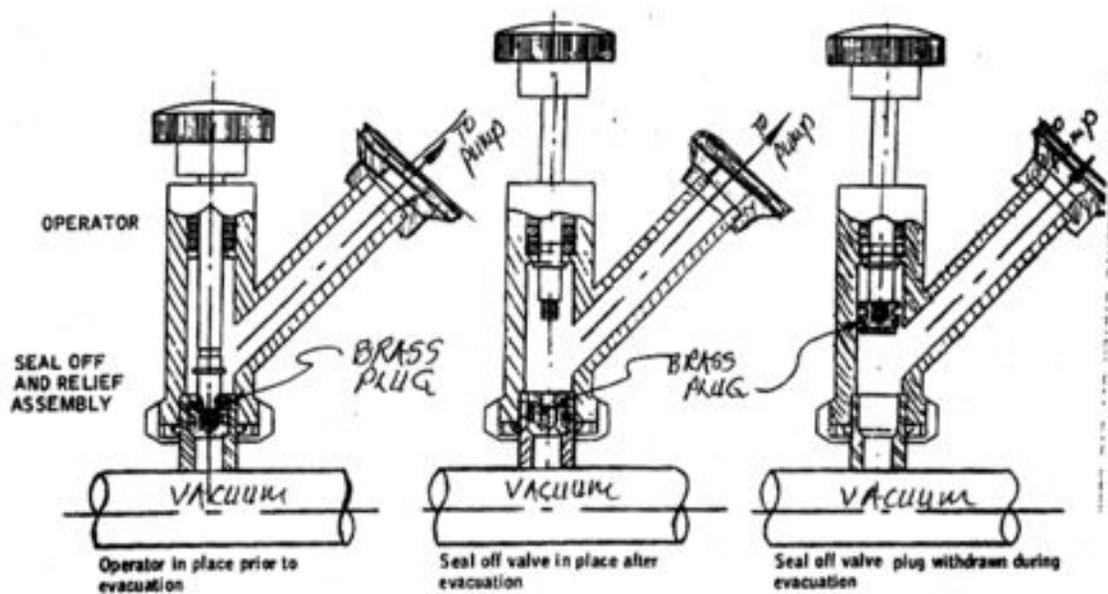


**Figure 156. The P1640 pressure sensor, and the corresponding pressure gauge. The gauge can be read in either Torr or mbar.**

- 2) Make sure the black-handled plunger is sealing the dewar closed, by ensuring the plunger is pushed all the way in. Remove the KF25 cap on the vacuum fitting and attach the vacuum pump.

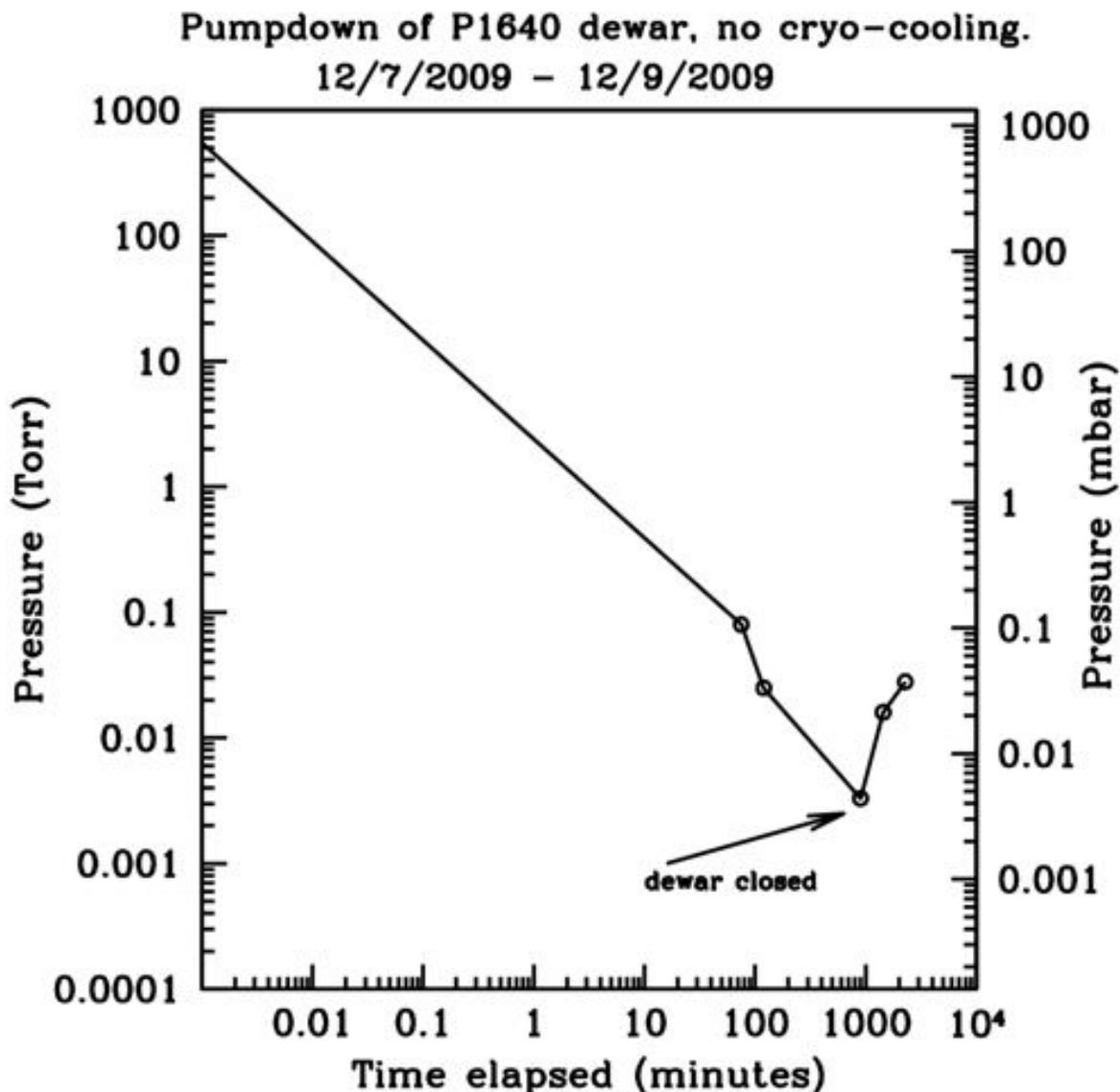


**Figure 157. The P1640 vacuum valve. The left picture shows the black-handled plunger out (dewar open), while the right shows the plunger down (dewar closed). Also the KF40 to KF25 adapter is shown on the right.**



**Figure 158. A diagram showing the inner workings of the brass plug which seals the dewar. Note that the black handle need not be unscrewed in any way. It only needs to be pushed or pulled in and out. Unscrewing will detach the shaft from the brass plug.**

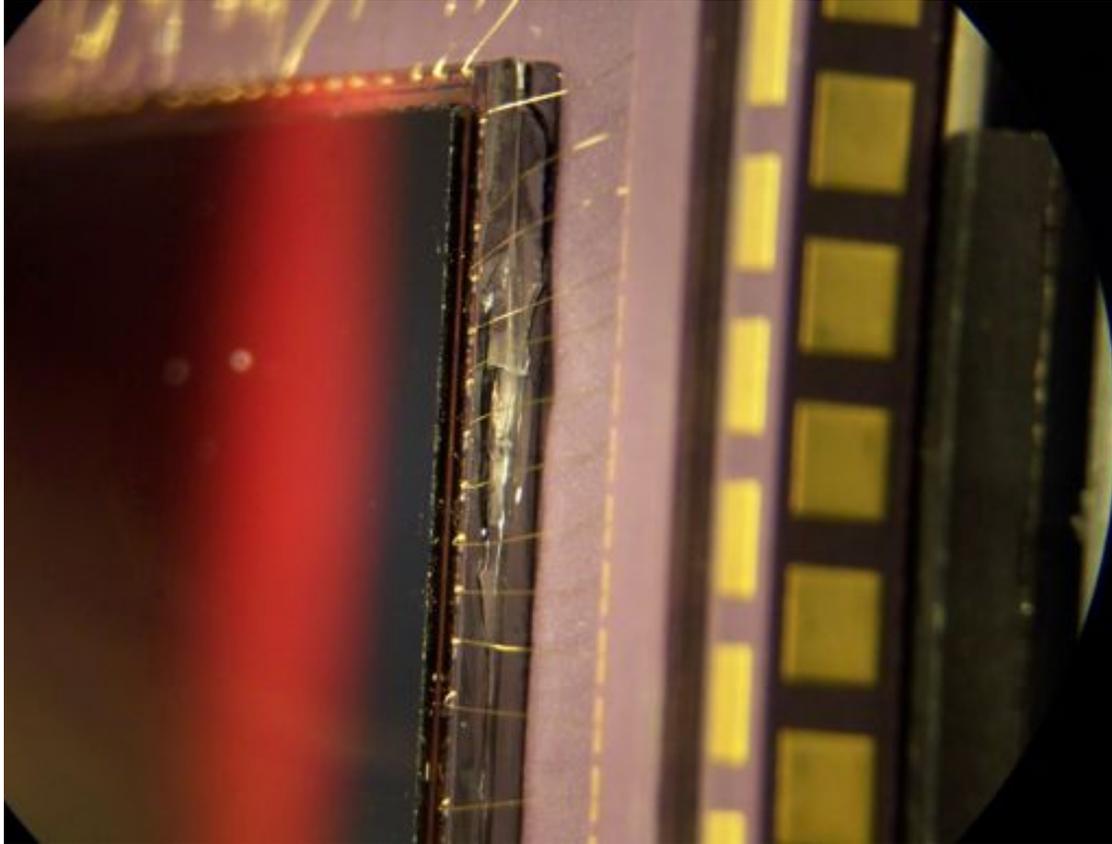
- 3) If the dewar internal pressure is room pressure, pull out the plunger (dewar open). Start the vacuum pump and verify that the pressure is going down on both the pump gauge and dewar gauge. If only the pump gauge shows a pressure drop, but not the dewar, either: a) the black handle has not been lifted, or b) if the black handle has been lifted, the brass plug is disconnected from the shaft, but still sealing the dewar (middle picture above). If this is the case, screw the handle back into the brass plug, and pull up to dislodge the brass plug.
- 4) If the pressure is significantly less than room pressure, leave the plunger pushed in (dewar closed), start pumping, and only release the plunger when the vacuum hose pressure is similar to the internal dewar pressure. Since the pressure in the vacuum hose is similar to the internal dewar pressure, it should be pretty easy to release the plunger.
- 5) Continue to pump down until the dewar reaches 0.2 – 0.1 mbar, (this may take 30-60 minutes). Close the plunger on dewar. The inner tank on the dewar is now ready for LN<sub>2</sub>.



**Figure 159. Measured pumpdown rate for the P1640 dewar. Pressure in Torr is on the left, mbar on the right. Note the logarithmic scale.**

### 3.2.3. Cooling procedure (AMNH)

The rate of cooling the dewar needs to be carefully controlled to ensure that the rate of cooling is not too fast. A good rule of thumb is that the detector should never experience a rate of cooling greater than about 1 degree K/minute. Substantially exceeding a rate in this area can cause the multiplexer portion of the the Hawaii II array to crack (see photo below).



**Figure 160. Detail of a cracked Hawaii-II array. This has likely occurred because of heating or cooling of the detector too rapidly.**

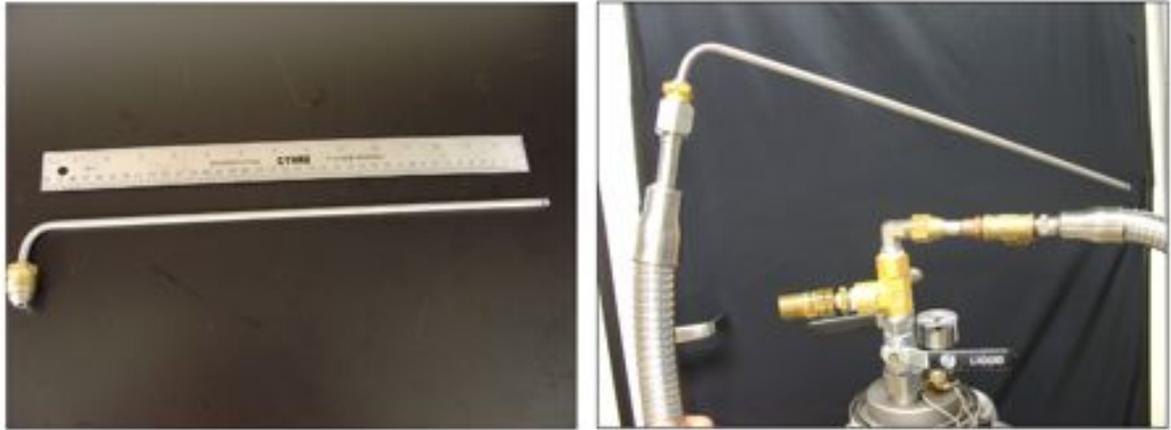
**Cooling Procedure:**

1) Attach the Y-shaped detector cable to the single connector on the dewar. Make sure you are well grounded before doing this. Place one hand on a well grounded surface to ensure that no static electricity jumps to the detector plug. Even a small spark can fry the detector. **PLEASE DO NOT FRY THE DETECTOR.** The two Leech-box connectors on the other end can be left dangling. Making this connection ensures that the detector is cooled with the power off and that the connector on the dewar won't ice up.

2) The dewar should be pumped down sufficiently over several hours (24 hours?) so that pressures of roughly  $2 \times 10^{-1}$  mbar are reached. It may be the case that the turbo pump being used does not exceed 1100-1200Hz, even after pumping for nearly 24 hours. This is probably due to continual and significant outgassing of water vapor from the mylar thermal shielding. The numerous layers of this shielding has a huge effective surface area, and can outgas continually even when being pumped down. It is a good idea to leave the pump running while doing the cool down.

3) Hook up the custom LN<sub>2</sub> “stinger” to the fill hose on the LN<sub>2</sub> dewar. Pictures of the stinger and the desired configuration are shown below. Note that the picture shows a 22 PSI safety valve on the liquid port of the dewar. It is a good idea to use this for safety reasons, but this valve has a tendency to freeze and become ineffective, causing liquid to leak out of it. A plug can replace this safety valve.

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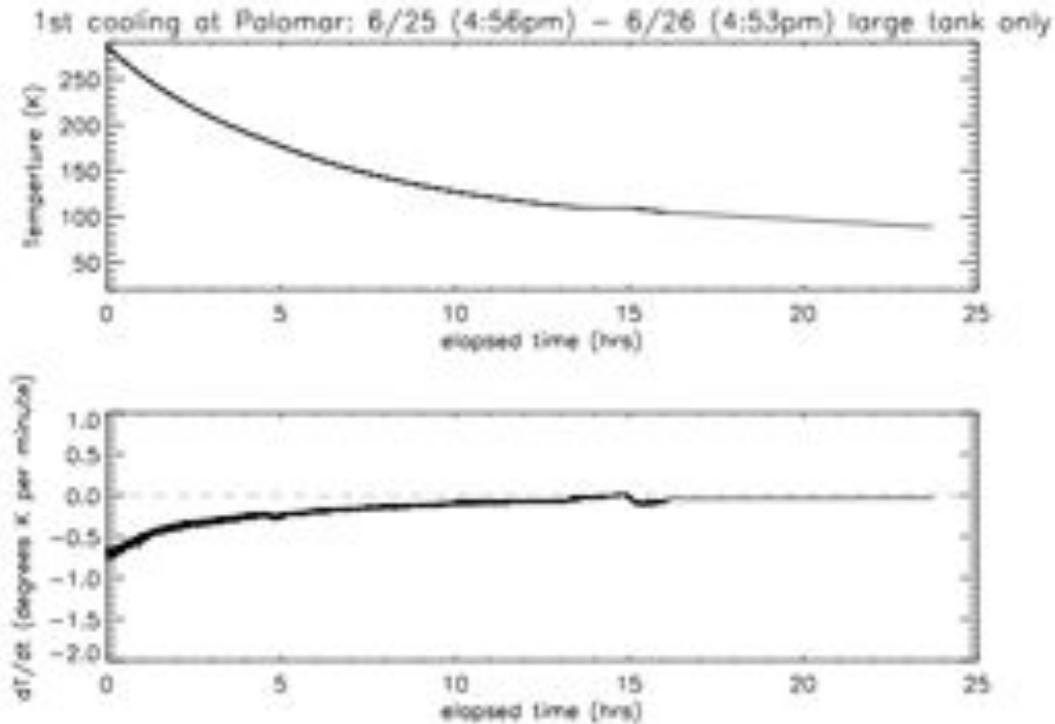
**Figure 161. The "stinger" used to fill both of the nitrogen cans (left). The configuration needed to begin the LN2 fill (right).**

4) Place the stinger into the large tank fill port, and open the stream wide open. Since the large tank is fairly well decoupled from the detector, the risk of harming the detector is very minimal here, and the large tank can be filled rapidly without any worry. However, **DO NOT PUT ANY LN2 IN THE SMALL TANK AT THIS STAGE.** The small tank should only be filled once the detector temp gets to about 93K. Note that it may take around 12 hours of keeping the large tank full to get to around 93K. Very soon (less than a minute) after starting to fill the large tank, the vacuum pressure starts to fall quickly. The temperature sensors will not change very much, however.



**Figure 162. Cryo gloves need to be worn at the very least.**

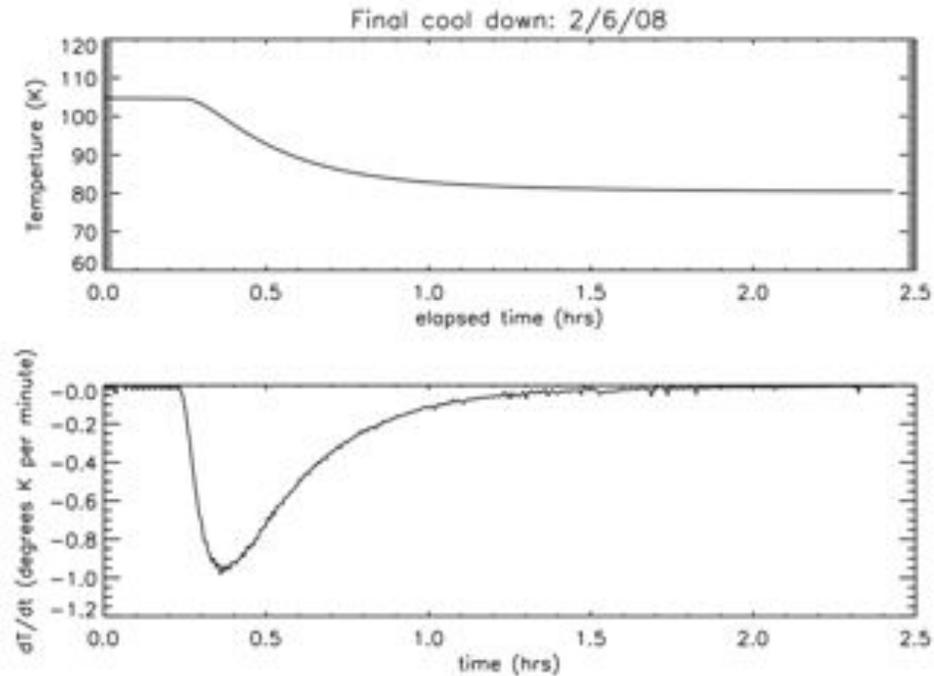
After about 7 minutes of filling the gushing noise should stop and the flow of LN2 is a bit quieter as some liquid begins to gather in the large tank. After about 15-20 minutes the large tank will be full. The temperature on the sensors will go down to 283-285K at the end of the large tank fill, and reach about 260-265K after one hour past the fill start time. The rate of temperature change as determined by the sensors may be as high as  $-1.0 \text{ deg}/100\text{s}$ . The pressure will fall significantly to between  $1\text{e-}03$  or  $1\text{e-}04$  mbar depending on whether or not the vacuum pump has been left attached.



