Evaluation, Design, and Construction of the Wallace Astrophysical Observatory Camera for Astronomical Observations

by

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Abstract

The goal of this thesis is to upgrade the scientific capabilities of the 24" Cassegrain reflector telescope at the George R. Wallace, Jr. Astrophysical Observatory (Wallace Observatory), part of Massachusetts Institute of Technology (MIT). The upgrade consists of evaluating, designing and constructing the Wallace Astrophysical Observatory Camera (WAOcam), optimized for 24" telescope. A full 3D model of the 24" telescope and dome was created to find the size restrictions for WAOcam. An optical model was also developed to maximize the field of view of the camera detector. WAOcam was designed using *SolidWorks* (3D modeling Software), the parts files from the designing process were also used to machine the instrument. The manufacturing of the WAOcam involved using the following: Computer Numerical Control (CNC) lathe, CNC mill, drill press, and a Waterjet (cutting machine). The manufacturing process also required learning of Omax (software for the Waterjet) and MasterCam 9.1 (software for the CNC lathe and CNC mill).

The resulting product is WAOcam, which consists of three modules: 1) vacuum dewar (houses a CCD detector), 2) shutter (controls when light hits the camera detector), and 3) filter wheel (modifies the light before hitting the detector).

The remaining work left on the WAOcam is the installation of two additional modules: 1) a four port instrument rotator and 2) a field rotator. This upgrade will allow for occultation observations, strip scanning surveys, and Kuiper Belt Object (KBOs) astrometry to be obtained using the 24" telescope.

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Table of Contents

1. Introduction 10
1.1. Background 11
1.1.1. CCD Detectors 11
1.1.2. Cassegrain Telescopes 13
1.1.3. Problems with the Current Camera (Apogee) 14
2. Project Description 15
2.1. Objective 15
2.2. Camera Requirements 16
2.2.1. Camera Parameters 16
2.2.2. Design Constraints 16
2.3. Requirements for Interfacing to the Telescope 17
2.3.1. Optical Diagram 17
2.3.2. Driver Motors 20
2.3.3. Space Constraints 20
2.3.4. Balancing the Telescope 21
3. Camera Components 22
3.1. Overview 22
3.2. Dewar 22
3.2.1. CryoTiger 23
3.2.2. Dewar Case 26
3.2.3. Back Lid 26
3.2.4. Electronic Connection 29
3.2.5. Front Lid 29
3.2.6. Dewar Window 31
3.2.7. Internal Components 32
3.3. Shutter 37
3.3.1. Shutter Mechanism 37
3.3.2. Casing 38
3.4. Filter Wheel 39
3.4.1. Filter Holders 40
3.4.2. Carousel 41
3.4.3. Casing 42
3.4.4. Filter Rotating 45
3.4.5. Removing and Adding Filters 47
3.5. Instrument Interfaces 49
3.6. Field Rotator 50
3.7. Four Port Instrument Rotator 51
4. Camera Specification 51
5. Current Status 52
6. Conclusion 52
7. Works Cited 53
8. Appendices 55

List of Figures

Figure 1 Charge Coupled Device General Layout 12
Figure 2 24" Cassegrain Reflector Telescope. 13
Figure 3 Images from Apogee Camera 14
Figure 4 Simplified WAOcam Schematics 15
Figure 5 Cassegrain Ray Tracing for WAOcam using *LensLab* 18
Figure 6 *LensLab* Ray Tracing: Behind Telescope 19
Figure 7 WAOcam on 24" Telescope at Home Position 21
Figure 8 24" Telescope: L) Assembly Inside Dome & R) Vertical Clearance. 21
Figure 9 WAOcam Assembled 22
Figure 10 Dewar Assembly 23
Figure 11 CryoTiger System 23
Figure 12 CryoTiger Head Thermal System 24
Figure 13 Cryohead Case. 25
Figure 14 CryoTiger Head: Capacity (W) vs. Temperature (ºC) 25
Figure 15 Dewar Case & Lid Components 26
Figure 16 Dewar Back Lid Design 27
Figure 17 Dewar Back Lid Exterior Face 28
Figure 18 Electronic Feed Through. 29
Figure 19 Dewar Front Lid 30
Figure 20 Dewar Window Holding Mechanism. 30
Figure 21 Dewar Window Transmission Curve 32
Figure 22 First CCD Mount Design 34
Figure 23 SiTe CCD Holding Mechanism 35
Figure 24 First Thermal Connection Design 35
Figure 25 Final Thermal Connection from Cryohead to SiTe 36
Figure 26 Shutter Mechanism 37
Figure 27 Shutter Casing 38
Figure 28 Shutter Casing Overlapping Joints. 39
Figure 29 Shutter Casing with Shutter Mechanism Inside. 39