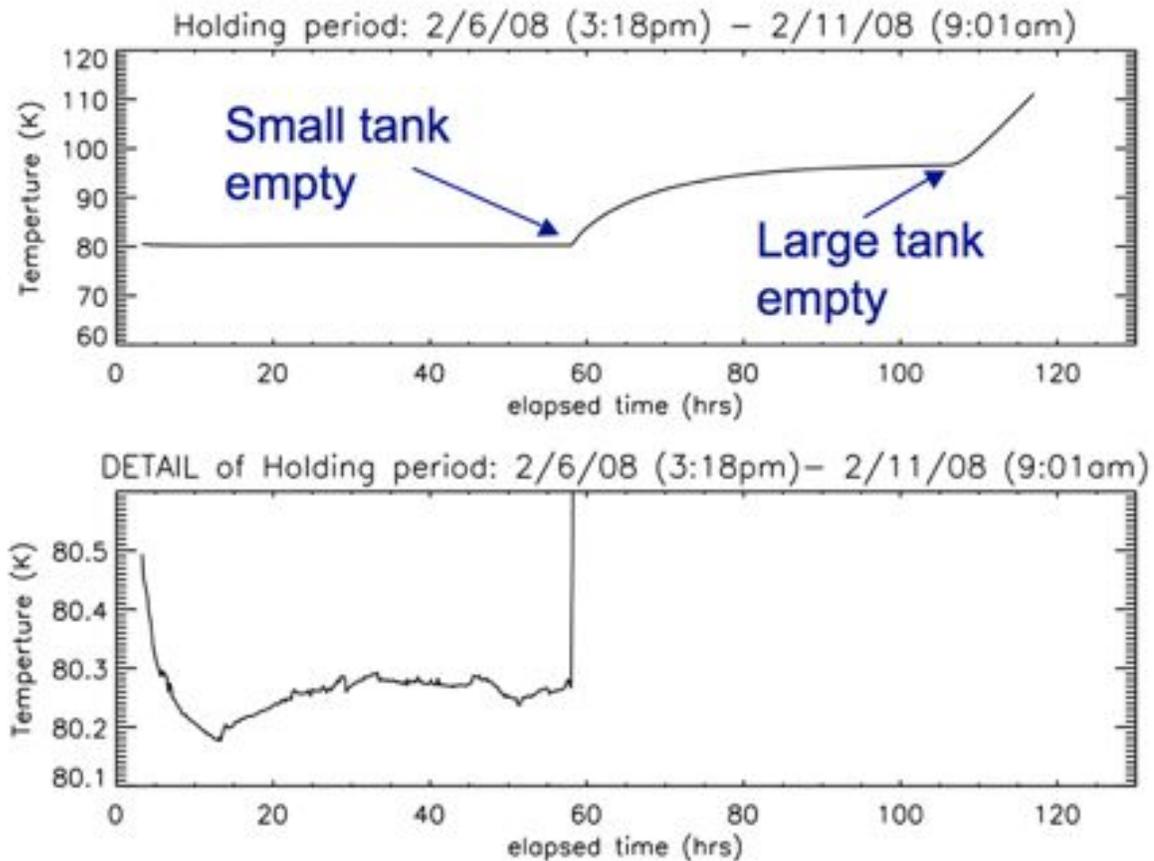
**Figure 163. The temperature when only the large tank has been filled. Some data between 16 and 24 hours was missing and has been extrapolated.**

5) When the dewar has reached about 95K, it is safe to put very small amounts of LN2 into the small tank. This can be done using the stinger or simply pouring some liquid in via a thermos or cup. If pouring in, only pour about  $\frac{1}{4}$  cup at a time. The temperature on the detector can change rapidly, even at these low temperatures. The plot below shows the detector temperature after adding some LN2 into the small tank (starting at about 105K, probably a bit high). Note that even at these low temperatures the  $dT/dt$  value can still approach  $-1$  degree K/minute. After about 2.5 hours, the detector has reached operating temperature.

The holding period for the system is shown in the last plot below. The system seems to consistently have a hold time around 60 hours.



**Figure 164. A plot showing the temperature drop after placing some LN2 in the small tank. This should only be done when the large tanks have been full for an extended period and have reached 95K-105K.**



**Figure 165. The points at which the two tanks are exhausted are shown in the top plot. Bottom: (Detail), showing the intrinsic temperature wander.**

### 3.2.4. Cool down procedure (Palomar Mountain crew)

Once the dewar has been evacuated down to 0.1 – 0.2 mbar, the outer (large) tank is safe to be filled. First the temperature sensor should be connected

#### 3.2.4.1. Connecting the Temperature Sensor

To connect the temperature sensor and read it out while doing the P 1640 cooldown procedure:

1. Connect the thick grey cable to the dewar (with the milspec connector on the port on the short side of the dewar (the "back, if you will).



**Figure 166. Milspec temperature controller cable.**

2. Connect the other side of this cable to the Temp. Sensor connector on the front panel of the electronics

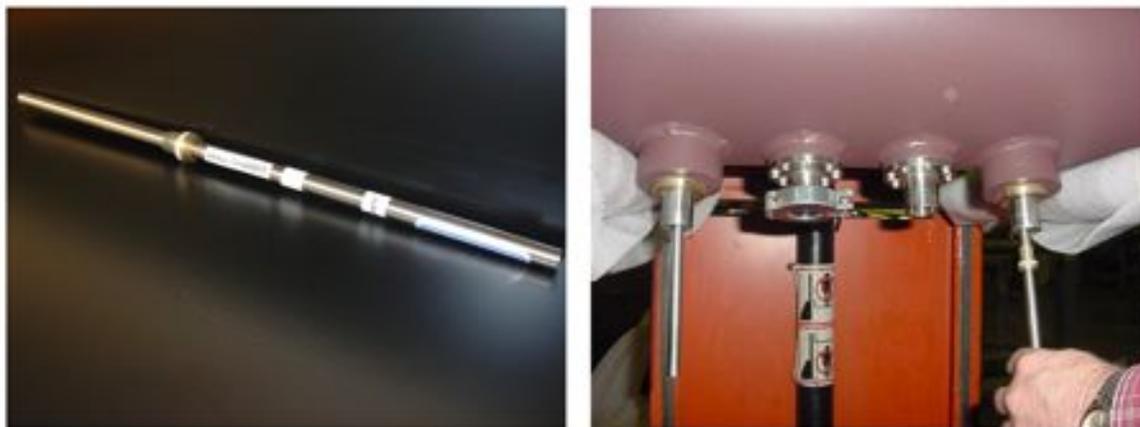
rack.

3. Plug in the electronics rack. The power cable is coiled and stored in the bottom left corner of the front panel, where this is an opening in the front panel. Just pull this cable out and plug it into a standard wall socket.

4. The only thing left to do is to power on the Lakeshore temperature controller. The power in the rack is controlled by a single power strip controlled via TCP/IP, but it can be controlled from the back of the electronics rack. Open the back of the rack. The power strip is at the bottom, and you should see to the left 6 unlit LEDs and a small circular red button. Press this button and one of the LEDs should start blinking. Press it again and the next LED over will start blinking. You want to illuminate the LED labeled 6. Once that one is blinking, hold the red button down until it goes solid. This should turn on the Lakeshore controller and if you then go to the front of the electronics rack, you will see its blue LED screen on at the bottom left of the rack. It should be reading out two temperatures, generally within a degree of each other.

### 3.2.4.2. Filling procedure

**The inner (small) tank can only be filled when the internal dewar temperature has dropped below about 95K. At no time prior to this should any Nitrogen be put into the small tank. Doing so could destroy the detector system in the instrument. Note also that the placement of the two cans are different between PHARO and P1640.** In the “optics down” configuration (on the telescope, or on the AO spit), two LN2 vent tubes, one for each tank, are screwed into the two tanks to both allow the Nitrogen exhaust gas to vent as well as prevent the liquid from pouring out. These two tubes are screwed via their brass threaded midsections, and are nearly identical to those for PHARO (see photo).



**Figure 167. Detail of one of the fill tubes (left), and showing how these are inserted into each tank.**

Steps:

- 1) Verify that the pressure gauge is plugged in and is near 0.1 – 0.2 mbar.
-



**Figure 168. The inner and outer tank fill ports. Each is identical to PHARO, but are in different places. Also, unlike PHARO insulating foam has been placed on the fittings.**

2) To fill the outer can, one of two LN2 stingers can be used: either the normal PHARO stinger, or the custom P1640 stinger. The stinger used for PHARO may stay in the tube better. To insert the stinger, the instrument must be rotated 30-40 degrees on its cart to allow access to the fill port. Remove the locking pin on the handling cart and allow the instrument to rotate. **Caution: The instrument will choose to rotate on its own, so be prepared for a rotation when the locking pin is removed.** Once the tube has been inserted, the instrument can be rotated back to its original position and the locking pin replaced.



**Figure 169. The threaded locking pin on the handling cart. Use care when removing this, as the instrument will immediately rotate when this pin is removed (see photo below).**

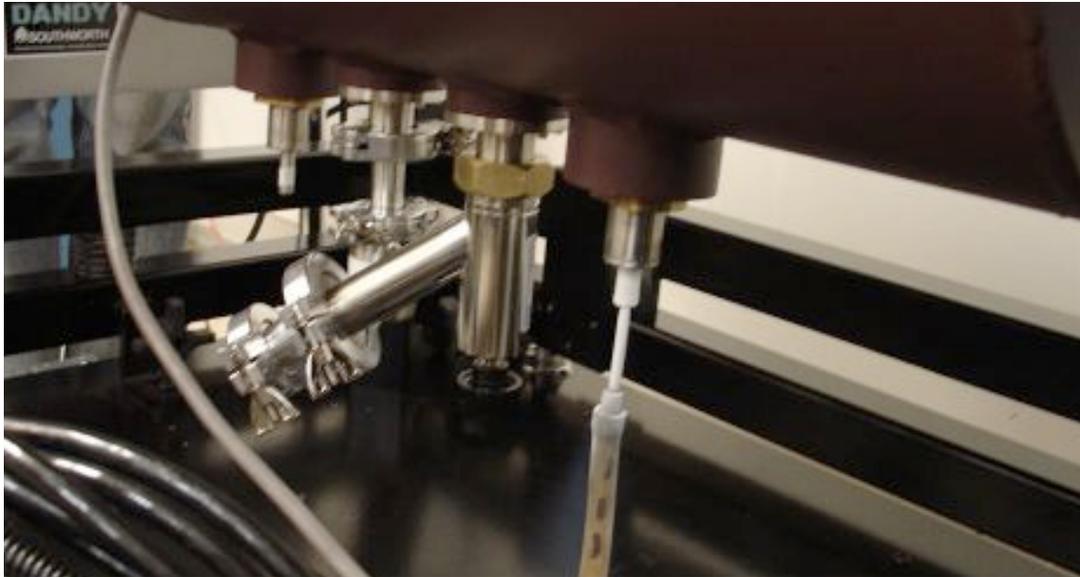
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**Figure 170. The locking pin is removed, and instrument is rotated in order to insert the LN2 stinger. This orientation is the instrument's natural orientation after the locking pin has been removed.**

3) Allow the Nitrogen to flow freely into the large tank. It is a good idea to drive the 50L dewar with Dry nitrogen to keep the pressure up around 6 psi. The pressure on the gauge will fall significantly to between  $1e-03$  or  $1e-04$  mbar during the fill.

4) The fill may take 20-30 minutes. Several fills over a few hours may be required to get the large tank full. Refill several times.



**Figure 171. The liquid Nitrogen stinger used for PHARO placed into the large tank on P1640. During the initial cool down, only the large tank should be filled. No nitrogen should be put into the small tank if the internal temperature is above 95K. Note also that the insulating foam is not shown in this picture.**

5) After several fills of the large tank, and roughly 24 hours, the small tank can be safely filled. Should we let the AMNH folks do that when we get here?

### **3.2.4.3. Expedited Warm-Up using Dry Nitrogen gas**

*Warning: when the dewar is cold and filled with dry nitrogen, the Nitrogen gas acts as a coupling between the cold dewar internals and the warm outer shell of the dewar. This will cause the outer shell of the dewar to become cold and water condensation to form on the outside of the dewar (including the dewar window!), and puddles of water may form under the dewar. This water can drain down into the optics base plate causing rust.*

If the dewar is in a cold state, and needs to be warmed quickly, the dewar can be flooded with Nitrogen gas (“dry nitrogen”). Such gas has no water vapor in it, and will not affect either the optics or the detector. However, this is a sensitive operation on many different levels, and care should be taken.

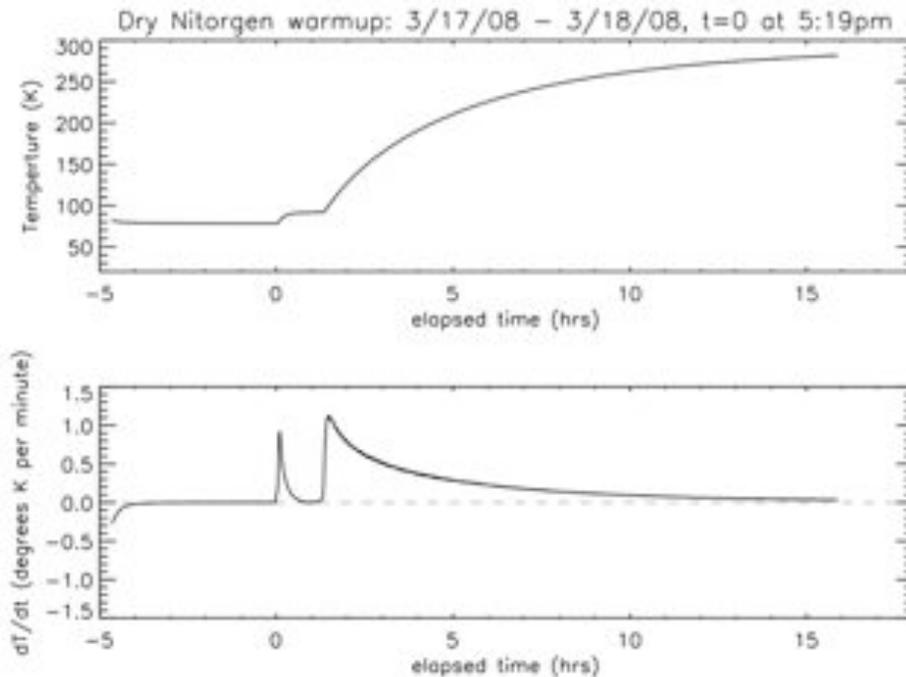


**Figure 172. Necessary setup for dry nitrogen warmup.**

Hook up the special KF-16 dry nitrogen fitting to the non-dewar end of the LN2 fill hose. Hook up the other end of the LN2 fill hose to the **VENT** port on the 50L LN2 dewar. To do this, you will need the threading adapter to fit on the VENT port. Once this step is done, clamp the special KF-16 fitting to the free end of the turbo pump T junction. A KF-25 to KF-16 adapter is needed. With the dewar closed and the pump hose connected to the dewar, fully pump down the hose. With the dry nitrogen fitting hooked up to the turbo pump, there currently is no way to measure the pressure in the pump hose. However, the pressure in the pump hose will be very low once the turbine has reached 1500Hz. When this has happened it is safe to open the dewar, by pulling up on the black handle. If the pressures between the dewar and the pump hose are comparable, it should be easy to pull this handle up. If it is a struggle, stop, something is probably wrong. Once the dewar is open, **SLOWLY** lift the VENT handle on the 50L dewar. This doesn't need to be turned much, perhaps only 5 degrees. An extremely faint hissing sound should be heard and the pressure in the dewar should rise. Do not open the VENT handle any more than it is already open.

It is important to not *over*-pressurize the dewar with dry nitrogen. When the pressure on the dewar has reached 400-500mbar, remove the KF-15 clamp securing the dry nitrogen fitting to the "T" on the pump, **while keeping the 50L hose and its fitting in place with your hand.** (This is most easily done with two people). As the pressure in the dewar begins to rise, and finally passes room pressure, you will be able to feel dry nitrogen leaking out of the seal between the dry nitrogen fitting and the "T" adapter. When you feel this excess

has rushing out, the dewar is at room pressure and the VENT handle can be fully closed. Next quickly lift the dry nitrogen fitting off the “T” and replace it with a KF-16 cap. Do not clamp this cap to the “T” junction. Instead, place a small weight on the cap: light enough to keep the cap in place, but light enough so that the nitrogen gas can escape as the dewar warms. The dewar will warm at a rate given by the plot below, and probably not exceed 1 degree K per minute.



**Figure 173. Temperature plot for the dry nitrogen warmup.**

### 3.3. Installation

#### 3.3.1. On telescope installation procedure

If the instrument and rack are being stored in the AO lab, both can be transported on their casters to the freight elevator and raised up to the observatory floor.

- 1) Prior to installation the IFU should be evacuated and cooled as per the procedure in Section 3.2.2 and 3.2.4.
- 2) The instrument should already be mounted on its handling cart in the “optics down, pucks up” configuration.
- 3) After the cage door has been removed, the Cassegrain ring needs to be rotated by 180°, shown in the figure below, with the widest part of the door in the North direction.



**Figure 174. The Cass cage has been rotated into the position needed for mounting.**

- 4) The green handle on the handling cart must be removed via the two large nuts at its base before the instrument can be raised through the Cass cage door.
-



**Figure 175. The AO bench showing the four mounting pucks.**



**Figure 176. The orientation of the instrument on the Palomar ram must be aligned with its mounting place on the AO system.**

---

- 5) The handling cart is placed onto the hydraulic ram in the same orientation as that which the instrument will be mounted on the AO bench (see photo below), which is the gold electronics box facing out. At this point the instrument is ready to be raised up on the ram.
- 6) Raise the instrument on the Ram so that the A-frame passes through the widest part of the cage door (see photo below).
- 7) Pump the handling cart pedal until the instrument lower platform (the yellow portion) is higher than the narrowest part of the Cass cage door (see photo below). When this has been achieved the cart can be moved towards the center of the cage.



**Figure 177. The instrument being raised on the ram through the widest part of the Cass cage door.**



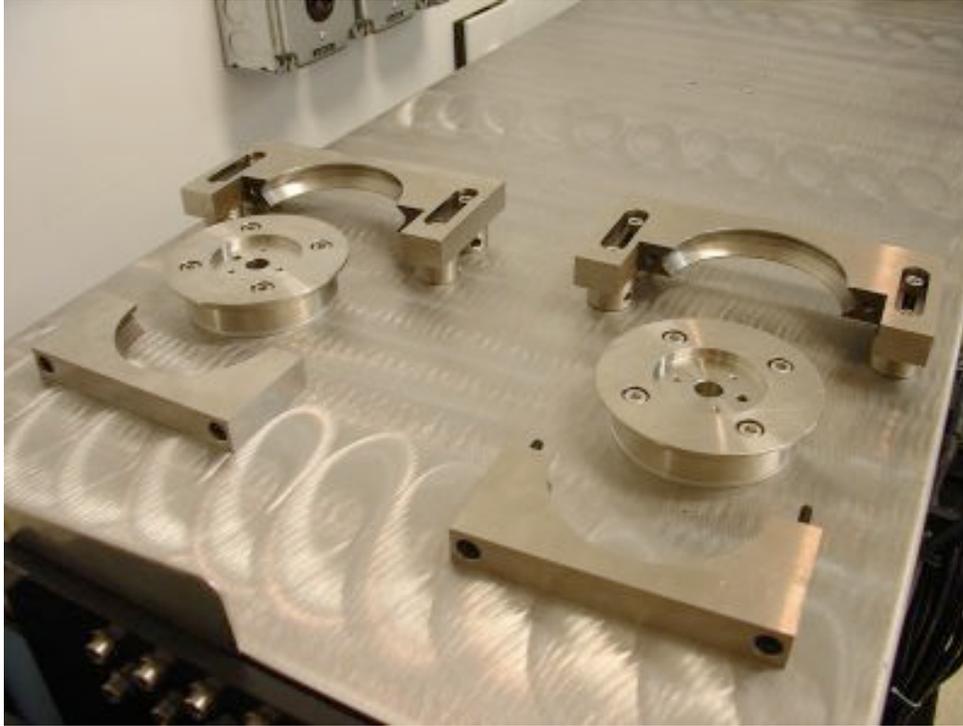
**Figure 178. The handling cart should be raised up via its pump mechanism until the yellow portion of the cart platform is higher than the narrowest part of the cass cage door. Then the cart can then be wheeled towards the middle of the cage.**

- 8) As the instrument is lifted via the foot pump up to the four AO bench pucks, the six screw mechanisms on the handling cart (which reposition the handling cart A-frame in an “x-y” manner) are used to position the four P1640 pucks directly under the four AO bench pucks.
-



**Figure 179. One of the six "x-y" adjustment screws. These are used to carefully align the four P1640 mounting pucks with the AO bench pucks.**

- 9) As the instrument continues to rise up, one of the instrument pucks will invariably reach its corresponding puck on the PALAO bench first. Assuming that the pucks are well aligned, the instrument can continue to be raised upward. The six springs on the handling cart will allow the side that has reached the top first to compress, and all four pucks will eventually meet as the instrument is being pumped upwards.
  - 10) Once all four pucks are well aligned and flush with each other each puck pair can be clamped. The current clamp configuration is tricky and it may help to have two people working on a single clamp. Long ball drivers should be used as well.
-



**Figure 180. The mounting clamps. Note that these clamps have had some posts installed, which raise the clamps making the installation easier.**

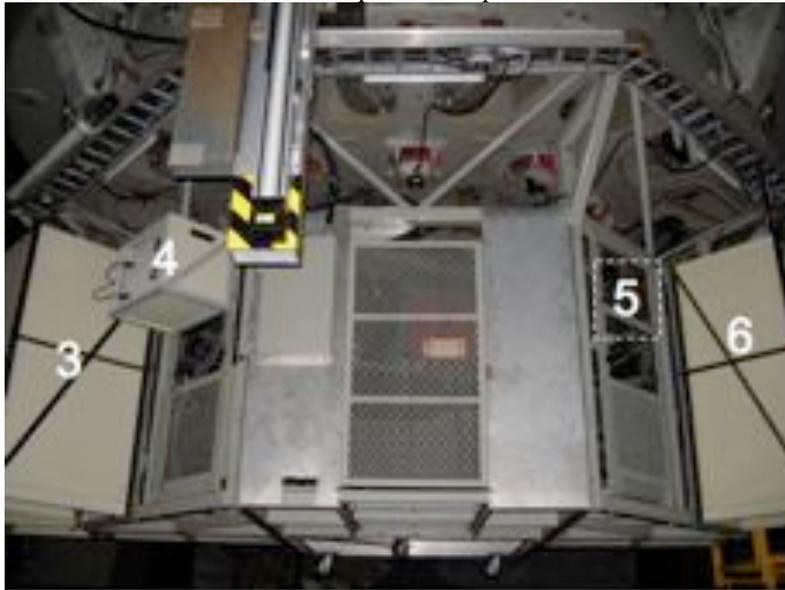
- 11) When the clamps are tightened, the eight M6 bolts on each of the instrument mounting plates can be removed. At this point, the instrument is fully mounted to the telescope and the handling cart can be lowered down and stored.
-



**Figure 181.** The eight M6 screws used to secure the instrument to each mounting pad on the handling cart.

### 3.3.2. Mounting Electronics Rack

The electronics rack will be placed in position 5 shown in the figure below.



**Figure 182.** The P1640 electronics rack will be placed in position 5.

### 3.3.3. On PalAO spit in the AO lab

Mounting the instrument on the AO bench on its spit is nearly identical to the mounting process on the telescope. The brake on the AO spit may need to be removed for clearance. Other than this, there are no serious clearance issues.

### 3.3.4. Cabling procedure

Connecting the electronics control box is a sensitive job and needs to be done carefully. Make sure you are fully grounded before making any connections.



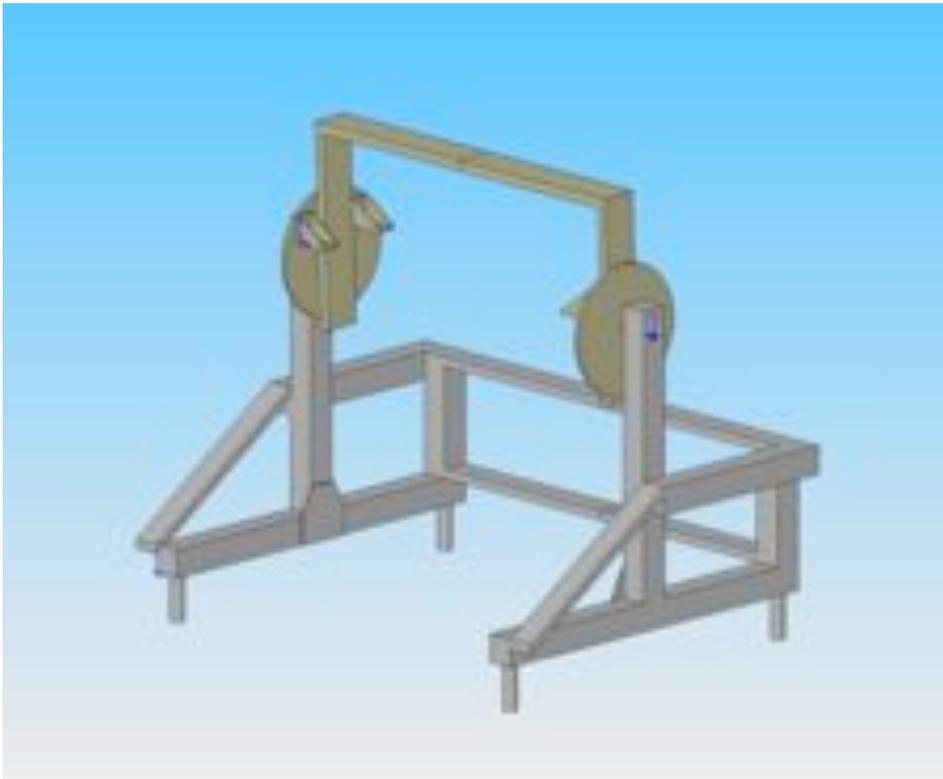
**Figure 183. Cable Bundle 1 connected to the rack.**

### 3.3.5. Control Room Setup and Power-up Procedure

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### 3.3.6. De-installation and stowage procedure

### 3.3.7. Crating procedure



**Figure 184. The AO spit.**

### 3.3.8. Transport and Shipping

Shipping from AMNH to New York was handled by Dietl, International (contact is Deirdre O'Connell, 212-400-9555, [doconnell@dietl.com](mailto:doconnell@dietl.com)) via aircraft. Airport supervision was in place at both JFK and LAX airports. The delivery to the Observatory was handled by a covered, air-ride truck. The crates were unpacked in the ground floor of the 200" dome, before moving the contents into the AO lab. The empty crates will be stored at Palomar. When shipping the instruments in the future, the same procedures need to be followed.

**Table 10. Weights for all project components.**

<b>Project Component</b>	<b>Weight (lbs)</b>
Handling cart + instrument	990
Handling cart alone	550
IFU + Coronagraph (with Nitrogen)	440
Electronics rack (with all cabling)	394

### 3.4. Software Configuration

#### 3.4.1. Structure and Design

Ben's notes:

Need lots of detail on AO Central + FSM Computer + DAC

Regarding DAC: server stuff, launch script, commands by xml, SSH stuff from Doug.

The software interface to the instrument is a LabVIEW front panel designed to give the user control of taking images, powering parts of the instrument. There are five main tabs on the front panel:

##### **System Init Tab:**

The system init tab contains several controls for powering on, and initializing, subsystems of the instrument

**Power Control** box: Allows the user to power on and off the Temperature Sensor, Data Acquisition Computer (DAC), the Tip/Tilt sensor, the SMC motor, Electronics rack KVM unit, FSM computer, FSM amplifier, and MM4006 motors

**Detector System Control and Configuration** box: This box contains three initialization buttons for the DAC: Launch Camera Servers, RST-RCO-Init, and Detector Power On. When powering up the systems, these buttons must be executed in that same sequence. A final button, Kill All Camera Processes, allows the user to terminate camera processes. This tab also contains several other buttons: Start TCS Communications, which allows the software to communicate with the Palomar TCS; Start FSM Communications, which initializes communications between the software and the FSM computer; Record Observations in Catalog is currently not used; and finally, Synchronize with NTP Time Server is also not currently being used.

---



Figure 185. Control software with details of the System Init tab shown.  
 Paths Tab:

This tab shows the locations where that current night's data are being stored, as well as IP addresses of the DAC, TCS computer, and TCP to RS232 converter.

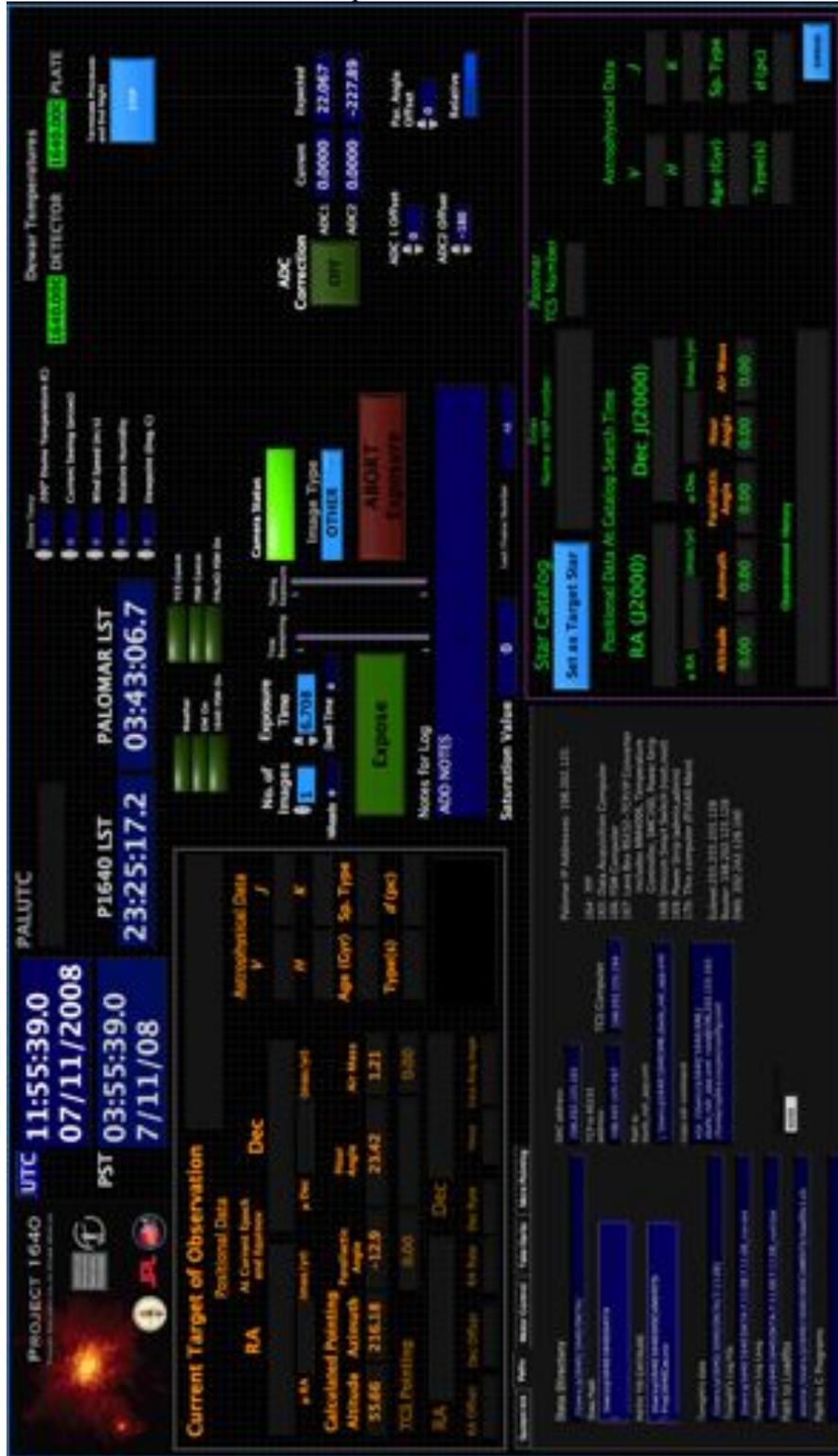


Figure 186. Software panel showing details of the paths tab.

**Motor Control:**

This panel allows full control over all the instrument's motors. This tab primarily consists of two boxes. The "Move Pupil on Lyot Stop" control box allows the user to tilt the FPM, which effects movement of the pupil image at the Lyot stop. The user can choose the amplitude of tilt to be imparted to the FPM. The "Move Star Behind FPM Hole" box imparts movements to the tip/tilt sensor housing. This effectively allows the user to move the position of the star under the mask. The current and nominal positions for the FPM and Tip/tilt motors are listed there, too. Also, two buttons allow the user to save the current motor positions to the nominal positions, or to go to the nominal positions.

Then FPM and TT x and y current and nominal

Three buttons: Set ADCs to Offsets, Go to Nominals, Save Nominals

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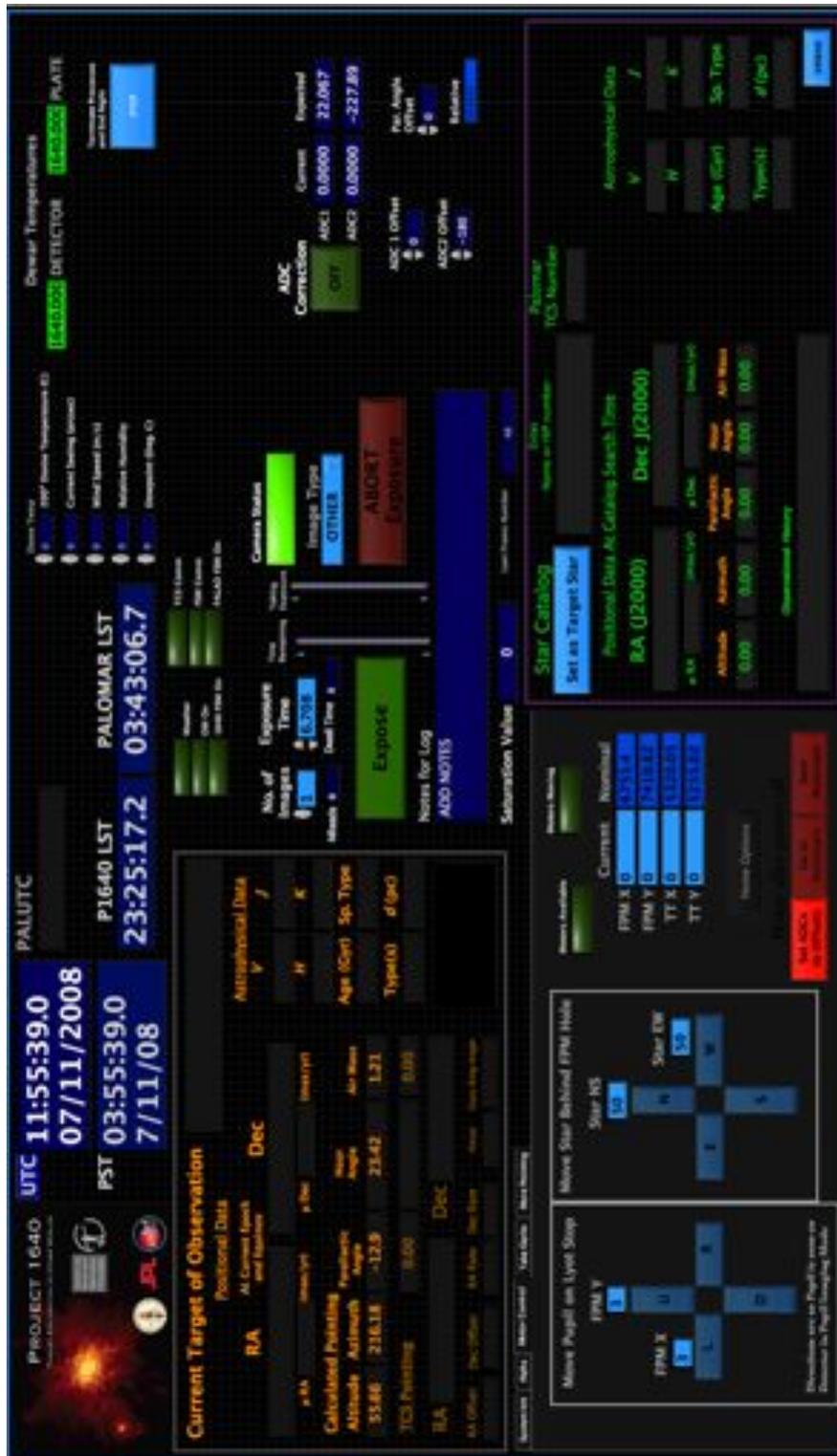


Figure 187. Software panel showing details of the motor control tab.

- 4) Take Darks
- 5) More Pointing

### 3.4.2. User's Manual



Figure 188. Front Panel of Operating software.

#### 3.4.2.1. VPN settings

Cisco VPN settings for main computer:

Create new profile  
 Connection Entry: AMNH  
 Description: AMNH  
 Host: vpn-gw.amnh.org  
 Group Authentication  
 Name: amnh  
 Password: r0tund@

### 3.5. Electronics Configuration

The electronics rack consumes 350W of power without the motors powered up. With the tip/tilt system on, the system consumes 10W of power.

#### 3.5.1. Detector System

Detector

Leach box

Data acquisition computer (DAC)

Set to boot up when powered on. Local login requires the password p1640dac. A second user, optics, used by the dazle software has the password DAZLE@ioa1

#### 3.5.2. Instrument Pressure and Temperature Sensors

Lakeshore Temperature Controller (Model 331)

Precision Calibration for sensor B (D6003010 on detector) is in channel 21; sensor A (D6007636 on base plate) in channel 22.

Connected via RS232 crossover cable to Lava TCP/RS232 box.

Heaters: 4 1 (?) ohm resistors

Heater Control Set Point: 81 K

Heater Control Parameters set using Lake Shore auto tune:

P Gain:

I Gain:

D Gain:

#### 3.5.3. Cassegrain Cage Rack

Motor Cables: (Number on cable, to label on front Panel, motor type)

- |    |                                   |           |
|----|-----------------------------------|-----------|
| 0. | FPM-x                             | CMA12CCCL |
| 1. | FPM-y                             | CMA12CCCL |
| 2. | T/T offset-x                      | CMA12CCCL |
| 3. | T/T offset-y                      | CMA12CCCL |
| 4. | Unused (Card for Goniometric)     |           |
| 5. | Unused (Card for large Rot Stage) |           |
| 6. | ADC-1                             | SR50CC    |
| 7. | ADC-2 (Connected to SMC100CC)     | SR50CC    |

Internet Cables (Unicom Fiber Switch)

- |    |                  |                 |
|----|------------------|-----------------|
| 1. | DAC              | 198.202.125.165 |
| 2. | FSM              | 198.202.125.166 |
| 3. | RS232-TCP/IP box | 198.202.125.167 |
| 4. |                  |                 |
| 5. |                  |                 |
| 6. |                  |                 |
| 7. |                  |                 |
| 8. | Power Strip      | 198.202.125.169 |
| 9. | Fiber Cable to   |                 |
-

Unicom Smart Switch (IP router see above)

MAC Address 00:00:1C:01:57:CE

IP: 198.202.125.168 (Use Safari or Internet Browser; do not use Firefox)

User/Password: root

Fiber Port connection (port 9) uses 100Base-FX technology to make it compatible with Palomar

Lava Ether to Serial Link (RS232-TCP/IP converter)

MAC Address 00:04:3B:00:3D:BF

IP: 198.202.125.167

Passwords: admin and port1, port2 etc.

TCP Ports

1. 4098 Newport Motion Controller
  - a. Mode: Raw Server
  - b. BAUD Rate: 19200
  - c. Bits: 8
  - d. Parity: None
  - e. Stop Bits: 1
  - f. Flow: None
2. 4097 Lake Shore Temperature Controller  
Use Crossover (Null Modem Cable)
  - a. Mode: Raw Server
  - b. BAUD Rate: 9600
  - c. Bits: 7
  - d. Parity: ODD
  - e. Stop Bits: 1
  - f. Flow: None
3. 4096 SMC100CC Motion Controller
  - a. Mode: Raw Server
  - b. BAUD Rate: 57600
  - c. Bits: 8
  - d. Parity: None
  - e. Stop Bits: 1
  - f. Flow: None
4. 4095 Power Strip
  - a. Mode: Raw Server
  - b. BAUD: 9600
  - c. Bits: 8
  - d. Parity: None
  - e. Stop Bits: 1
  - f. Flow: None

Data Acquisition Computer (DAC)

MAC address: 00:E0:81:54:5D:58

IP: 198.202.125.165

---

Operating System: Linux version xx.xx  
User: root  
Password: p1640dac

Note: The dazle software uses two users. The second is optics; the password for optics is DAZLE@joal

To run dazle software outside of labview from the main computer send the following from an xterm

```
>ssh root@198.202.125.165 -XY where 172... is DAC's IP address  
>xterm -e /root/dazle_startup
```

IP Power Strip:

MAC Address:  
IP: 198.202.125.169  
Name/Password: admin      Ports:  
1. Empty  
2. KVM Drawer unit  
3. DAC  
4. FSM Amplifier  
5. FSM Computer  
6. Lakeshore Temperature Controller  
7. MM4006 Motion Controller  
8. SMC100CC Motion Controller

Main Power Strip

RS232-TCP converter  
IP addressable power strip (2)  
Unicom Smart Switch  
Pupil Camera (?)

### **3.5.4. Control Room Electronics**

Main Control Computer:      198.202.125.164  
Data Reduction computer:    198.202.125.170

### **3.5.5. Cabling**

#### **3.5.5.1. Observing Configuration**

Palomar IP Addresses: 198.202.125.164-170 is open and now reserved for you.  
The netmask is 255.255.255.128,  
the gateway is 198.202.125.129

---

### 3.5.5.2. Palomar Lab Configuration

### 3.5.5.3. AMNH Lab Configuration

We created a subnetwork at AMNH using Palomar IP addresses. Our fiber switch in the rack is connected to another fiber switch in the 5<sup>th</sup> floor closet, via an ST-SC MM fiber in Fiber port MM2 in the electronics room. That switch is connected to the AMNH Internet via a firewall router (PIX from old Lyot Project). This firewall allows incoming and outgoing traffic to/from the Palomar AO system and the Palomar TCS, since it is on their subnet and gateway, but on the museum's DNS servers (172.16.5.15 and 16). Our firewall has the AMNH internal IP address of 172.16.32.28. Exterior to the museum it has a dynamic IP address (can be found at [whatismyip.com](http://whatismyip.com) from any computer behind the firewall). This IP address will change each time the firewall (PIX) is rebooted. This may be an issue for Palomar. If so, we request from Kurt or Shadi that our firewall be given a static IP that Palomar allows incoming and outgoing traffic from/to. Doug's computer jack in his office (R94-384) is on this internal network as well, behind the PIX firewall, so that his computer is also configured to be on the Palomar IP addresses but with the AMNH DNS server.

In this way, our rack components and the main control computer, all have Palomar IP addresses (198.202.125.164-170), the Palomar subnet mask (255.255.255.128), the Palomar gateway (198.202.125.129), but the AMNH DNS (172.16.5.15, 16). When we move to Palomar, we need only change the DNS on all components.

## 3.6. Observing Procedures

Here we describe the procedure for observing with Project 1640, once the instrument has been cooled, mounted, and all cables and communication links for the Cassegrain cage are in place.

### 3.6.1. System Initialization

After the Data Acquisition workstation has been powered on, log in with the user/password p1640/p1640. Load the LabVIEW control panel (**LOCATION, FILENAME?**). If configured properly, the Lab View front panel will indicate the dewar temperature, which at this point should be near 78 +/- 1 Kelvin for both the detector and the plate.

Find the **System Init** menu tab at the lower left corner of the panel. Turn on the DAC machine with the power button. After it finishes booting, hit the 'Launch Camera Servers' button. This will open three terminal windows and a ds9 window for displaying the most recent detector image. Unfortunately, the DAC machine may have to be rebooted many times before it initializes properly. Once it is working, the user should leave it on for the duration of the observing run. Next hit the 'RST, RCO, Init' button to initialize the camera. Next, power on the detector.

---

In order to minimize the amount of charge that builds up on the detector when it is left idle, there is a mode of operation implemented in the control panel called **‘Maintenance Mode’**. Switching this on will cause the detector to be continuously read when not taking data. We recommend switching on the **‘Maintenance Mode’** before beginning a night of observations, at least one hour before taking any science or calibration data. Make sure that **‘Maintenance Mode’** is switched on whenever data is not being taken.