Figure 30 Filter Holder Assembly 40
Figure 31 Filter Holder in Carousel 41
Figure 32 Corner of Filter Holder 41
Figure 33 Filter-wheel Carousel 42
Figure 34 Filter Wheel Fully Assembled Front and Rear View 44
Figure 35 Filter Wheel Rotation Mechanism 47
Figure 36 Filter Wheel Removal Alignment 47
Figure 37 Filter Wheel Removal Handle. 48
Figure 38 Filter Wheel Sliding. 49
Figure 39 Module Interface Assembly 50
Figure 40 Interface: Lock and Key 50
Figure 41 RC Optical System Inc. Field Rotator 51
Figure 42 Dewar Cryohead Assembly 63
Figure 43 Dewar: Front Lid Assembly Layout 73
Figure 44 Dewar: Case Assembly Layout 74
Figure 45 Shutter Assembly Layout 86
Figure 46 Shutter Signal Testing 105
Figure 47 Shutter Wiring Diagram 106
Figure 48 Shutter Signal Wave Form 107
Figure 49 Shutter Electronics: Circuit Board Layout 108

List of Tables

Table 1. 24" Optics Optimization from Janet Wu's Thesis (2000) 17

Table 2. Location of Supporting Instruments & Modules of WAOcam 19

Table 3. SiTe CCD Specifications 33

Table 4 Improvement for new Filter-Wheel Case 42

Table 5. Filter Wheel Case Assembly Pieces 43

Table 6 Filter-Wheel: Filter Control Parts 45

Appendices

Appendix A WAOcam Parts List 56

Appendix B Cryohead Drawings (CryoTiger Info Sheet) 60

Appendix C Cryohead (Drawing: W_D_H_v1) 61

Appendix D Cryohead Case (Drawing: W_D_Case v1) 62

Appendix E Cryohead Assembly Schematic 63

Appendix F Dewar Back Lid (Drawing: W_D_BL_v1) 64

Appendix G Hermetic Connection (Drawing: W_D_EI_v1) 66

Appendix H Hermetic Connection Pin Layout 67

Appendix I Hermetic Connection Wiring 68

Appendix J Dewar Case (Drawing: W_D_C1_v2) 69

Appendix K Dewar Front Lid (Drawing W_D_FL1_v1) 70

Appendix L Dewar Front Lid Lock (Drawing W_D_FL_clamp_v1) 71

Appendix M Dewar Window (Drawing: W_D_FL_G_v1) 72

Appendix N Front Lid Assembly 73

Appendix O Dewar Case Assembly 74

Appendix P Dewar Internal: ABS Plastic Raisers (Drawing: W_D_Interior_rods v1) 75

Appendix Q Dewar Internal: CCD Mount (Drawing: W_D_H2_v1) 76

Appendix R Dewar Internal: SiTe 2kx2k CCD (Drawing: W_D_E_SiTe) 77

Appendix S Dewar Internal: SiTe 2kx2k Manufacture Dimensions (SiTe 2kx2k 1994) 78

Appendix T Thermal Control: CCD Press (Drawing: W_D_TC_CM_v1) 79

Appendix U Thermal Connection: Cryohead Connection (Drawing: W_D_TC_C1_v1) 80

Appendix V Shutter Mechanism (Drawing: W_SC_Shutter Assembly) 81

Appendix W Shutter Case: Front & Back Plate (Drawing: W_SC_FB Parts) 82

Appendix X Shutter Case: Top (Drawing: W_SC_Top v1) 83

Appendix Y Shutter Case: Top/Power (Drawing: W_SC_TB_power part v1) 84

Appendix Z Shutter Case: Right & Left Plate (Drawing: W_SC_RL Parts V2) 85

Appendix AA Shutter Assembly (Drawing: W_D_C) 86

Appendix BB Filter Wheel: Holder (Drawing: W_Fw_Sliders_v1) 87

Appendix CC Filter Wheel: Carousel (Drawing: W_Fw_Carosel_v1) 89

Appendix DD Filter Wheel Case: Front & Back Plate (Drawing: W_Fw_Case_BS V3) 90
Appendix EE Filter Wheel Case: Top Bar (Drawing: W_Fw_Case_H_Top v2) 93
Appendix FF Filter Wheel Case: Right & Left Bar(Drawing: W_Fw_Case_H_R&L V2) 94
Appendix GG Filter Wheel Case: Bottom Bar (Drawing: W_Fw_Case_H_Bottom v2) 95
Appendix HH Filter Wheel Case: Covers (Drawing: W_Fw_Case_Control Covers v1) 96
Appendix II Filter Wheel Stepper Motor: 5728L-03S Lin Engineering 97
Appendix JJ Instrument Interfaces: Locks & Keys 98
Appendix KK Apogee CCD: SiTe 1kx1k Details (Wu 2002) 99
Appendix LL SiTe 2kx2k: Quantum Efficiency (%) vs. Wavelength (nm) (SiTe 2kx2k 1994) 100
Appendix MM SiTe 2kx2k: Temperature (K) vs. Dark Current (Electrons/Pixel/sec) 101
Appendix NN SiTe 2kx2k: SI424A Pin Definition (SiTe 2kx2k 1994) 102
Appendix OO SiTe Wiring Diagram From CCD to Electronic Control Box 103
Appendix PP Shutter Electronics Controls 105
Appendix QQ Optical Diagram *LensLab*: Wallace Camera.V19.nb 109
Appendix RR Excerpts from PT30 Datasheet 117

1. Introduction

In the last one hundred years, great improvements have been made in the field of astronomical detectors. Measurements evolved from what was seen by the astronomer's eyes (revealed to the rest of the world through drawings), to capturing light from astronomical objects on photographic plates, to the current technology of charge coupled devices (CCDs). Most discoveries have been made using high performance instruments that maximize the performance of a telescope.

The MIT George R. Wallace Jr. Astrophysical Observatory (Wallace Observatory), located in Westford, Massachusetts, houses three 14", one 11", and one 24" Cassegrain reflecting telescopes (Wallace Observatory Website 2007). While the four small telescopes are used for teaching purposes, the 24" telescope is often utilized for research oriented tasks. For example, in 2002 Dr. Stephen Slivan used the 24" telescope to calculate the "Spin Vector Alignment of Koronis Family Asteroids" (2002). Other projects have used the 24" telescope for: 1) Pluto-Charon occultation predictions (McDonald et al 1996), 2) asteroid light-curves (Slivan 2002), 3) astrometry for occultation prediction refinement, and 4) stellar occultations of Kuiper Belt Objects (KBOs).

In 2000-2006 the 24" telescope was renovated to update the drive mechanisms. The next step in the renovation was to upgrade the charge coupled device (CCD) camera. The new system replaces an off-the-shelf Apogee AP8p SiTe SI003AB 1kx1k camera (Apogee camera) which had problems from day one (Wallace Observatory Website 2007 & Apogee Instruments Website 2007). One of the main problems with the Apogee camera was the cosmetics of the CCD, the solution was to replace the CCD detector. Since the Apogee camera could not be easily modified for the new CCD detector, the solution was to make a new camera. In order to continue supporting the capabilities for innovative and creative research projects from Wallace Observatory, it was crucial to update the previous camera system, both to fix the issues with the Apogee camera as well as to increase the capabilities for future research goals.

The project consisted of constructing the Wallace Astronomical Observatory Camera (WAOcam), a new astronomical CCD camera for the 24" Cassegrain reflector telescope. The previous CCD detector on the 24" telescope at Wallace, the SiTe SI-003AB 1kx1k (Apogee camera) CCD, was replaced with the new detector, a SiTe SI424A* 2kx2k (WAOcam) CCD, superior in both quantum efficiency and field of view (SiTe Scientific-Grade CCD 1994).