In addition to the LabView control panel, a separate application called the ‘AO Paddle’ needs to be launched in order to permit small changes to the instrument pointing. To start this, open an xterm on the Data Acquisition workstation. Run the following commands:

```
$ssh -X aousr@harbor.palomar.caltech.edu  
(enter password ao$usr)
```

```
$idl
```

```
IDL> aopaddle
```

Now select ‘P1640’ from the instrument menu, and the AO paddle will be ready to step the instrument pointing by an adjustable angular increment in any cardinal direction.

The beginning of every Project 1640 observing run requires especially close coordination with the Palomar Adaptive Optics (AO) System operator. There is a fair chance that both the beam alignment and the Zernike polynomial coefficients of the AO system will need to be tweaked, requiring the Project 1640 user to take a series of test images of a “white light” source built into the AO system. The user should plan to dedicate roughly one hour of the start of every observing run to optimizing the optical interface with the AO system.

Before astronomical observations begin, power on the Data Analysis workstation and log in as DataAnalysis/abaur. This machine is useful for a second observer to process and inspect incoming data. The disk drive of the Data Acquisition machine can be mounted from the Data Analysis machine over the ethernet network, facilitating rapid transfer of data. To take advantage of this capability, open a Finder window on the Data Analysis workstation, select SHARED, select p1640, and connect with user/password p1640/p1640.

### 3.6.2. Target Catalog

The Project 1640 target catalog will inevitably grow over the lifetime of the instrument as new objects of interest are added. Here we outline the procedure for loading a new version of the target catalog into the data acquisition interface and the Palomar Telescope Control System.

The LabVIEW control panel expects a catalog stored as a Microsoft-format .csv file. Example files are stored on the Data Acquisition workstation. The location of the current catalog file can be viewed in the LabVIEW control panel by opening the ‘Paths’ tab in the lower left corner. By placing the new catalog at the same location, the user can replace the old catalog. To load the new catalog into the interface, restart the LabVIEW control panel. The user can verify that the new catalog is in place by checking for the existence of one of the new entries. To do this, enter either the HIP number or another identifier in the box in the ‘Star

---

Catalog' area in the lower right corner of the front panel. The coordinates and other observational data of the requested star should appear.

In order to observe targets in a new version of the catalog, the AO operator needs to load his own version of the new catalog into the main telescope control system. The perl script 'makePal.pl' takes the .csv target catalog file and produces a text file catalog in the Palomar-specific format. This is accomplished with the following command:

```
$. /makePal.pl MS_format_catalog.csv
```

This will immediately produce the text file `Pal1640-{current date}.txt` in the current directory. Transfer this text file to the Palomar machine vulcan. This can be accomplished through a UNIX shell with an scp operation to `vulcan.palomar.caltech.edu`, using the username/password `user/b34mmEU9`. Be sure to tell the telescope operator the name and location of the new catalog file on vulcan, and have him check that the file is formatted correctly before observing begins.

### 3.6.3. Data Acquisition

Once the target catalog has been loaded, entering the HIP number or other identifying name in the object box will bring up a history of observations for that target. The history will come up automatically when you set the image type, the number of observations, the integration time, and the number of reads. To prepare the instrument for the new target, hit the 'Set as Target Star' button. Executing the 'Set as Target Star' command loads the relevant target information into the appropriate .xml files that make up DAZLE's instruction set, and sets the values for the header of the FITS data files.

Tell the telescope operator the 'Palomar TCS number' of the target, so he can slew the telescope and lock the AO system. Note that you should always switch off the atmospheric dispersion corrector (ADC) while the telescope is moving. A button on the right side of the front panel switches the ADC on or off.

Before an exposure sequence begins, the user can set the 'Image Type' option to either 'CORE' or 'OCCULTED', based on whether or not the star is currently behind the focal plane mask. The 'CORE' and 'OCCULTED' options are solely for the purpose of organizing the data; the focal plane mask remains physically fixed in place regardless. There is also a 'PUPIL' option to form an image of the coronagraph pupil on the detector. Switching to and from 'PUPIL' mode requires a few moments to allow the motors to position the optics appropriately. Monitor the indicator box underneath the 'Image Type' switch to verify that the instrument is ready for the new exposure.

The user should carefully set the 'No. of Images' and 'READS' controls for each target. The camera reads occur in 7.7-second intervals. The 'No. of Images' value dictates how many times the DAC will loop through the read sequence and produce an individual FITS file. A simple way to optimize the number of reads is to first acquire an exposure of minimum duration, two reads. Then, inspect the new image in the ds9 window. Measure the counts/sec values of the brightest pixels. Calculate how many 7.7 second reads can be accumulated without saturating (65,000 counts/sec). In practice, the P1640 team has found most occulted stars can be recorded with satisfactory count values using 5, 10, or 20 read exposures. Sticking to those exposure lengths also simplifies the data processing. After setting the number of reads,

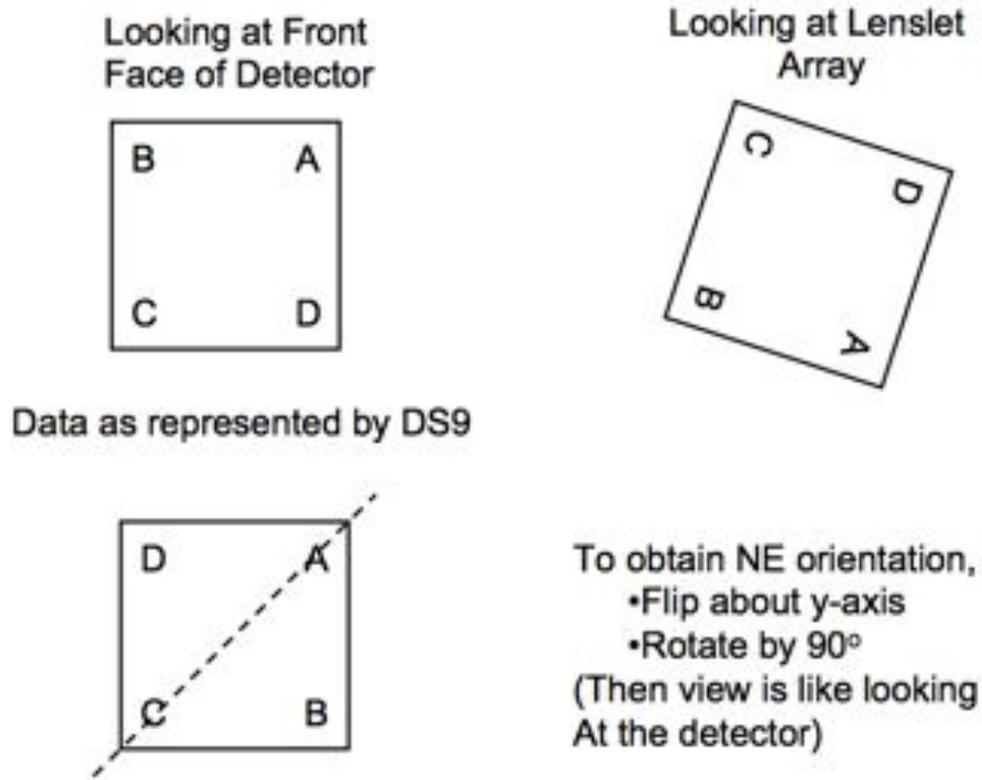
set the 'No of Images' field to however many exposure loops are needed to reach the desired cumulative exposure time. For example, with 20 read exposures, setting the 'No of Images' to 15 will result in a total of  $7.721 \times 15 \times 20 = 2316$  seconds (38.6 minutes) of exposure.

Hitting 'Expose' starts image acquisition. Two indicator bars display the progress in the current exposure sequence. Once the desired number of images has been taken, the history window changes to a note window where comments may be entered. During the acquisition of each exposure, an assortment of observational information is collected from the Palomar AO system. All relevant data (such as time, telescope position, and air mass) are written to the header of the corresponding FITS file.

After each image acquisition, the DAZLE software executes a script called `1640_export_data` in `/home/optics/ucam/bin`. This script uses FTP to move FITS files to the Data Acquisition workstation. The DAC informs the LabVIEW control panel that the file has been sent using the script `file_sent` in `/home/optics/ucam/data`. The Data Acquisition workstation listens over a designated port for the `file_sent` signal. Prior to sending the file, the Data Acquisition workstation is told that image acquisition is complete so that the software can grab the latest position settings.

After the exposure completes and the FITS file is transferred to the Data Acquisition machine, the new image appears in the ds9 window. The orientation of the image with respect to celestial coordinates is diagrammed in Figure 1, along with the relationship to the orientation of the lenslet array. Figure 2 shows an example of raw data as it appears in the ds9 window during observations.

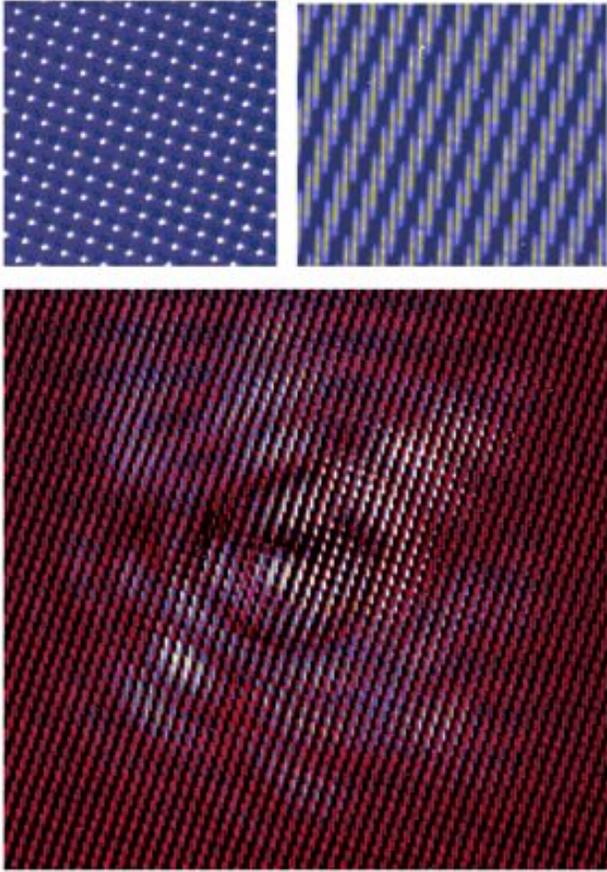
---



**Figure 189. Schematic showing how the data are oriented on the detector (upper left), on the lenslet array(upper right), and as it first appears in the DS9 window.**

Between exposures, the observer can fine-tune the pointing with the ‘AO Paddle’ (as described in section 1.1.1) in order to move the image of the target on the detector. This will be necessary, for example, to accurately occult a star with the focal plane mask or to move a star’s point spread function to a favorable region of the detector.

Once the observer verifies that the desired target is in the field of view, and that the AO correction is optimal, he should align the pupil of the coronagraph. This step is necessary before acquiring data on each target because the ADC prisms introduce a sky position-dependent shift in the pupil position. After switching to ‘PUPIL’ mode, take a single exposure, and inspect the detector image. Ideally, the illuminated ring is round and symmetric in thickness. To adjust the pupil accordingly, change the pupil motor positions in ‘Motor Control’ tab at the lower left corner of the front panel. Once the pupil is aligned, the observer can switch back to image mode to begin acquiring science data.



**Figure 190. Initial data from the instrument. Top left: the IFU has been illuminated with a 1330nm laser showing the expected pattern of dots. Top right: A uniform light source. Lower: A broadband APLC image on an IFU obtained in the lab.**

#### **3.6.4. Acquiring Calibration Data**

In order to enable useful measurements from the science data, it is necessary to acquire several pieces of calibration data during each observing run. By setting aside time for these tasks, the observer allows whoever is analyzing the data in the future to constrain the wavelength-dependent transmission of the atmosphere and the instrument, the spatially varying sensitivity of the detector, the bias/dark-current contribution to the detector signal, and the angular scale and orientation of the camera.

#### **3.6.5. Core Exposures**

Either before or after acquiring occulted data of every target star, the observer should record a sequence of unocculted “core” images. Core images are useful for photometric

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calibration. Before initiating the core exposure sequence, be sure that the star is well placed in the field of view. For the best quality core images, the star's image should be centered away from both the focal plane mask and the edge of the detector, preferably centered on one of the quadrants, so that a large area of the point spread function can be recorded. Keep in mind that despite the appearance of the raw focal plane data, the measurable extent of a bright star's diffraction pattern easily extends beyond a quarter of the detector diameter.

### **3.6.5.1. Moon**

If the Moon is visible during the observing run, the user should set aside time to acquire a sequence of exposures for future flat-fielding purposes. The coordinates of the Moon can be determined from the JPL Horizons website (<http://ssd.jpl.nasa.gov/horizons.cgi>). The 'MOON' option in the 'Image Type' switch was designed to annotate this data. In addition, call up 'Moon' from the target catalog to be sure the exposures are named correctly. So that the beam entering the coronagraph is approximately uniform, special steps need to be taken. Request that the AO control system loop be left open, and that the sidereal tracking be switched off. Lastly, the number of reads should be set to at least 10, so that any surface features are averaged out in the resulting FITS file of each exposure. To minimize flexure distortion in the images, observe the Moon as close to transit as possible. Repeat at least 5 read sequences.

### **3.6.5.2. Spectroscopic Standard Stars**

In order to account for the wavelength-dependent transmission of the atmosphere and the instrument, during each observing run the observer should obtain a core exposure sequence of at least one star with a readily available reference spectrum. A suggested list of F and G stars has been compiled for this purpose, printed on a table titled "**IRTF Spectroscopic Standard Stars**". They are all stars that have publicly available spectra in the Infrared Telescope Facility (IRTF) Spectral Library. Also note these stars are dim enough ( $V \text{ mag} > 5.5$ ) that the PSF core won't saturate the detector in a single read. Repeat 5 exposure loops for each spectroscopic standard star.

### **3.6.5.3. Calibration Binary Stars**

To enable high precision astrometry, it is necessary for the data analyst to constrain the plate scale and orientation of the science images. Observations of calibration binary star systems are the currently favored solution to this. It is necessary to use binary stars with well-determined orbits, so that the angular separation and orientation of the stars can be computed to adequate precision for the observation epoch. The Project 1640 team has assembled a list of binary stars (printed out on a table titled "**P1640 Calibration Binary Stars**") that meet the criteria of (1) fitting in the field of view, (2) a brightness differences large enough so that the AO system can lock on one of the stars, and (3) an orbit well-determined and listed in the U.S. Naval Observatory Sixth Orbit Catalog. There are only a handful of binary systems meeting

---

these criteria for a given time of the year, so the observer should acquire unocculted data of as many of these as possible on each run. Acquire 5 read sequences for each calibration binary.

#### **3.6.5.4. Dark Frames**

At some point during the run, at either the beginning or end of a night, the observer should record dark frames. Before doing this, make sure that the coronagraph window is covered. We recommend repeating 11 dark read sequences for each read length used during the run. For example, if the observer acquired science data in 10 and 20-read sequences, then they would take 11 x 10 reads and 11 x 20 reads in the dark.

#### **3.6.6. Procedure Summary for Observing One Star**

The following list summarizes the steps needed for a typical target star observation.

1. Immediately after the last exposure, switch on **‘Maintenance Mode’**
2. Set the target in the control panel
3. Turn off the ADC
4. Tell the operator the slew to the chosen target
5. Switch coronagraph to **‘Pupil’** configuration
6. Turn on the ADC
7. While the operator is locking the AO system, align the Pupil
8. Switch coronagraph configuration to **‘Image’** mode
9. Switch exposure mode to **‘Core’** and acquire Core images
10. Occult star using AO Paddle
11. Lock the tip/tilt system
12. Switch exposure mode to **‘Occulted’** and expose

### **3.7. Data Processing**

The Project 1640 Data Pipeline processes and calibrates the raw detector images to prepare the data for inspection and analysis. Most importantly, the pipeline extracts data cubes from the detector images (two spatial dimensions, the third in wavelength). The pipeline can run on any computer with a GNU C Compiler, IRAF version 2.14 or newer, and a Perl interpreter for the initial configuration. For maximum efficiency during an observing run, we recommend a second observer oversee the operation of the Data Pipeline on incoming data at the Data Analysis workstation while the other observer leads the acquisition of new data with the main Project 1640 control panel. The username/password for the Data Analysis workstation is DataAnalysis/abaur, and the IP address is 198.202.125.17

---

### 3.7.1. Data Pipeline Description

In order to extract cubes from the raw detector image, the Data Pipeline program has a library of images made using a laboratory tunable laser, spanning the operating band of the instrument (1100 nm to 1760 nm). Each laser image contains the response of the Integral Field Spectrograph (IFS) to laser emission at a specific wavelength, a matrix of point-spread functions, where the rows and columns correspond to the individual lenslets of the IFS. These laser images were reproduced in 10 nanometer increments across the band. Each laser image is effectively a key showing what regions of the 40,000 spectra landing on the detector correspond to a given central wavelength. The matrix of laser point spread functions are used as filters to extract the science data and map them onto a cube, forming images of the observed target at the series of wavelength channels represented in the laser point spread function (PSF) library.

The Data Pipeline carries out the following steps:

1. Bad pixel and cosmic ray cleaning of detector images.
2. Subtracts the bias from the detector images.
3. Performs a cross-correlation to align the detector plane data with the laser reference library (the projection of the lenslet array onto the detector vary with telescope pointing due to mechanical flexure).
4. Extracts a data cube from the detector image
5. Flat-fields the cube based on a library of Moon observations.
6. Calibrates the flux in the spectral channels of the data cube to account for the transmission of the atmosphere and the response of the instrument.
7. Produces “collapsed” images by summing the slices of the extracted cube, facilitating the detection and photometry of faint objects.

### 3.7.2. Installing the Data Pipeline

In order for the cube extraction pipeline to compile, two C libraries need to be installed: CFITSIO and GNU Science Library.

CFITSIO is currently available from:

<http://heasarc.nasa.gov/docs/software/fitsio/fitsio.html>

Get the latest version of the UNIX tarball, and after unpacking it somewhere (home directory works fine), follow the standard UNIX installation described in the README (./configure, make, make install). Be sure to preface the `make install` command with `sudo`.

The GNU Science Library is currently available from:

<http://www.gnu.org/software/gsl/>

After unpacking this, configure the installation with the “disabled-shared” option, as in:

```
$. /configure --disable-shared followed by $sudo make and $sudo  
make install.
```

---

After obtaining the pipeline program tarball, unpack it in an appropriate location where it can reside permanently. Copy the `lib` subdirectory of the CFITSIO source code directory into the pipeline directory, overwriting the existing `lib` subdirectory. There is a subdirectory in the pipeline directory called `include`. Into `include`, copy the `fitsio.h`, `fitsio2.h`, and `longnam.h` header files from the CFITSIO source code directory.

Next, you will need to edit a few file system paths in `configure.pl`, a Perl script located at the root of the pipeline source code directory. The following variables should be changed:

`$IRAF_PATH` is the file name of your IRAF interpreter (`cl.e`).

`$PIPELINE_PATH` is the full path to the directory where the pipeline source code and executable will reside.

`$DATA_PATH` is the directory where the processed data will be stored.

`$LIBRARY_PATH` is the directory of the pipeline library files. Initially these are located inside the pipeline directory.

`$IRAFSCRIPTS_PATH` is the directory of the IRAF scripts. Initially these are located inside the pipeline directory.

After those are set, run the Perl script on the command line:

```
$. /configure.pl
```

This will produce a customized Makefile. By default, the Makefile links to an Intel Mac version of the CFITSIO library included in the pipeline tarball. If you're not using an Intel Mac, you'll need to modify this location to your own machine's installed version of CFITSIO.

Next, to compile the pipeline, run

```
$make
```

The program should compile with no errors or warnings. Last, to allow the IRAF scripts called by the pipeline executable to run, do

```
$mkiraf
```

to initialize a `login.cl` file in the pipeline directory.

### 3.7.3. Using the Data Pipeline (Provisional for March 2010 run)

---

The newest version of the pipeline on the Data Analysis workstation is in the directory `~/proj1640pipe-2010march/`. Open an xterm and change to this directory. To test that the pipeline is installed correctly, you can run a test cube extraction by simply calling the executable with no arguments:

```
$/pipeline -o
```

This will produce one example data cube from a detector image in the library subdirectory, along with a sequence of comments directed to the terminal describing the various stages of processing. To run the pipeline on a directory called e.g. `~/DATA/goodstuff` containing a set of Project 1640 detector images, run

```
$/pipeline ../DATA/goodstuff/
```

The extracted cubes will be organized under the directory `/DATA/PROCESSED/` by target name and date. Within the date subdirectory, normal data cubes are stored in the subdirectory **FITScubes** (standing for least squares fit to the read sequence). As an example, the full filename of one processed data cube could be `/DATA/PROCESSED/POLLUX/2008-10-25/FITScubes/POLLUX_C_2008-10-25_529.fits`.

There are a few command line options to modify how the pipeline operates. The optional switches, placed after the input directory, are:

- o for overwrite mode, which will overwrite data cubes that have already been made for the given raw focal planes

- d for .dat file mode (which requires the .dat files corresponding to a given .fits file be in the given directory). In this mode, the pipeline forms a cube using slope fits to the individual bias-subtracted .dat file reads rather than the FITS file from the camera to form a cube. If the .dat files are handy along with up-to-date dark frames, this gives significantly cleaner results, with better removal of bias tilt, hot pixels, and cosmic rays. The finished cubes are placed in a subdirectory called **DATcubes** rather than **FITScubes**.