Quantum efficiency, the sensitivity of the detector to photons, varies with the material properties of the detector surface (McLean 1997). For a given observation, the quantum efficiency influences the integration time, the amount of time that the CCD is collecting photons. Low-quantum efficiency detectors, like the SiTe SI-003AB 1kx1k (SiTe 1kx1k), require longer exposures (integration time) to obtain the same number of photon counts as a high quantum efficiency detector, like the SiTe SI424A 2kx2k (SiTe 2kx2k) (Wu 2000). The quantum efficiency of the SiTe CCD detector is twice that of the Apogee, thus cutting the amount of time to acquire equal quality images by half (McLean, 1997). A shorter integration time also means: 1) an increase in the quantity of data obtained, and 2) data that is less sensitive to changes in the sky conditions and image trailing for solar system objects.

* This is a custom CCD chip. The CCD chip used is the engineering CCD from the MagIC Camera in Las Campanas Observatory, in Chile.

Field of view, the area over which the CCD detector can take an image, increases with the physical size of the detector (McLean 1997). The SiTe 2kx2k CCD has a four times larger active area than the SiTe 1kx1k[†]. Therefore, the new SiTe detector sees a larger section of the sky, also known as increasing the solid-angle, hence increasing the number of stars in the range of the detector. Combining the increased solid-angle coverage with the increased quantum efficiency means that sky survey projects can be completed in one eighth of the time required by the previous system.

The camera upgrade improved on the previous facilities by a factor of eight, a factor of two in quantum efficiency and a factor of four in field of view. Hence, creating a new camera was a cheaper and more efficient way of increasing the scientific capabilities of the 24" at Wallace Observatory.

While the new WAOcam is superior to the Apogee camera there are future upgrades to the system that would further optimize the use of the 24" telescope. One future upgrade for WAOcam will be the addition of a field rotator. Another foreseen upgrade is the addition of a four port instrument rotator to incorporate a high speed camera for occultation work, POETS, with an E2V 47-20 CCD as the detector (E2V CCD 47-20). The instrument rotator would allow the user to switch between POETS and WAOcam electronically by flipping a mirror. The SiTe CCD and E2V CCD were designed for different astronomical applications. The SiTe is good for astrometry and differential photometry as it has a wide field of view, while the E2V is good for measuring high-speed light variations such as that seen in transits and occultations. The difference between the CCDs readout times and size of the active region illustrates how they are designed for different applications.[‡] Therefore having both cameras on the same telescope would improve the efficiency of the telescope usage, while at the same time minimize maintenance (or instrument change time).

1.1. Background

1.1.1. CCD Detectors

A CCD is a solid state chip containing a series of tiny, light sensitive photosites separated into pixels (MIR 2008). The device stores the data for an image as an array of pixels, which can be displayed by converting the number of counts in each pixel into electrical signals. Silicon is the primary material used to create the potential wells, created through a series of column implants (vertical confinement) and electrodes (horizontal confinement; Space Research Station 2007). Silicon is the material of choice because it is sensitive to photons from the ultraviolet (400nm) to the near-infrared (1100nm). Boyle & Smith describe the CCD essentially as a "monolithic semiconductor shift register in which the shifted information is in the form of a charge packet stored on a capacitor" (1970).

† The active regions for the SITe 1kx1k and SITe 2kx2k CCD respectively are :24.6mmx24.6mm and 49mmx49mm. Hence the new CCD has four times area of the old detector.

‡ The SiTe CCD has a read out time of 25 seconds, while the E2Vs read out time is only 0.7 seconds. The advantage of SiTe chip is the large active area of 49 mm by 49 mm, compared to the E2Vs 13.3 mm x 13.3 mm (SiTe CCD, E2V CCD).