- t causes the pipeline to use the .dat file to make a series of cubes from the difference of every pair of consecutive reads in a given exposure sequence.

- f to turn off the flat field (by default it is on)

- b to fit the bias in the detector image rather than subtracting one of a library of dark images. This is necessary

- a to process all types of images in the given directory rather than just Core and Occulted images

These switches can be combined, so for example, the user can run

```
$/pipeline ../DATA/goodstuff/ -do
```

or

```
$/pipeline ../DATA/goodstuff/ -odf
```

---

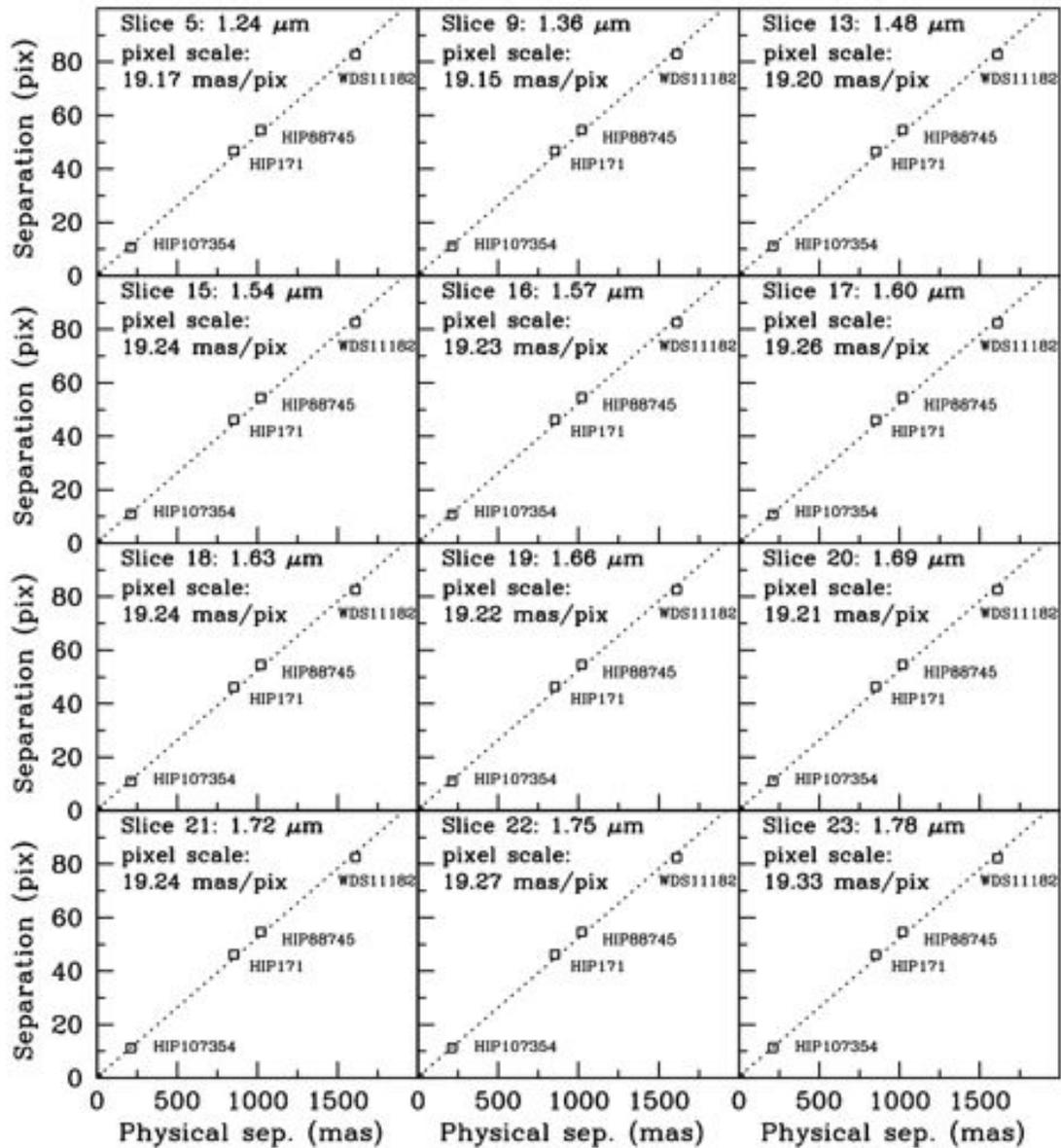
Lastly, the `-s` switch allows the user to override the focal plane alignment determined by cross-correlation with a laser reference. For example,

```
$. /pipeline ../DATA/goodstuff/ -so 0.3 -0.6
```

instructs the program to shift the detector image by 0.3 pixels in x and -0.6 pixels in y before extracting, as opposed to using values determined by the cross-correlation algorithm.

#### **3.7.4. Procedure Summary for Running Pipeline (Provisional for December 2009 run)**

1. Transfer the `.fits` focal plane files you want to process (e.g. `HD172648_O_127.fits`) to some directory on the Data Processing workstation (e.g. `/DATA/goodstuff/`).
  2. In an `xterm` window, change to the pipeline directory (`~/proj1640pipe-2010march`).
  3. At the command line, execute `$. /pipeline /DATA/goodstuff/`
  4. After the pipeline indicates the processing is complete, open the result in a `ds9` window.
-



**Figure 191. Project 1640 pixel scale measured using four different binaries and 12 channels.**

### 3.8. Observatory Testplan (Commissioning Run)

#### June 10-13<sup>th</sup>:

- Final software version
- Lab Data for validation tests
- Hg Lamp ordered
- Schedule movers for 6/23

#### June 16<sup>th</sup>:

- Neil + Sasha test for several hours in mock observing run

#### June 17<sup>th</sup>:

- Last software Bugs Removed
- Begin dewar warm up, maintain vacuum.
- Swivel casters installed on handling cart
- Optics covered, check for loose parts
- Uncabing of instrument. Cables rebundled for observatory ops

- Seal optics, and secure instrument internals.

#### June 18<sup>th</sup>:

- Instrument mounted on handling cart.
- Rotation and balance tests.
- Install 0.15" shims beneath pucks.
- Rubber for beam entry hole.

#### June 19<sup>th</sup>:

- Pack loose parts + E-rack, computers, KVM, etc.
- Write inventory
- Remind Rick, Mark C. about WFS, accelerometers

#### June 20<sup>th</sup>:

- Safe Art Transport personnel to finish packing

#### June 23<sup>rd</sup>:

- Dietl to pickup ~3:30 pm

#### June 24<sup>th</sup>:

- Sasha, Ben, Doug Arrive 12:09pm SAN, ~3:30pm Palomar

- Move instrument to AO Lab.

- Get observatory vacuum pump and pump down if possible. We have KF25 connection on the valve.

#### June 25<sup>th</sup>:

- Brief visit from JPL people early afternoon to see instrument for CAL system issues (Marty to send list of people)

- Machine placement holes for pucks (Bruce Baker?)

- Reassemble instrument.

- Recable instrument to E-rack.

- Run instrument on handling cart, verify detector functionality, motors, etc.

- Check instrument pressure, pump down, begin cool down ~24 hours.

---

Set up computer systems and iron out networking issues (Dan Zieber) (i.e. fiber box connection (100base FX standard))

### June 26<sup>th</sup>:

Rick Arrives for 26, 27<sup>th</sup> (possibly available over weekend). Rick to bring Accelerometers for vibration tests (from Mark Colavita)

AO system replaced to spit by mountain crew.

Install instrument on AO bench.

With free cart: plan out intra-observatory transport (write procedure)

Cart on Cass Ram if possible. ~12 days for any unexpected cart modifications.

Verify LN2 filling procedure in "optics down" configuration on bench.

Electronics Rack mounting

### June 27<sup>th</sup>- July 6<sup>th</sup>:

Ian arrive July 5.

Hope is that from 27<sup>th</sup> to 8<sup>th</sup>, team is essentially not a burden on observatory staff, except for additional LN2

Begin Alignment to AO system (budget 4 days)

Imagine-Optic WFS Alignment (will be in lab on arrival)

Need to verify AO system communication is working

Verify correct keywords are being written to headers.

Additional software testing and debugging

FSM: Lightsource readouts changed from what we would expect?

FSM: Make sure x,y,gain and PID gains are giving the expected results.

Apodizer: Test grid with AO WLS

Apodizer: Test pupil alignment to telescope (AO pupil to p200 pupil)

Infrasil window: angle needs to be calibrated.

Wavelength Calibrations:

Hg lamp. Lambda scale reference images.

Realign Pupil Cam

Determine 0-point offsets for each ADC prism

Vibration measurements on AO Bench

Flexure: Verify alignment is same after rotation back to optics-up position.

White-Light stimulus lab performance (coronagraphic contrast estimate)

Pupil alignment: Check alignment and look for signs of wander at different spit angles.

Attempt to make FSM work

### July 7<sup>th</sup>:

All observatory procedures written with reviews by mountain crew

### July 8<sup>th</sup> (observing):

**Present: Doug, Sasha, Ben, Antonin, Rick, Lynne, Ian**

Morning: Mount P1640 on AO bench in Cass cage following procedures written, adjust procedures as needed.

Configure control room

Verify AO systems communication

Verify local area networks are working as planned.

On Telescope:

Verify AO Alignment with stimulus source

Align Pupils using bright sky (pre-sunset) tweak cass ring angle to align spiders  
 Obtain on-telescope Hg lamp data to check for flexure/lambda changes  
 Check pupil cam sensitivity with dome lights

**Verify and Calibrate ADC performance**

ADC calibration. motor rotation algorithms need to be verified, and scale factor determined (5 bright stars at airmasses of 1.0 to 1.56)

Test for pupil wander (5 airmasses, 5 HAs) also tests for instrument flexure

**Verify star acquisition:** occulted images

Acquire multiple sky flats

**July 9, 10 (observing):**

Morning: Acquire suite of on-telescope darks and additional dome flats

**Astrometric and photometric data quality verification**

HIP 101769 - RA 20h38m, sep 0.44",  $V_{\text{primary}} = 3.64$ ,  $\Delta V = 0.91$

HIP 102531 - RA 20h47m, sep 0.22",  $V_{\text{primary}} = 4.27$ ,  $\Delta V = 0.88$

**Spatially Resolved Spectroscopy Data verification:**

Uranus and Neptune (e.g. methane chemistry across FOV)

Disks: HD 141569A (7<sup>th</sup> mag), DoAr 25 (9<sup>th</sup> in J, 12.65 in R), Vega (0<sup>th</sup>)

Acquire non-AO corrected G star flats (do we need to implement G-star flat mode on FSM to raster the star?)

**Magnitude Limits and FSM tracking limits:**

Vega, short and long exposures occulted

5 stars at 2, 5, 8, 10 and 13<sup>th</sup> mag (V)

**FOV Distortion and initial coronagraphic performance:**

Crowded Field (Barnard's star, Doradus Deep Field?)

Coronagraphic performance as function of V magnitude

Young stars: Altair, Rasalhague (type A, additional binary position)

HIP98767, other high priority targets from Lyot Project

Continue with science observations.

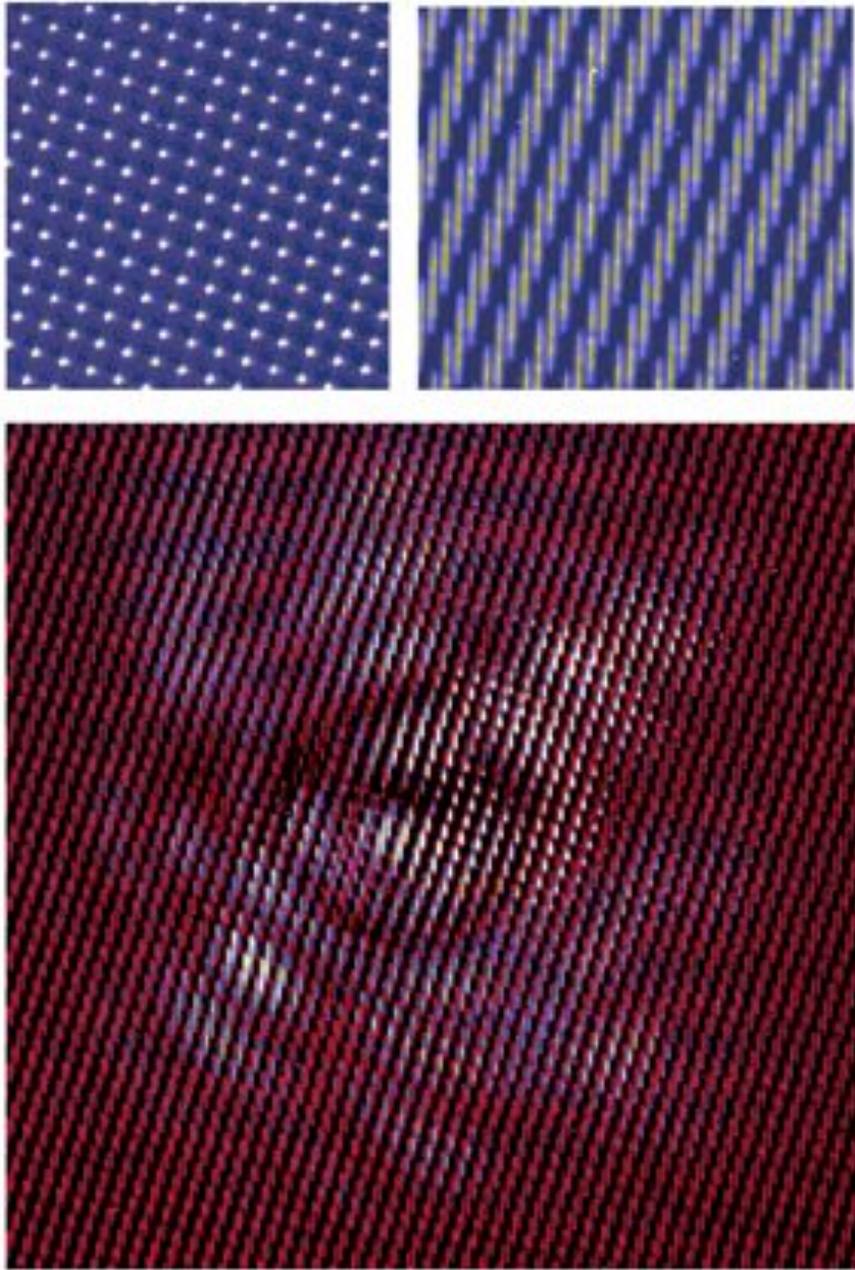
**Verify and Implement data backup procedure**

**July 11: Assist with Instrument removal and storage**

Modify removal procedure as needed

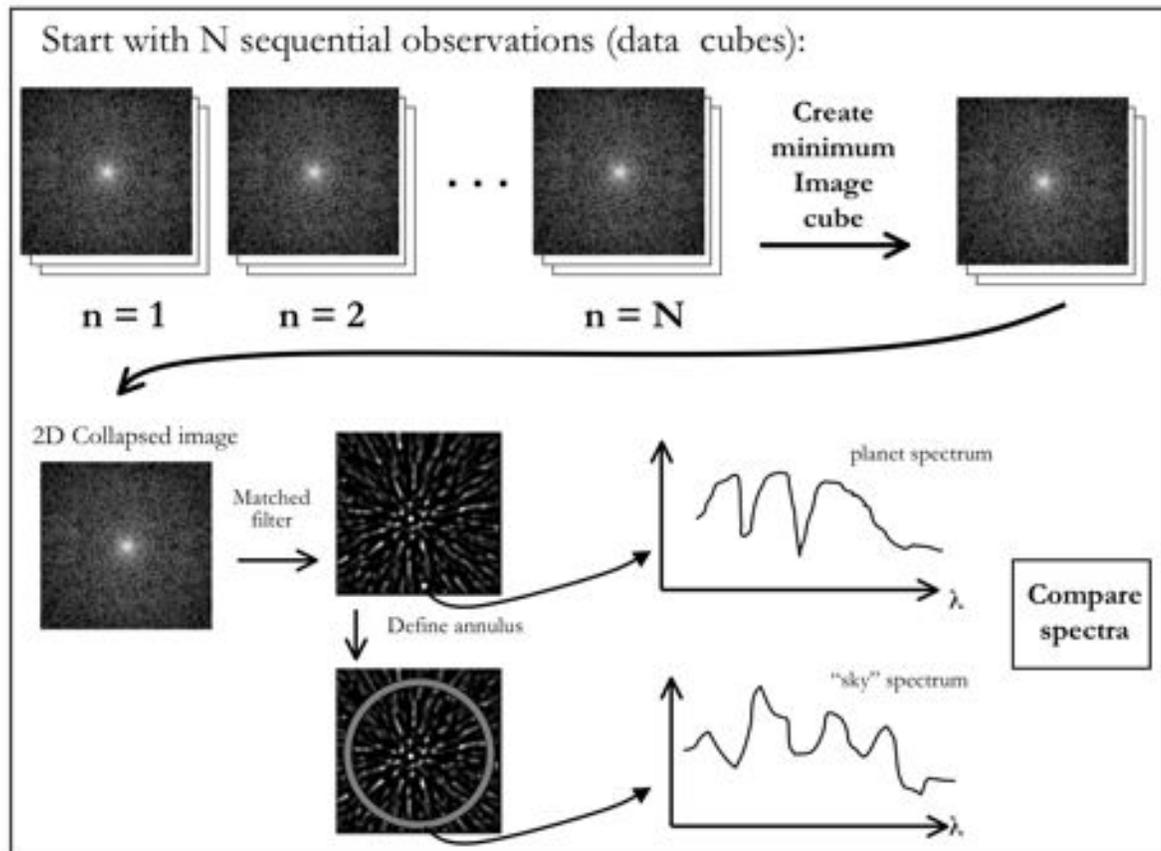
Departure noon

### 3.9. Data Reduction Manual



**Figure 192. Initial data from the instrument. Top left: the IFU has been illuminated with a 1330nm laser showing the expected pattern of dots. Top right: A uniform light source. Lower: A broadband APLC image on an IFU obtained in the lab.**

---



**Figure 193. Preliminary data reduction strategy.**

## 4. Appendices

### 4.1. Data File Sample Header

```

SIMPLE =           T / file does conform to FITS standard
BITPIX =          16 / number of bits per data pixel
NAXIS  =           1 / number of data axes
NAXIS1 =           0 / length of data axis 1
EXTEND  =           T / FITS dataset may contain extensions
COMMENT  FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT  and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
BZERO  =          32768 / offset data range to that of unsigned short
BSCALE =           1 / default scaling factor
HIERARCH START_PAR_VALUES = '*UNKNOWN*' / Application parameter
value
VERSION = '*UNKNOWN*' / Application parameter value