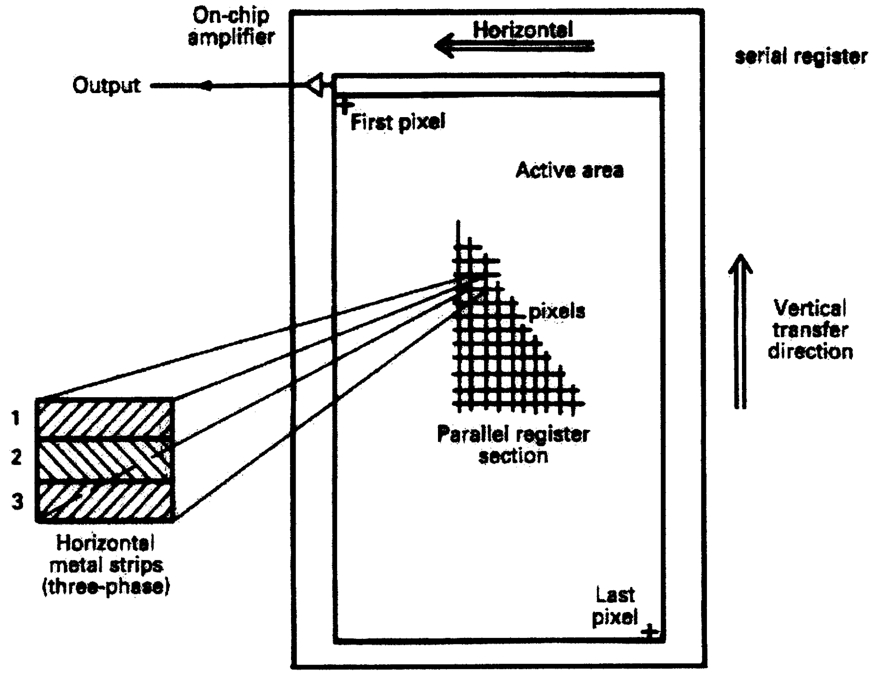


Fig. 6.6. The general layout of a CCD showing numerous square pixels laid out in a grid.

Figure 1 Charge Coupled Device General Layout

General layout for a CCD showing a standard pixel layout, active area, and readout. The image is from Electronic Imaging in Astronomy by McLean pg 139.

The CCD converts photons to electrical signals using the physical properties of Silicon. Photons that penetrate the silicon surface of the CCD create hole electron pairs. The number of hole-electron pairs created depends on: 1) wavelength (photon energy), 2) intensity (number of photons), and 3) exposure time (length of time exposed to light; McLean 1997). Every individual pixel collects the electrons as they are created. The number of electrons collected in each pixel corresponds to the light intensity projected onto the sensor at that point. The counting error given by the Poisson distribution is the squared-root of the total number of counts (McLean 1997). For more information regarding the operations of CCD detectors see chapter six in *Electronic Imaging in Astronomy* by McLean (1997).

There are several properties to consider when comparing CCD detectors which include: 1) quantum efficiency, 2) dark current, 3) read noise, and 4) cosmetics (surface quality of the active area of the CCD). Quantum efficiency is the sensitivity of the CCD, determined by the ratio between the counts emitted of a known source and the counts detected. Having a high quantum efficiency detector decreases the time required to acquire an image. The quantum efficiency of a CCD varies with the wavelength of the detected photon. This component is also device dependent; each CCD has a unique characterization. Dark current is the amount of background noise due to temperature; hence, lowering the operating temperature of the CCD minimizes the effects of dark current. The read noise is created by the resistance in the capacitors which reflects as noise added by the electronics in the CCD. The amount of read noise is directly correlated to the exposure time. For short exposures the read noise is low, and vise versa. The fourth consideration is the cosmetics of the CCD, which can drastically affect the image quality. Bad pixels or pixel columns, arcs on CCD, and coating are just some qualities of the CCD cosmetics.

1.1.2. Cassegrain Telescopes

A Cassegrain reflector telescope focuses optical light by using a parabolic concave primary mirror with a hyperbolic convex secondary mirror. The size of the Cassegrain telescope refers to the diameter of the primary mirror, the limiting factor on the amount of light that gets collected.[§] Figure 2 shows the layout for the 24" Cassegrain telescope at Wallace Observatory.