```

```

NUM_EXPS= '1' / Application parameter value
DWELL = '7' / Application parameter value
LED_FLSH= '*UNKNOWN*' / Application parameter value
NUM_READ= '2' / Application parameter value
X_START = '1' / Application parameter value
Y_START = '1' / Application parameter value
X_SIZE = '2048' / Application parameter value
Y_SIZE = '2048' / Application parameter value
RD_TIME = '6000' / Application parameter value
RS_TIME = '10' / Application parameter value
HIERARCH END_PAR_VALUES = '*UNKNOWN*' / Application parameter value
HIERARCH COM_TAB_START = '*UNKNOWN*' / Application parameter value
UT_DATE = '6/4/08' / UT date at start of night
TSCOPE = '200'_HALE' / 200" Hale Telescope at Mt Palomar
INSTRMNT= 'P1640_CIFU' / AMNH Coronagraphic IFU
FOC_PLNE= 'HAWAII -2' / Dazle Hawaii2 detector
WAV_BAND= 'JH' / Wave Band
SPEC_RES= '30' / Spectral Resolution
FILE_NAM= 'AB Aur_O_72.fits' / Object_Date_Type_Number.fits
OLD_NAME= '00001330' / As assigned by DAC run#.fits
OBJECT = 'AB Aur' / Object
RA = '4:55:45.93' / Target R.A. in hours J2000 epoch 2000
DEC = '30:33:46.1' / Target DEC in degrees J2000 epoch 2000
RA_PM = '2' / RA proper motion mas/yr
DEC_PM = '-24' / DEC proper motion mas/yr
VMAG = '7.06'
JMAG = '5.94'
HMAG = '5.06'
KMAG = '4.23'
OBJ_CLSS= 'D T B E' / Disk, Bright, Faint, Binary, Exoplanet, Other
DISTANCE= '144' / Distance (pc)
SPC_TYPE= 'A0e' / Spectral Type
AGE = '650000' / Age (Gyr)
IMG_TYPE= 'O' / Core, Occulted, etc.
TOT_EXP = '1' / Total number of exposures
EXP_NUM = '1' / This exposure number
EXP_TIME= '6.707000' / Exposure time for each image
ST_TIME = '6/4/08 7:43:46 PM' / Exposure start time (UT)
POINTING= ''
RA = '04:55:31.60' / RA in hours J2000 current ep & eq
DEC = '30:34:36.38' / Dec in degrees J2000 current ep & eq
INIT_ALT= '33.094813' / Initial altitude in degrees
INIT_AZI= '353.392362' / Initial azimuth in degrees
INIT_PAR= '82.562940' / Initial parangle in degrees
INIT_HR = '4.550858' / Initial hour angle in degrees
INIT_AM = '1.831414' / Initial air mass
FINL_ALT= '33.033597' / Final altitude

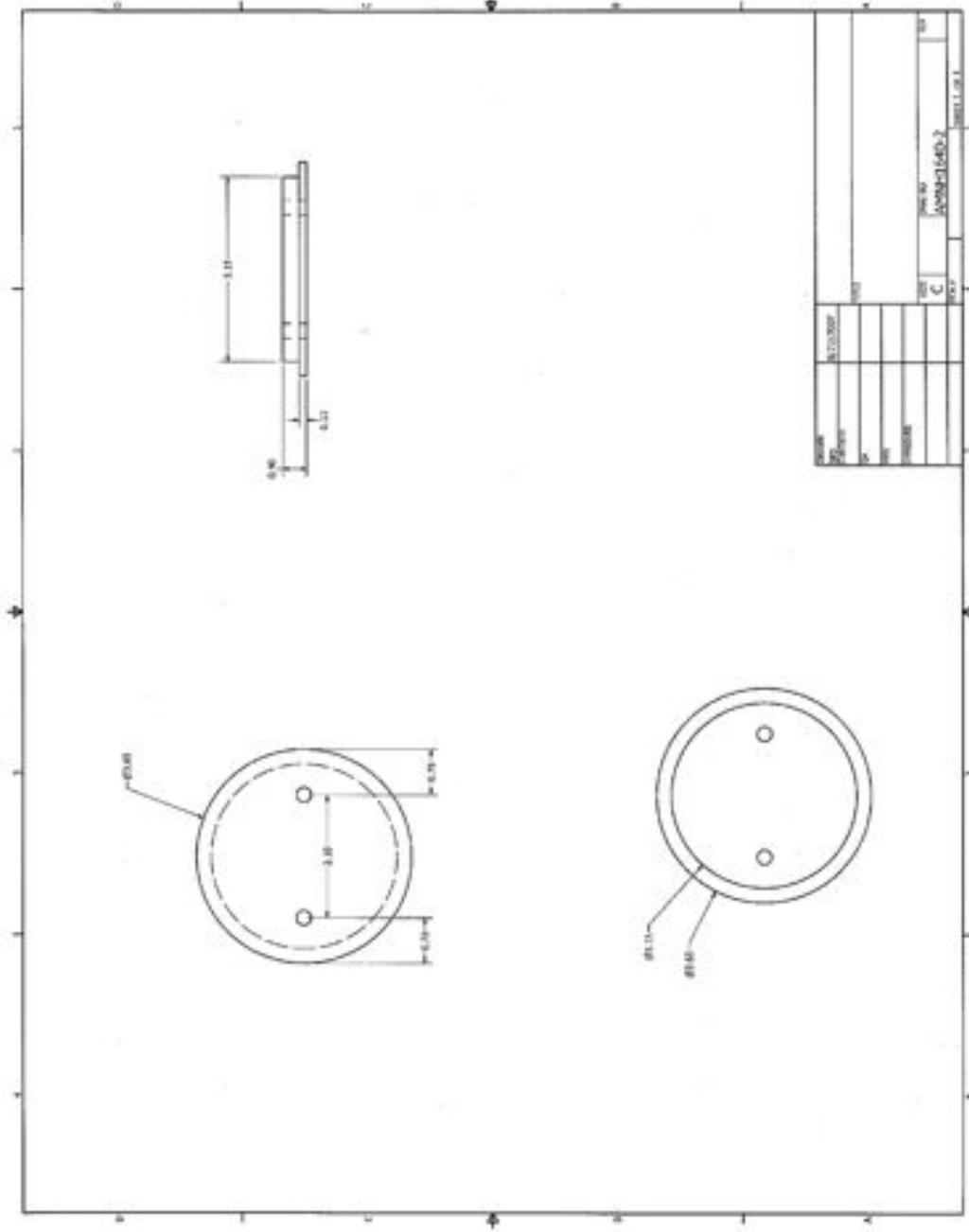
```

---

```
FINL_AZI= '353.390383' / Final azimuth
FINL_PAR= '82.546847' / Final parangle
FINL_HR = '4.555977' / Final hour angle
FINL_AM = '1.834422' / Final air mass
RA_OFF = ' ' / RA offset in arc secs
DEC_OFF = ' ' / DEC offset in arc secs
RA_T_RATE= ' ' / RA track rate in arc secs/hr
DEC_RATE= ' ' / DEC track rate in arc secs/hr
CASS_ANG= ' ' / cass ring angle
AO_DATA = ' '
WFS_X = ' ' / offset for WS field stop center to
WFS_Y = ' ' / detector center (arc secs)
FSM_INT = ' ' / FSM gains
FSM_PROP= ' '
DM_INT = ' ' / DM gains
DM_PROP = ' '
FSM_RATE= ' ' / FSM update rate
WFS_RATE= ' ' / WFS camera readout rate
CON_NAME= ' ' / reconstructor name
STATUS = ' '
AO_TCS = ' ' / number of seconds of disconnect
TSTABLE = ' ' / number of seconds of instability
CIFU_MOT= ' ' / CIFU motors
FSM = ' ' / on/off
INI_ADC1= ' ' / Initial ADC motor1 position
INI_ADC2= ' ' / Initial ADC motor2 position
FIN_ADC1= ' ' / Final ADC motor1 position
FIN_ADC2= ' ' / Final ADC motor2 position
WEATHER = ' '
TEMP = ' ' / Centigrade
HUMID = ' ' / %
CLOUD = ' ' / %
WIND = ' ' / mph
SEEING = ' '
END
```

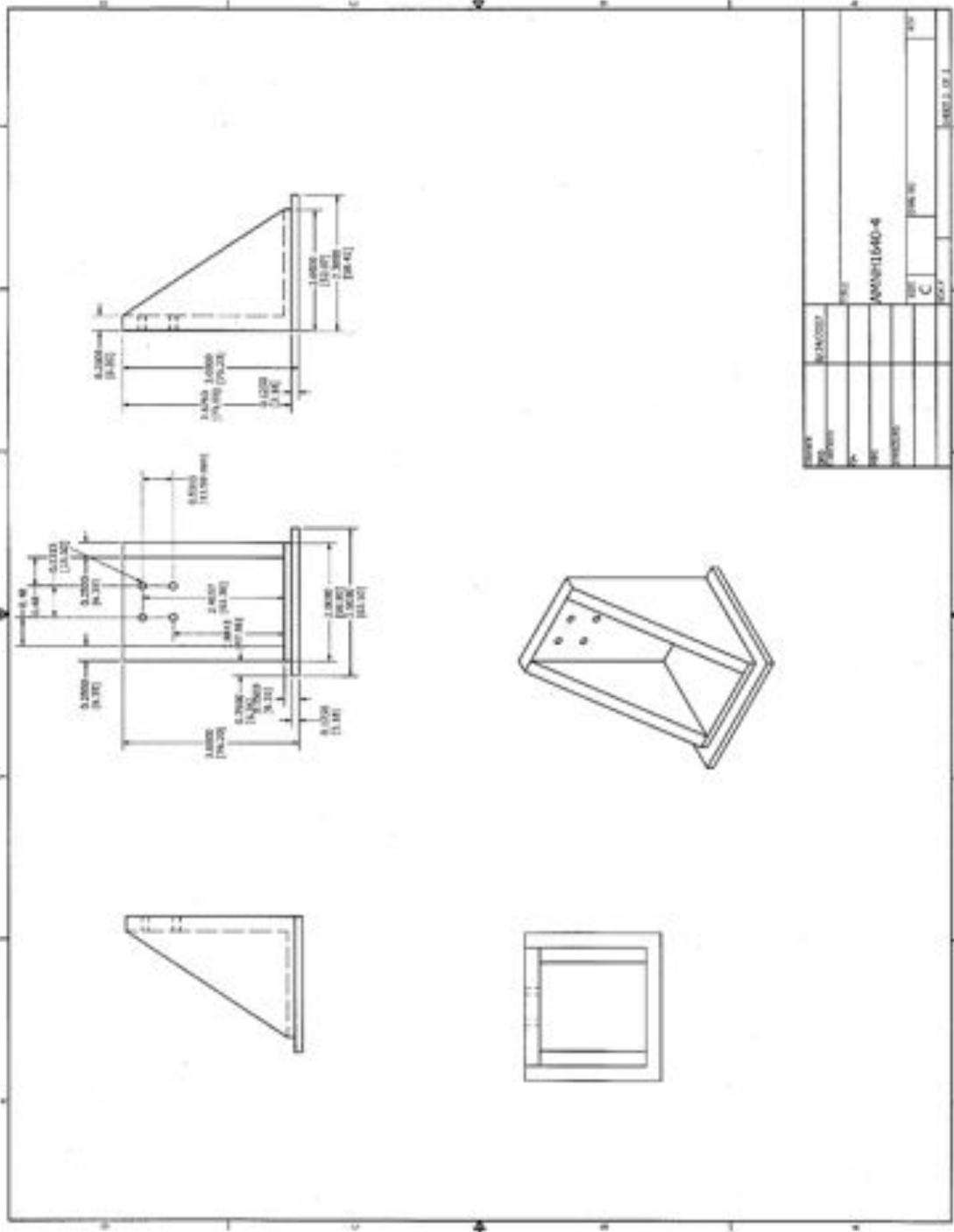
---

### 4.2. Coronagraph Optical mount Diagrams

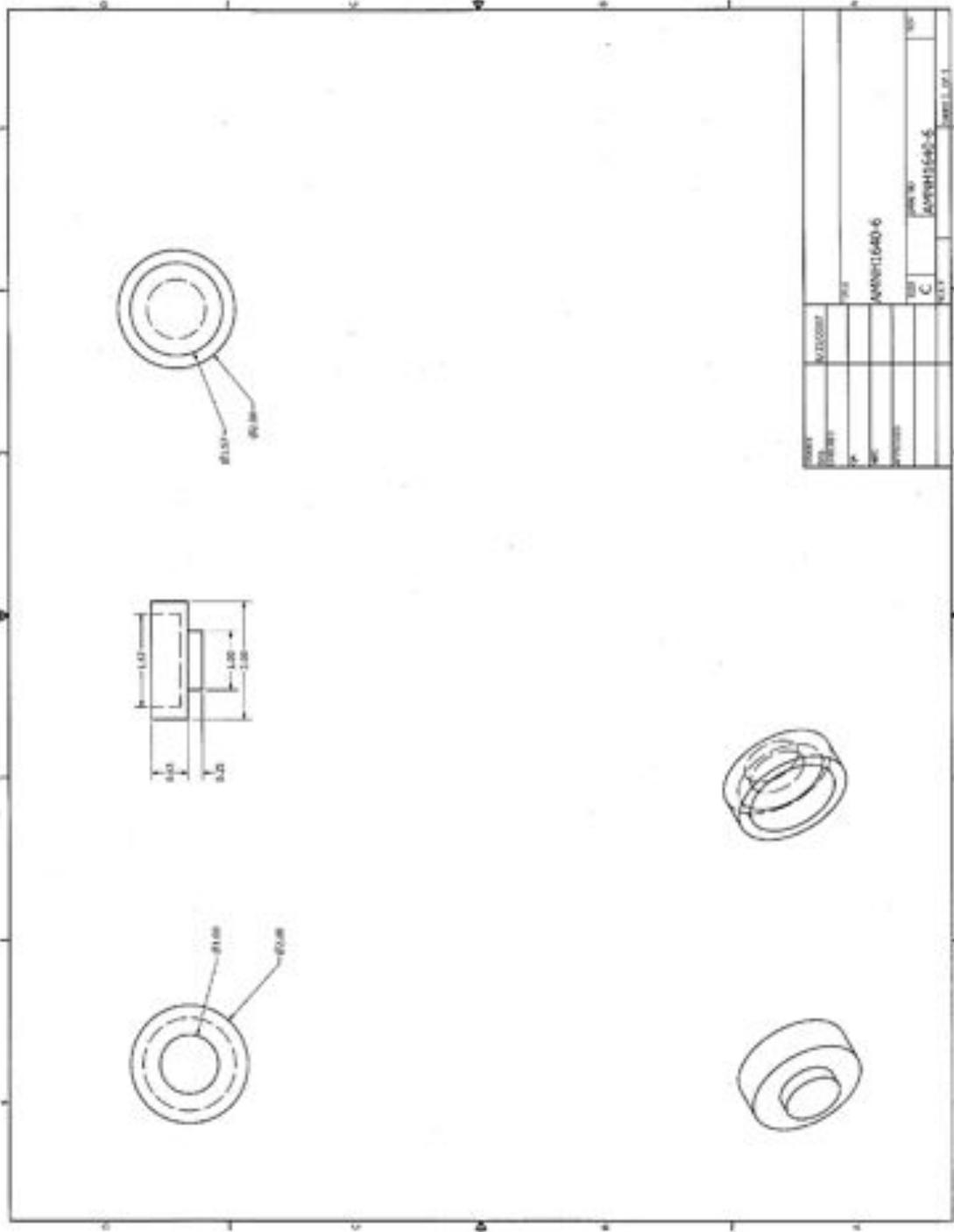




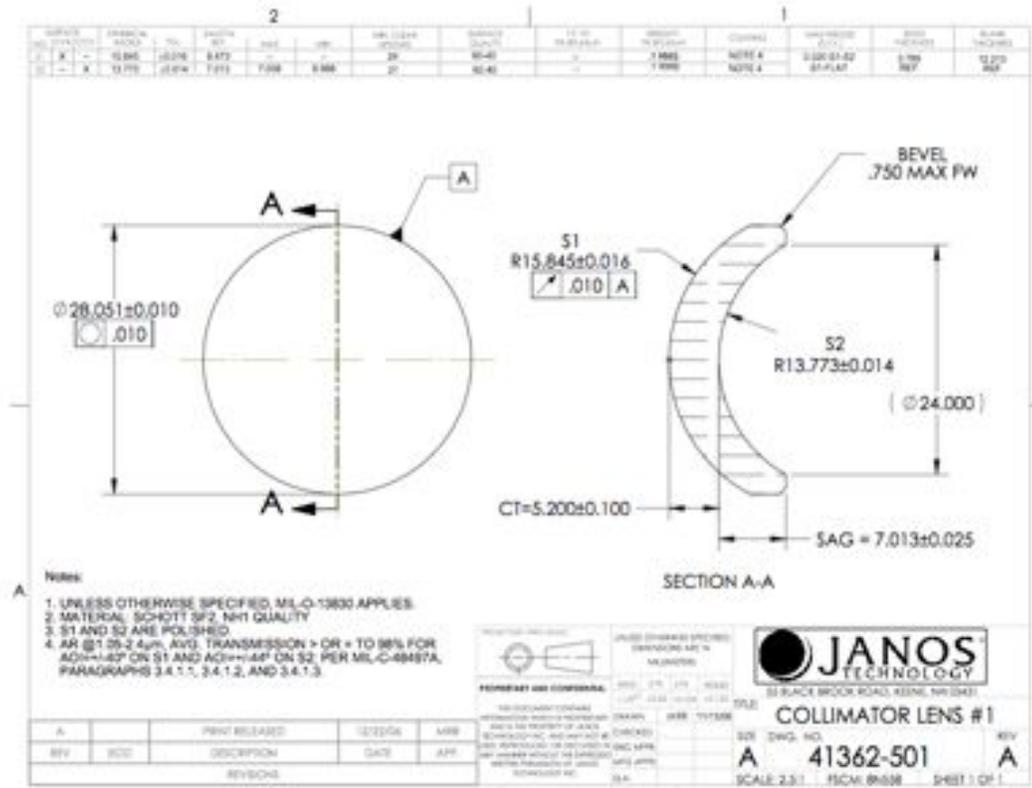


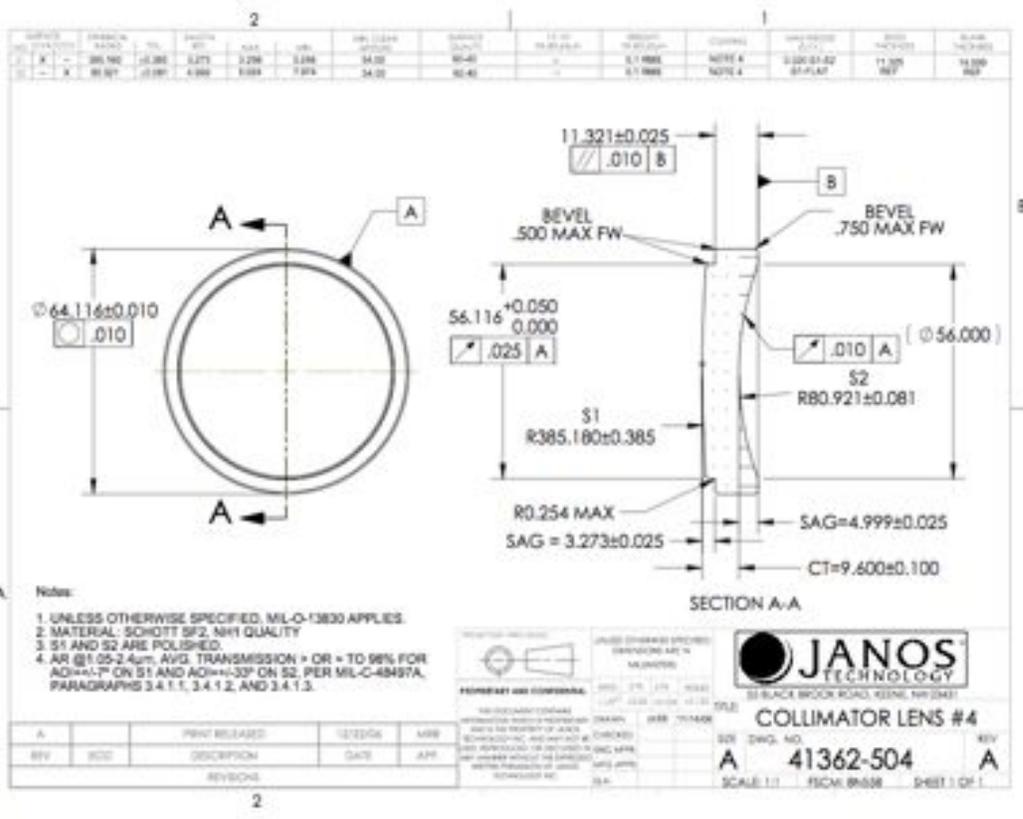
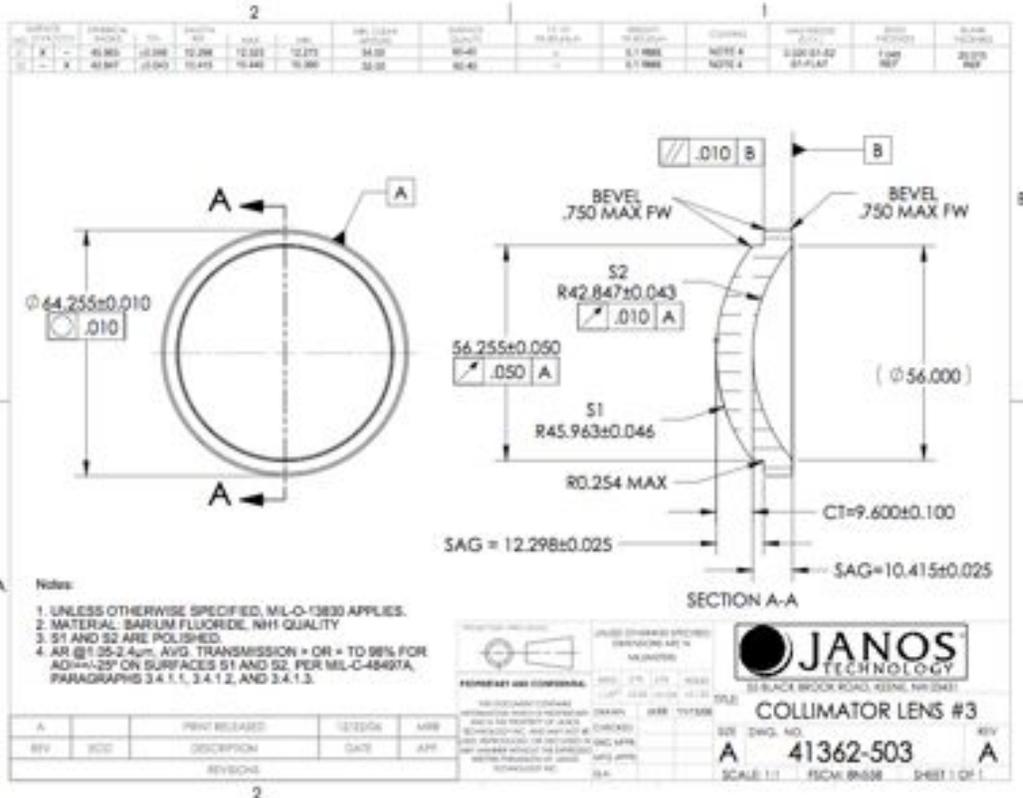