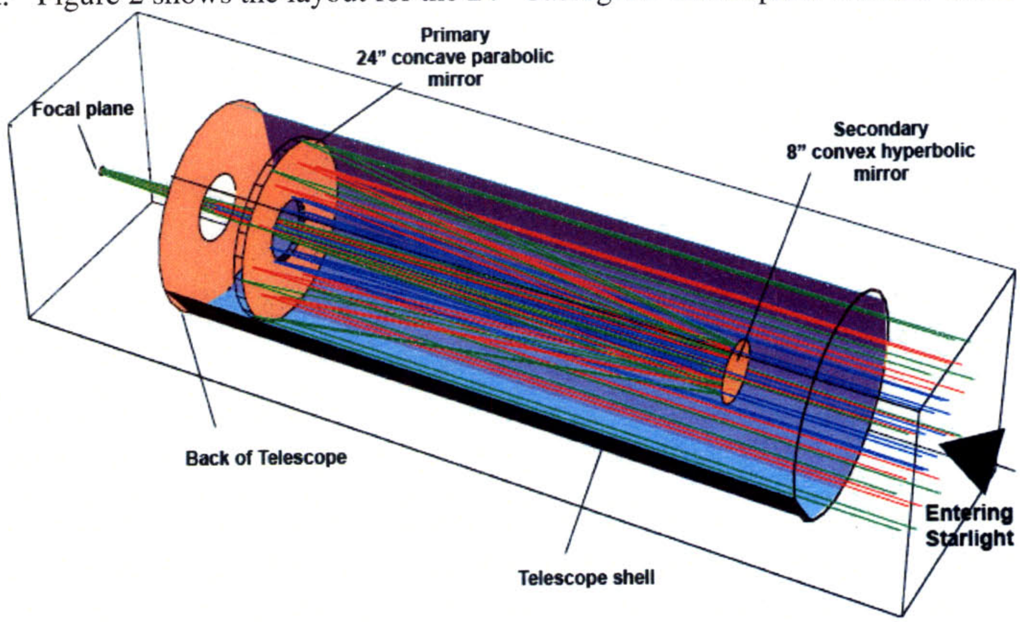


Figure 2 24" Cassegrain Reflector Telescope.

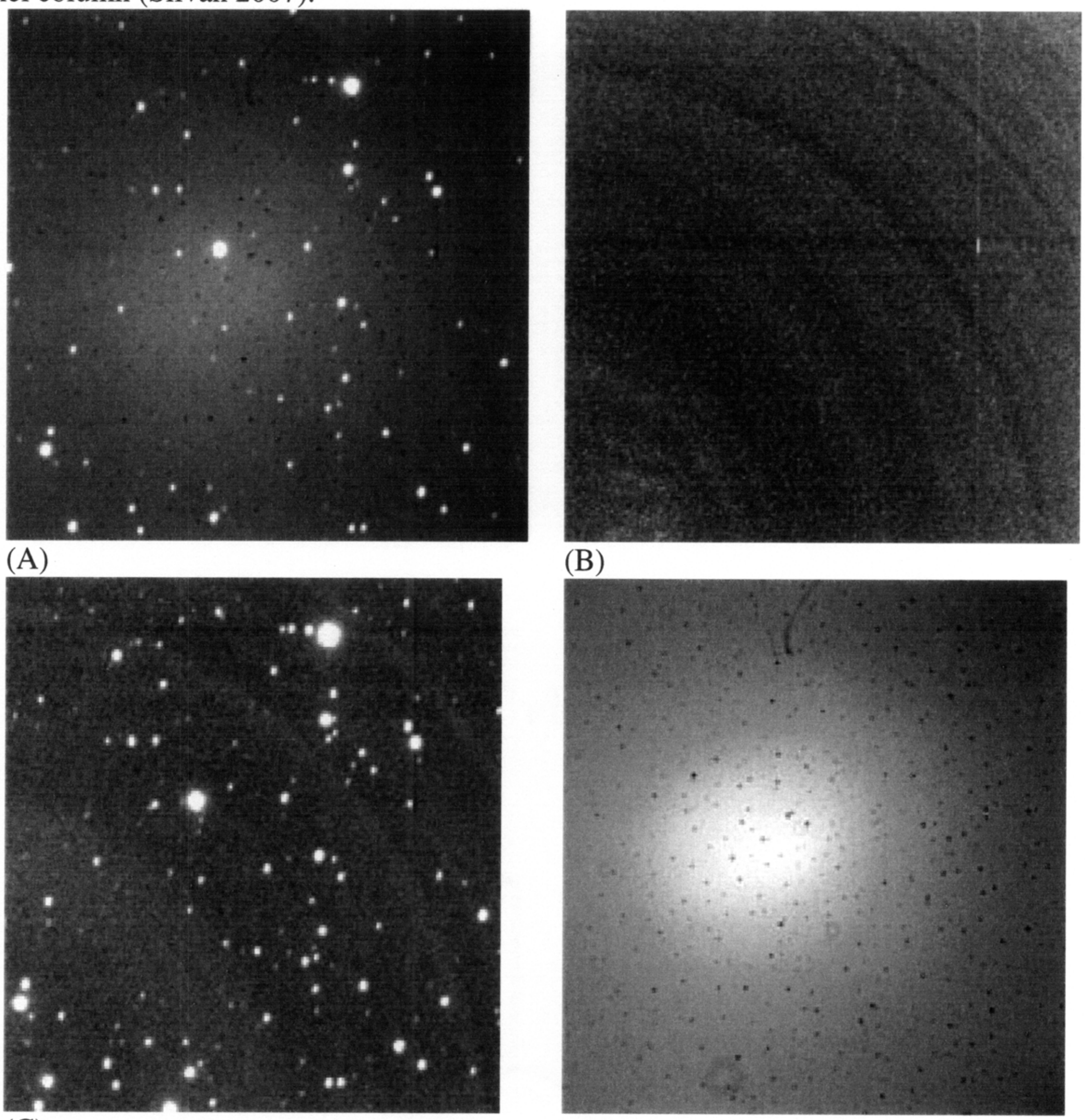
The green lines trace the light path at the edges of the primary parabolic mirror. The light rays bounce off the primary mirror onto the secondary hyperbolic mirror, which focuses all rays at one plane, the focal plane. The blue light rays trace the light path at the inner diameter of the primary mirror. The red light rays trace the midway between the center and the edge of the primary mirror. Note that all colors converge in the focal plane to the left.