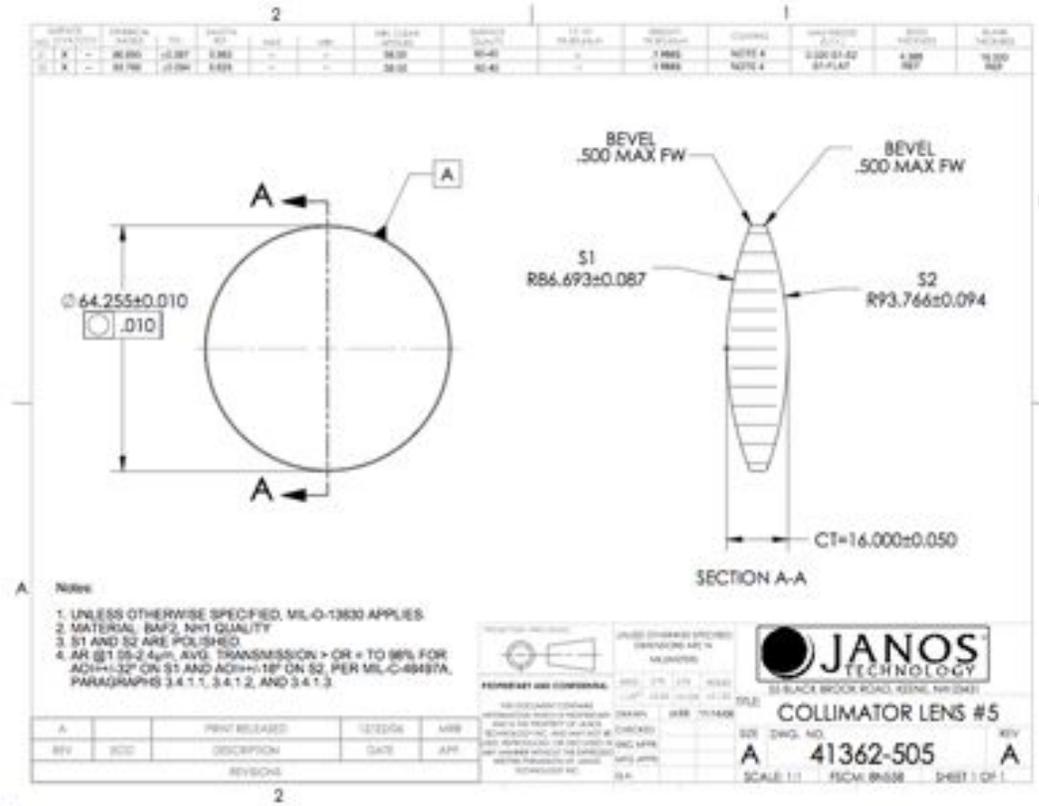




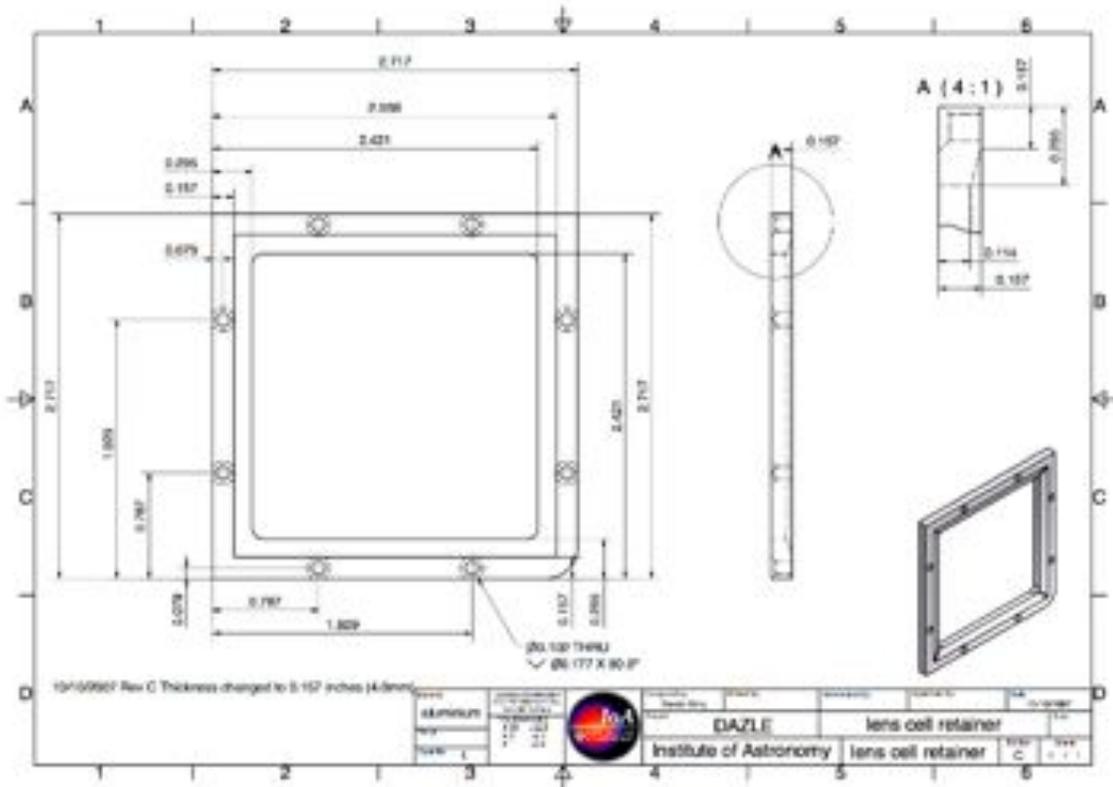
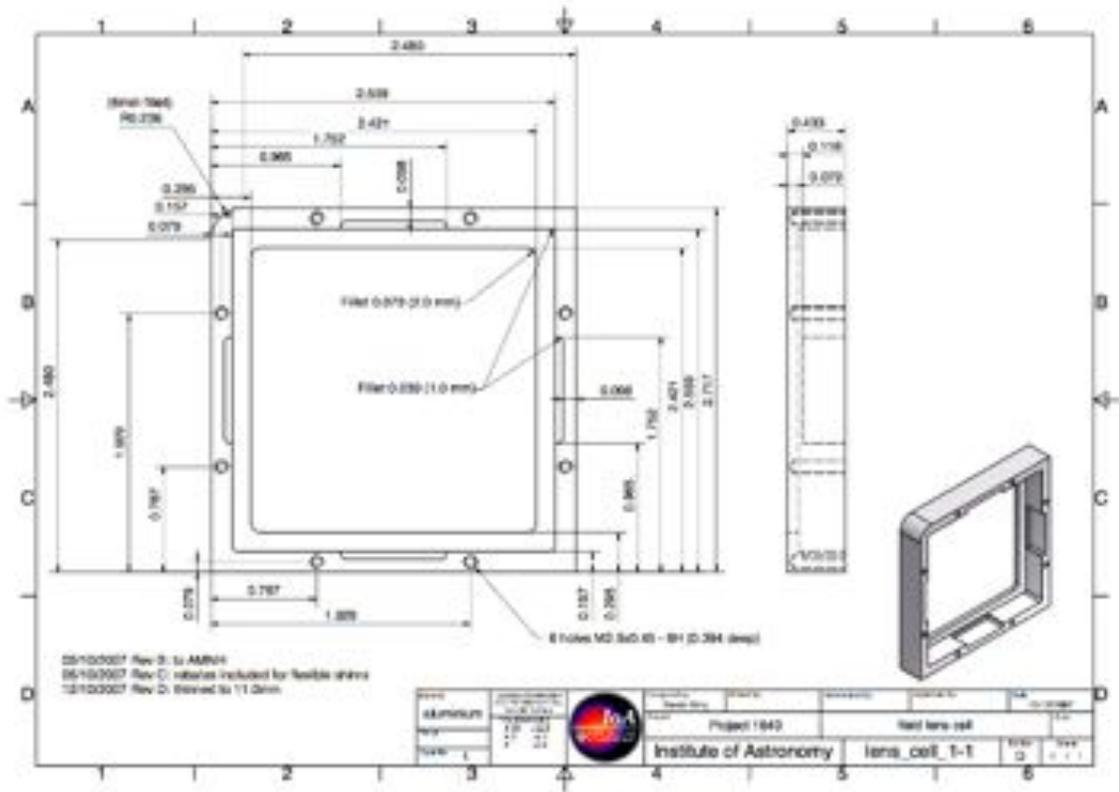
### 4.3. Collimating Optics Drawings

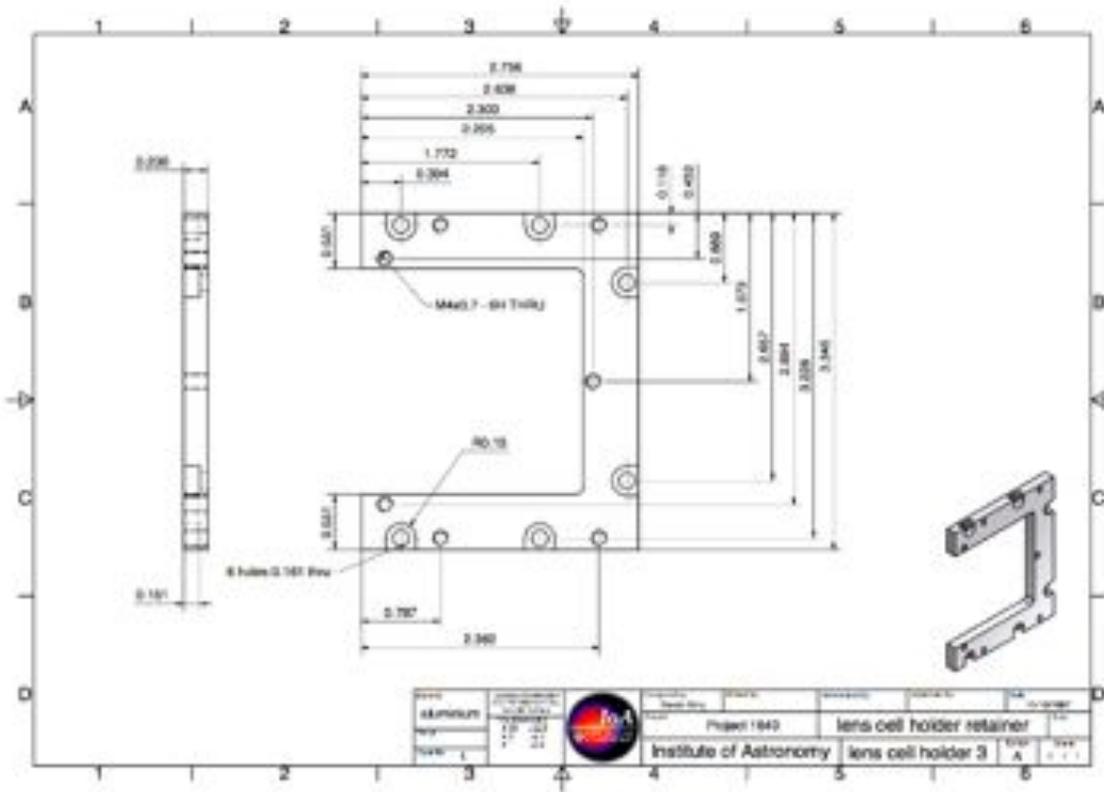














### 4.5. Detector Circuit Diagrams

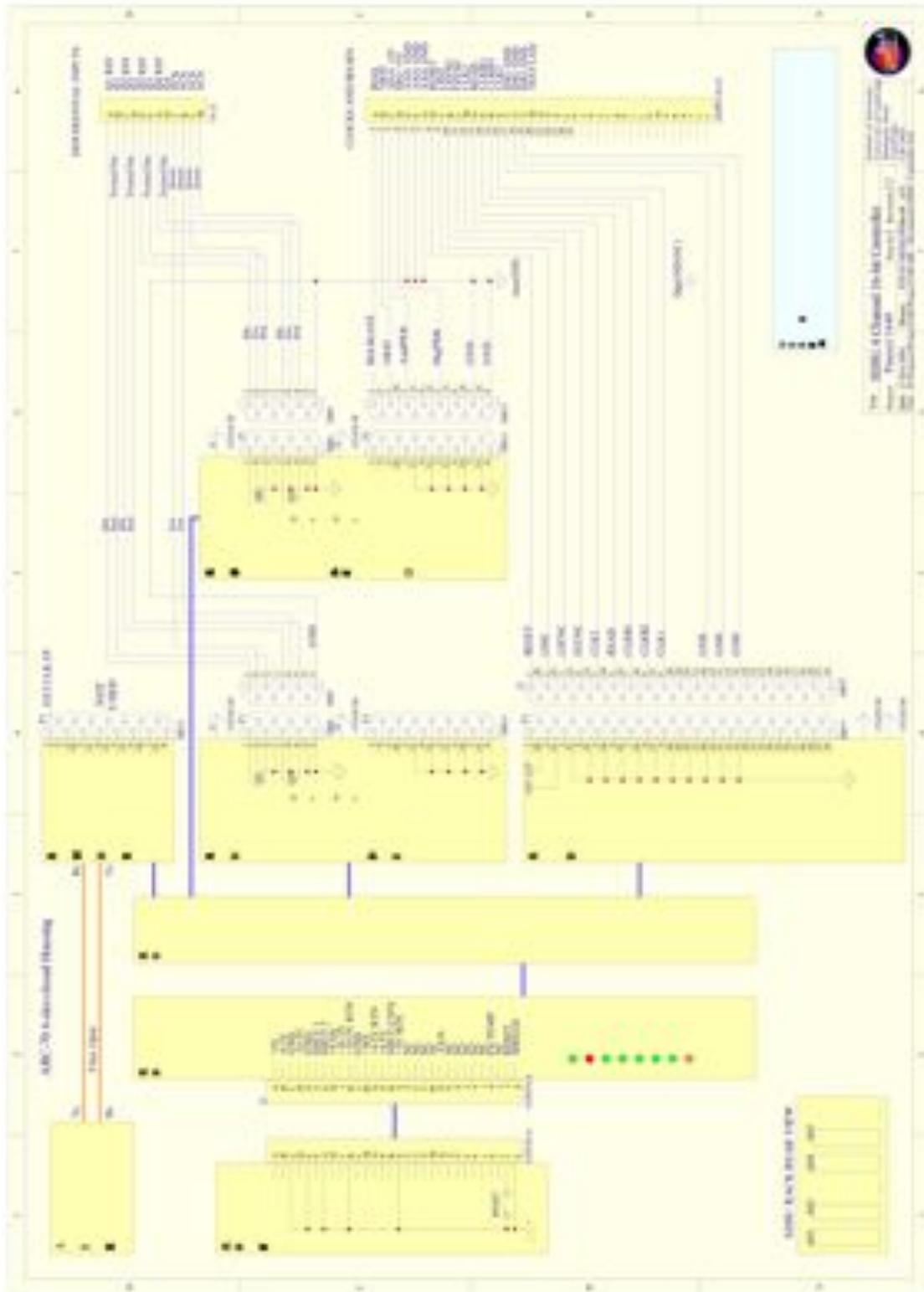


Figure 194. Wiring diagram for SDSU four-channel controller.



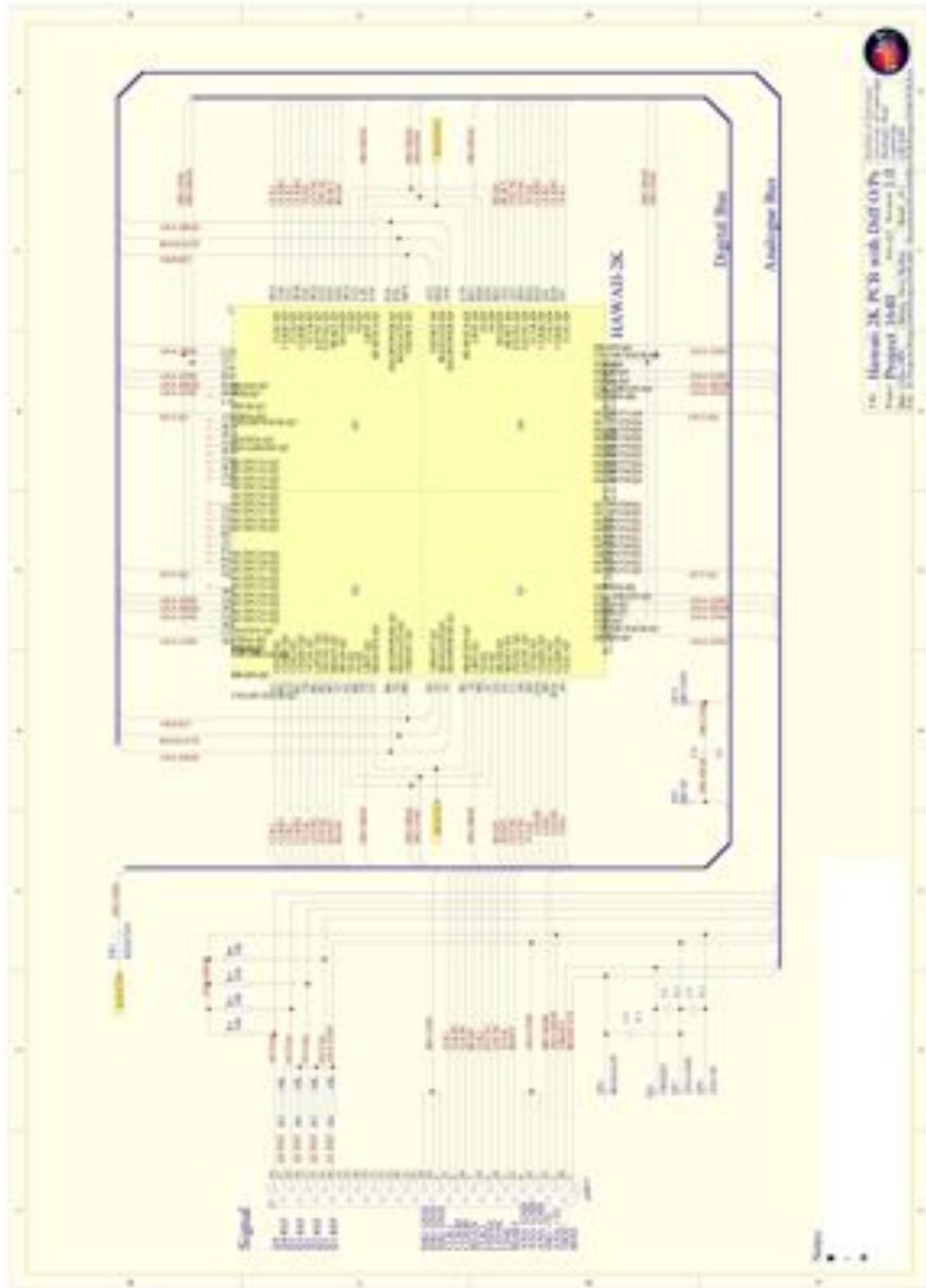
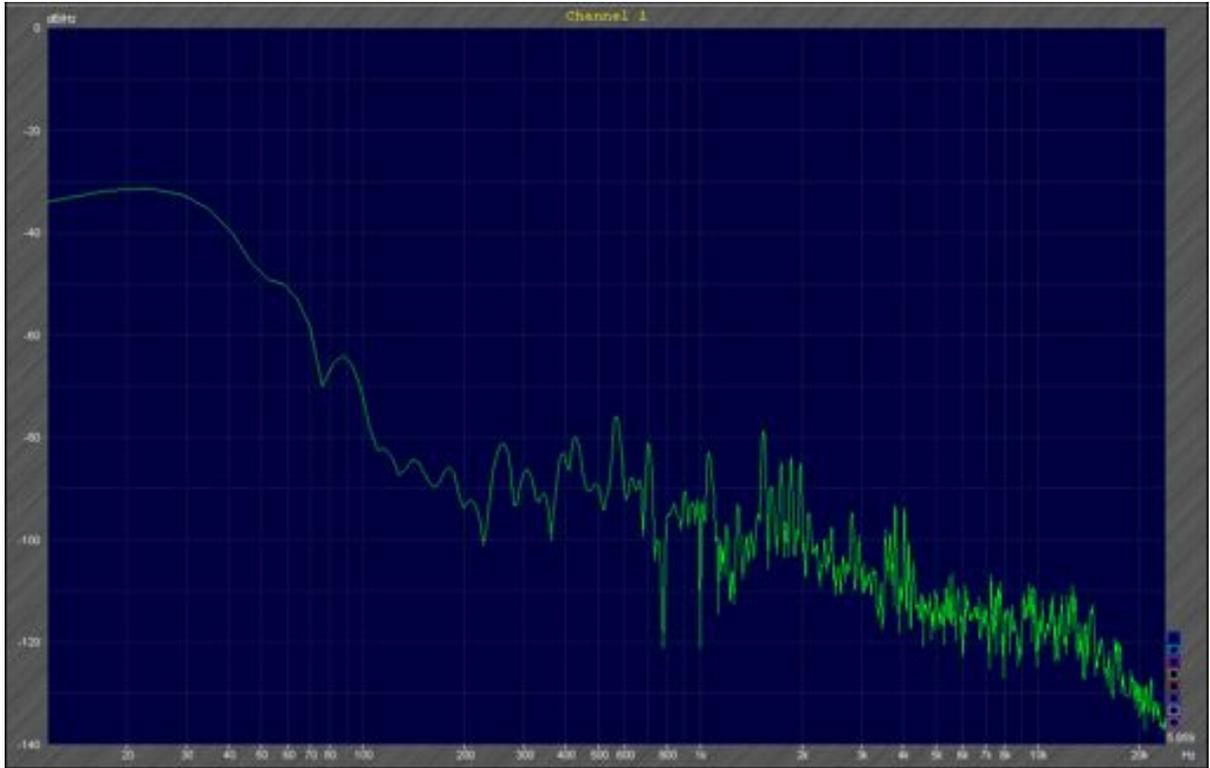
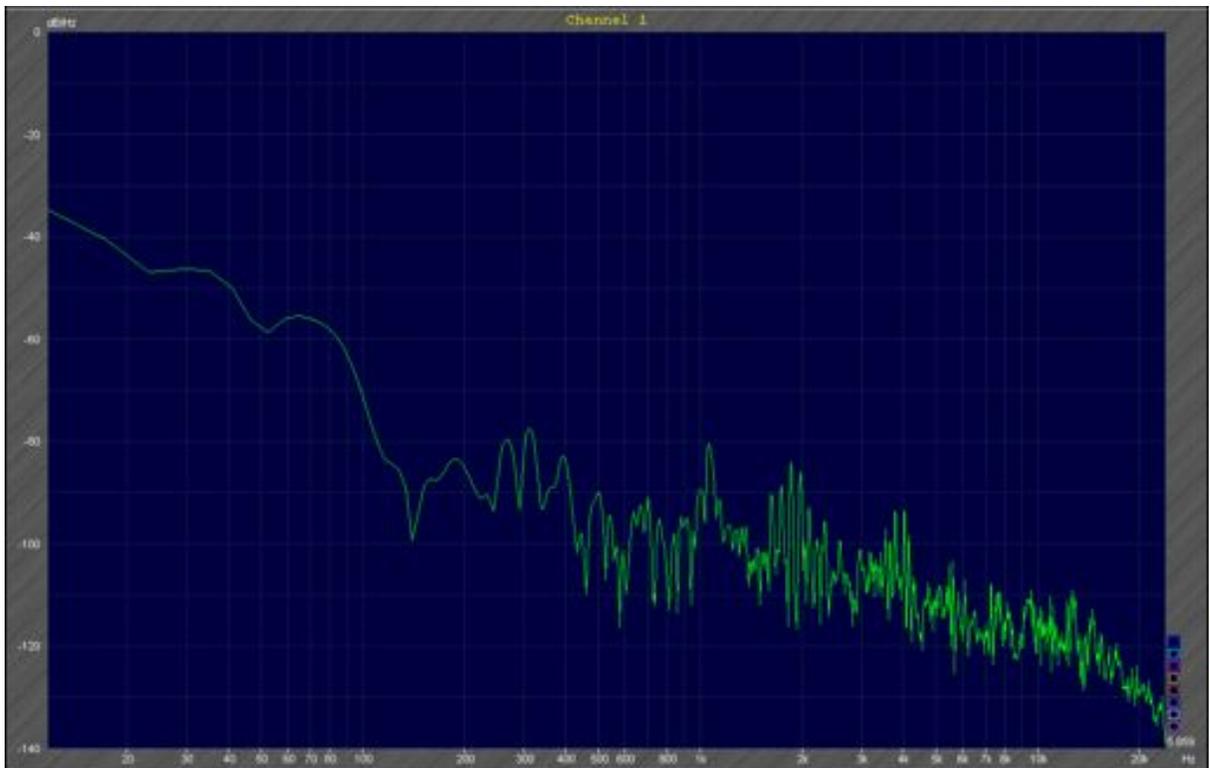