The optical light focuses at the back of the telescope in a plane, referred to as the focal plane. Light detectors, placed at the focal plane, in the form of an eyepiece, photographic plate, digital camera, or other astronomical camera (such as a spectrograph or high resolution imager) collect this light which is then used to determine properties of the observed object. A series of electronic components and software processes the signal to produce an image. The images are used to determine sizes, variations, trajectories, and atmospheric compositions of solar-system bodies, stars, galaxies and other celestial objects.

[§] The size of the telescope also limits the absolute image quality due to diffraction, although changes in Earths atmospheric conditions pose a greater problem to the quality of the image.

1.1.3. Problems with the Current Camera (Apogee)

The images collected using Apogee AP8p were of poor quality, which made the camera unsuitable for astronomical imaging. The four main problems identified by Dr. Stephen Slivan with the Apogee camera include: 1) a number of "small, high-contrast, sharp-edged spot defects … in every light frame," 2) "a quarter-circle light and dark arc … across every image of nonzero integration time," 3) the appearance of residual bright objects on subsequent images, and 4) a bad pixel column (Slivan 2007).



(A) (B) (C) (D)

Figure 3 Images from Apogee Camera

All of the following images, taken by Dr. Steve Slivan, show the flaws of the Apogee camera. (A) Sample image from the Apogee camera showing quarter arcs bands, residual bring stars, and the radial dark dots. (B) Dark image showing only the arcs. (C) Regular image showing the residual bright stars from a previous image. (D) Flat image showing the "small, high-contrast, sharp-edged spot defects" (Slivan, Wallace Observatory Website).

As shown in Figure 3 the flaws in the Apogee CCD significantly impact the signal to noise ratio (SNR) of the data. It was believed that some of the flaws could be removed in the image processing phase before analyzing the data. However, it was found in 2002 by Janet Wu that this was not the case for all of the problem elements. The ¼ dark arcs in the image can be removed by subtracting the dark counts from the image. A similar process was done to remove the radial dark dots; however, it was concluded that the dark spots depend on the level of illumination. Another complication is that some of the black dots cover the light detected from stars hence introducing counting errors into the analysis process. Therefore, removing the flat image from the sky observation does not remove the effects of the dark spots. For more information regarding the effects of the dark spots and the attempts to remove them see Janet Wu's 2002 thesis (2002).