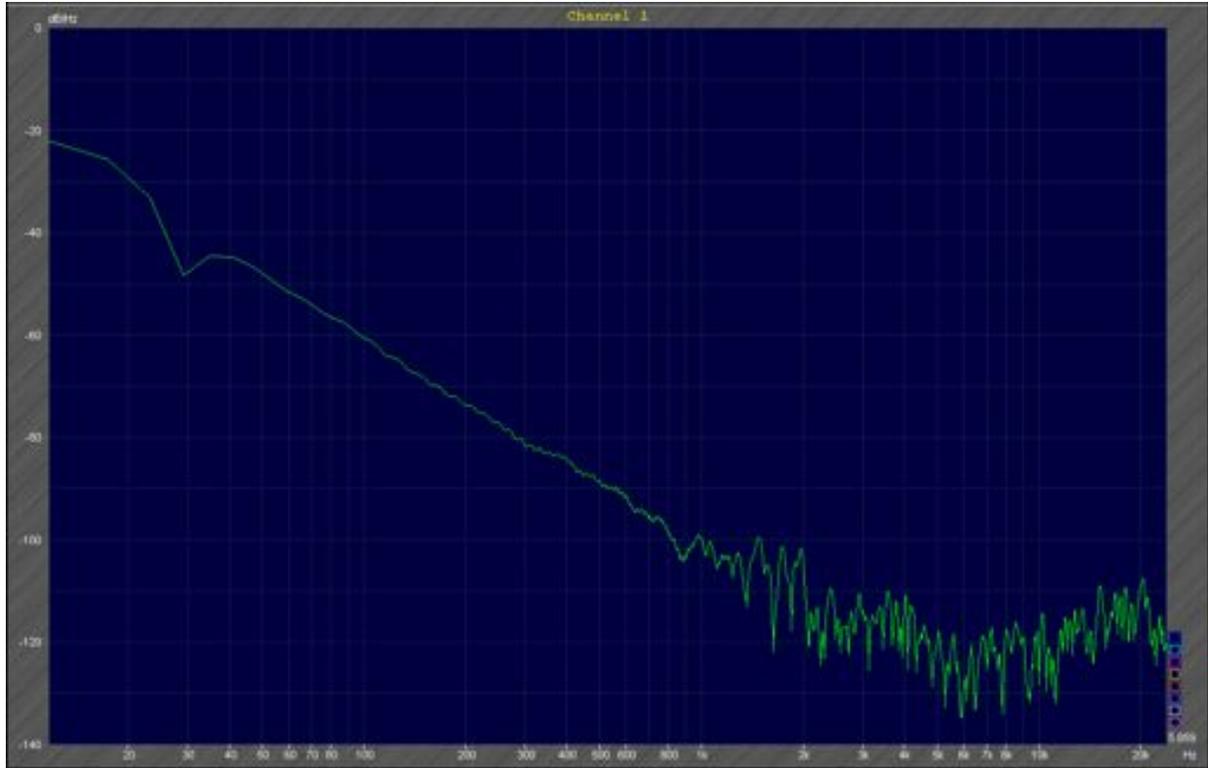
Figure 196. Printed Circuit board wiring diagram.



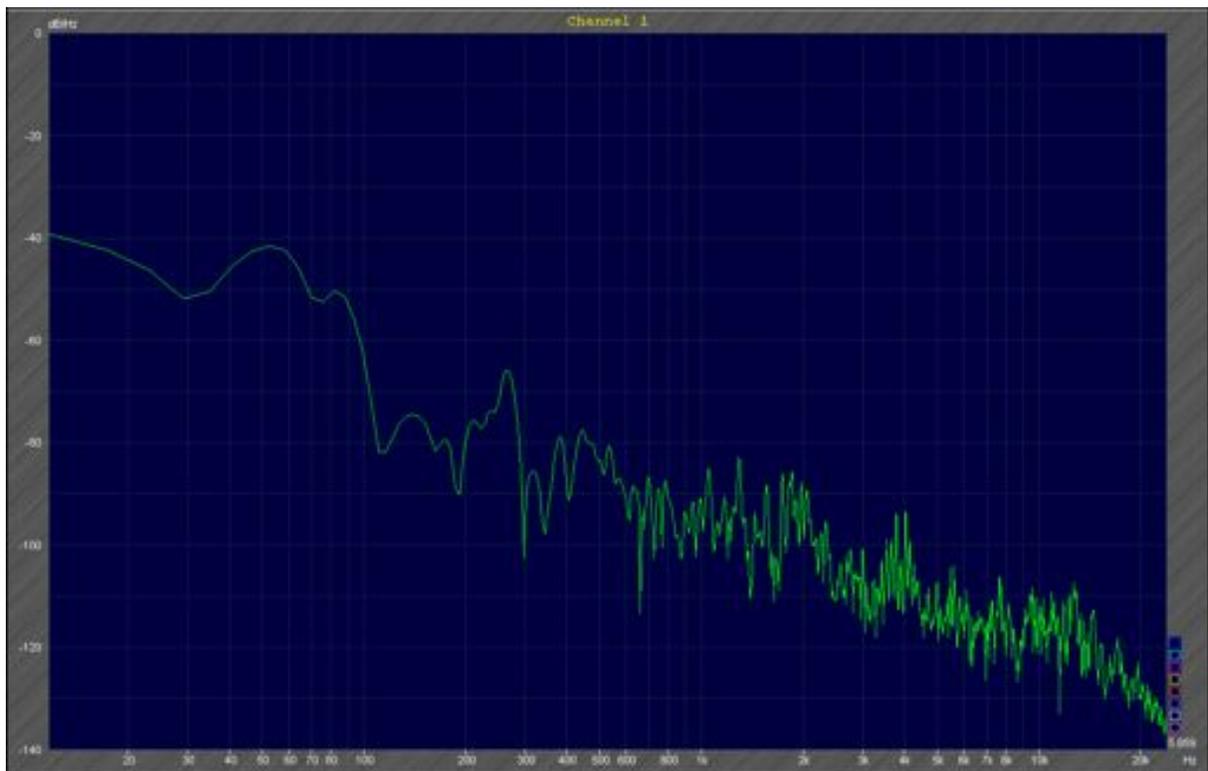
**Figure 197. Accelerometer measurements taken on the P1640 bench in longitudinal direction of the instrument, with no telescope tracking.**



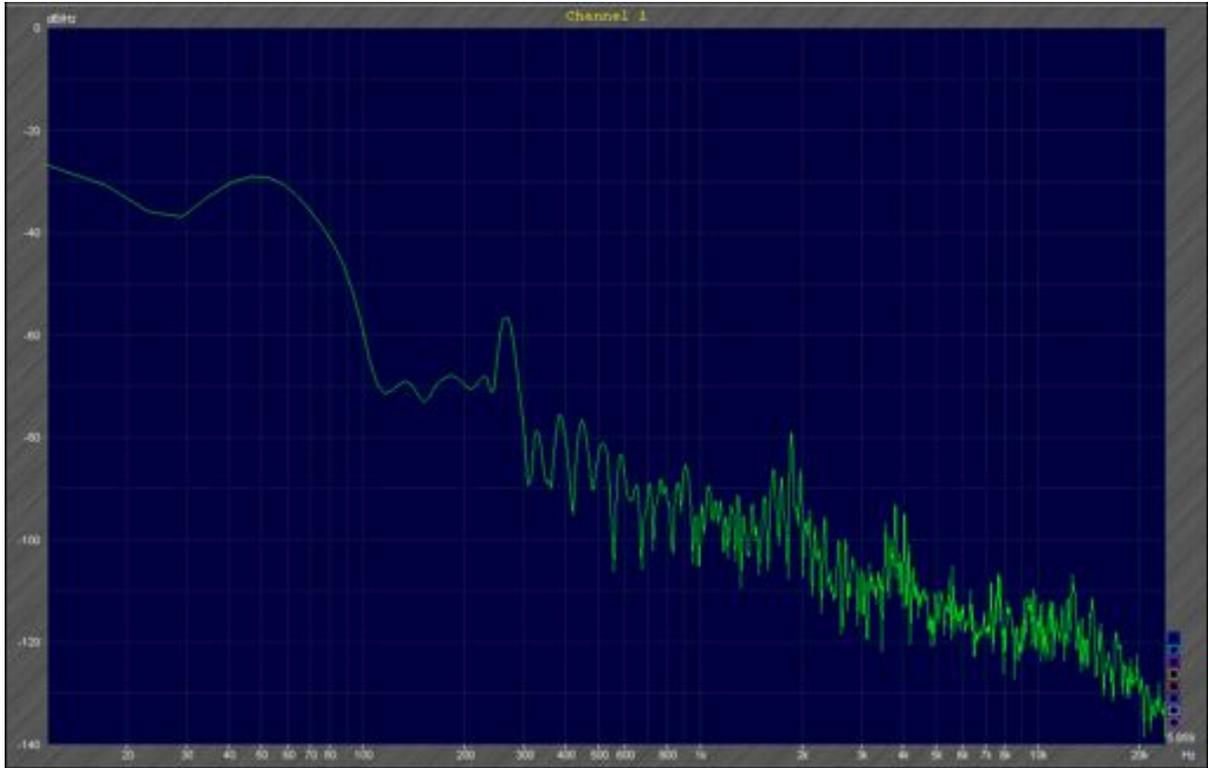
**Figure 198. Longitudinal measurement, with telescope tracking on.**



**Figure 199. Longitudinal measurement, with tracking on and dome spin.**



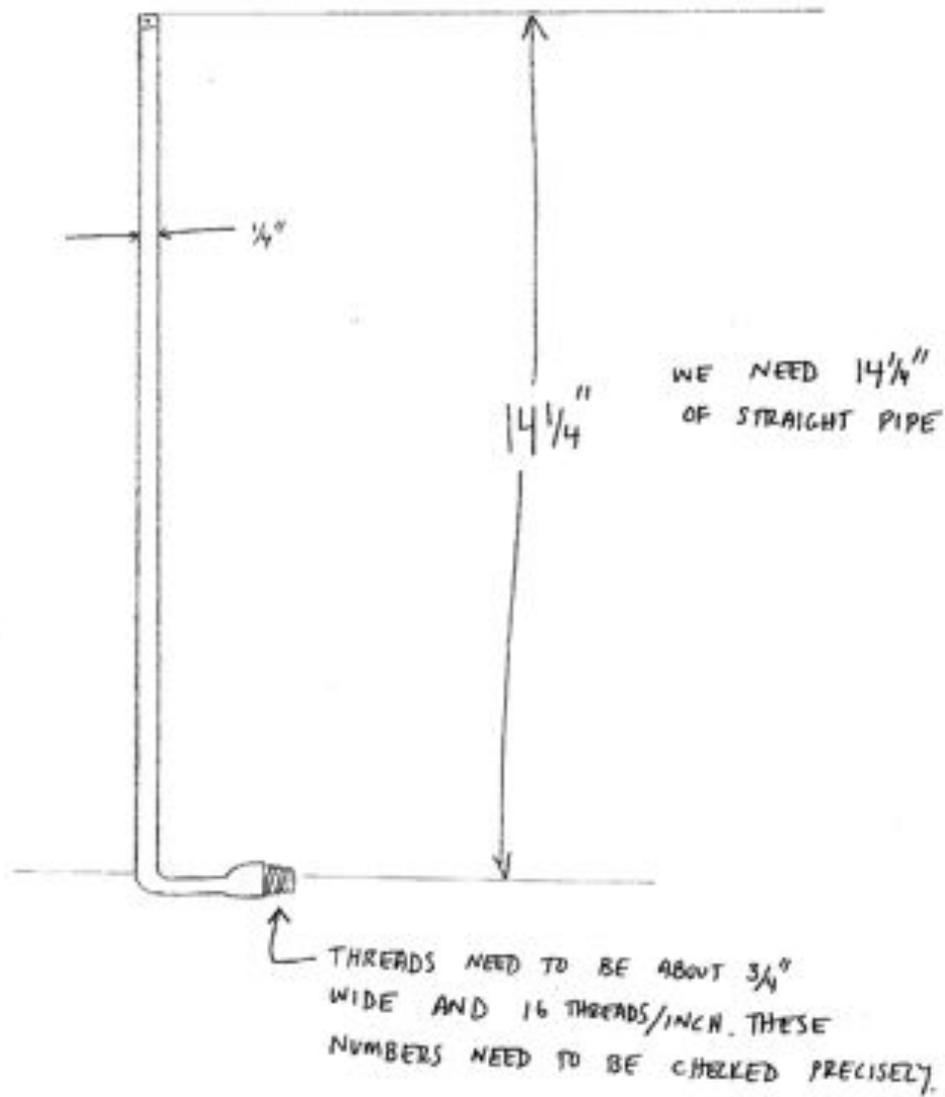
**Figure 200. Measurement along the telescope axis, with tracking on.**



**Figure 201. Measurement along the telescope axis, with tracking on, and spinning dome.**

#### 4.6. Miscellaneous Drawings

LN2 FILL TUBE



(2)

Figure 202. Liquid Nitrogen "stinger" used to fill the dewar.

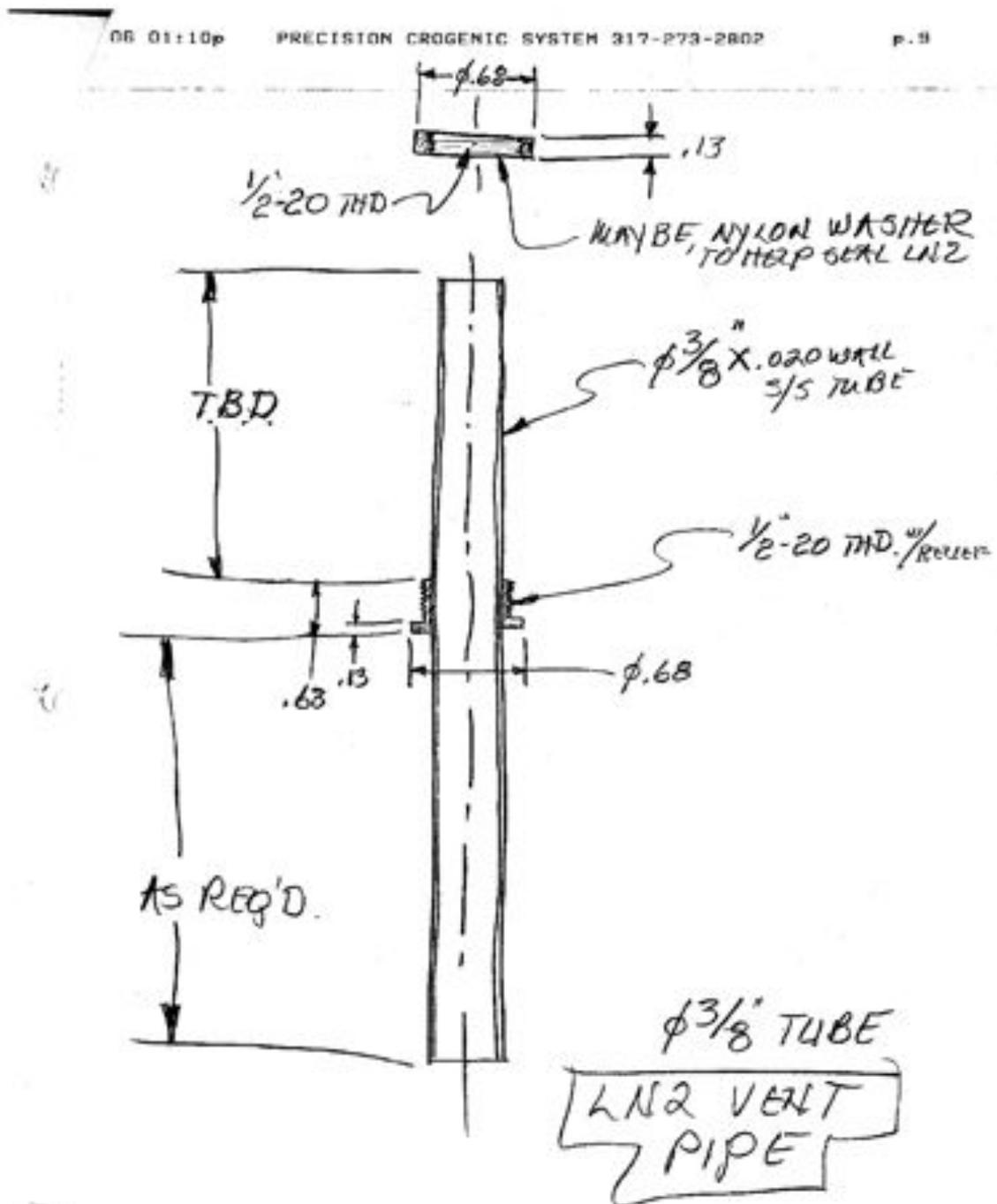


Figure 203. Design drawing for Liquid Nitrogen vent tubes. Both vent tubes have a nylon washer to seal the Nitrogen in the cans, and preventing draining.

## 4.7. Parts Inventory

### Project 1640 Part Inventory (updated: 7/7/08)

Item	Qty
<b>Primary</b>	
IFU+Coronagraph	1
Handling cart	1
Electronics rack	1
IFU+Coronagraph+handling cart crate	1
Electronics rack crate	1
Miscellaneous crate	1
<b>vacuum &amp; cryo accessories</b>	
KF40 to KF25 adapter	1
KF40 clamp	1
KF40 caps (blanks)	2
Lesker series 900 gauge controller	1
Custom KF25 dry Nitrogen adapter	1
LN2 vent tubes	2
<b>Electronics</b>	
1640 Control Computer	1
Control Computer keyboard, mouse	1 each
Tip/tilt Etronix computer monitor	1
3 button Mice	2
bag of fiber caps	1
Leach to detector plug cable	1
IR fiber (yellow)	1
IR fiber (orange)	1
Fibers for rack to cass patch panel	1
Pupil cam monitor serial: CIW16294	1
black Dell Keyboard	1
power cables	2
Detector resistors	3
<b>Tools</b>	
hex key set (non-metric)	1
hex key set (metric)	2
metric wrenches 10mm-15mm set	1
non metric wrenches 3/8" - 5/8" set	1
phil. Scwdrv, box cutter, wire cutter	1 each
magnum marker	1
exacto knife set	1
adjustable spacing optics ring remover	1
fixed spacing optics ring remover	1
mini mag lite	1
1/4-20 screw kit	1
Dewar/rad shield screws	1 bag each
8-32 nylon tipped steel screws	1 bag
6-32 screws (set and normal)	
<b>Palomar mounting hardware</b>	
mounting pucks	8
mounting half clamp (stationary)	4
mounting half clamp (moving)	4
<b>Calibration Hardware</b>	
Mercury vapor bulb	1
Mercury Lamp	1
1310nm Laser source	1
1550nm Laser source	1
<b>Miscellaneous</b>	
5" and 6.5" wide rubber sheets	2
Dewar window aluminum blank	1
Phosphor-Br sheets, .22, .36mm thick	1 each
.25" thick spacer plates, 1/4-20 holes	2
0.5" thick spacer plate, 1/4-20 holes	1
Velcro strips	1 pack
Dewar handling mech rail dummies	3
standard optical table clamps	several
1" enclosure corner blocks	6
1/4-20" enclosure block screws	many
Newport XE25T4 rail nuts	4
1/2-20 enclosure bolts	3 boxes
M6 screws: 16, 25, 30, 50mm	1 bag each
Adhesive black felt material	1 sheet
Corona Beer sign	1
Extra locking pin	1
shims (thickness?)	2