The most difficult to remove blemish, created by flaws in the Apogee Camera, is the residual bright stars from previous images. It is difficult to differentiate between the residual bright stars and the stars that are supposed to be in the image especially as stars get fainter.

2. Project Description

2.1. Objective

The objective of this project was to design and build the WAOcam. The main driving power behind this project was the availability of the SiTe CCD to replace the Apogee CCD. WAOcam includes a shutter (limits the exposure time), and a filter wheel, which allows the user to change filters between exposures. The camera was divided into four components: 1) dewar, 2) shutter, 3) filter wheel, and 4) interfaces, each with its own requirement. Figure 4 shows a simplified schematic layout of the WAOcam.

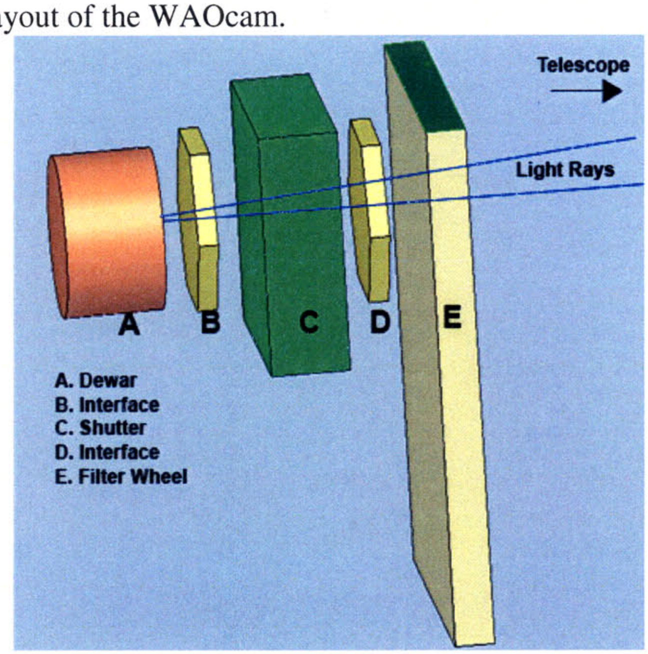


Figure 4 Simplified WAOcam Schematics

A second objective was to allocate space for future upgrades to the camera such as the addition of a field rotator, for strip scanning, and a four-port instrument rotator, for additional detectors on the 24" telescope. Both the field rotator and four-port instrument rotator are discussed only briefly in the optical design section of this document, since they are future developments and not part of this project.

2.2. Camera Requirements

The engineering requirements were dictated by the desired scientific capabilities of the camera and projected future upgrades outside of this project.

2.2.1. Camera Parameters

The first and foremost requirement for the WAOcam was to utilize the full field of view of the SiTe CCD, hence no vignetting[**]. Provisions also had to be made to have a filter wheel with six filter slots. The camera design had to also allocate space for future upgrades such as the field rotator and instrument rotator. The instrument rotator is going to be used to mount a Portable Occultation, Eclipse, and Transit System (POETS), on one port and an eyepiece in the other (Souza et al 2006). The long term goal is to use the WAOcam for remote observations; therefore, every part of the WAOcam should have the capability to be controlled electronically.

2.2.2. Design Constraints

The clear optical path for WAOcam was determined by the unvignetted criteria, using an optics model of the 24" telescope. The size of the camera was determined by the physical space available in the telescope dome.

The dewar, the enclosure that harbors the CCD detector, had to satisfy the following requirements: 1) it needed to be light tight, 2) it had to be fully vacuum sealed, and 3) the interior had to be cooled to -120 °C in order to minimize dark current in the detector. Light leaks into the dewar result in high background noise and false signals from the CCD. The vacuum seal serves to prevent water condensation on the CCDs surface which is much colder than the ambient temperature. The dewar must be cold in order to reduce the dark current, and improve the efficiency of the CCD. The dewar must be cooled by a high efficiency cooling unit such as a CryoTiger® cooling unit (CryoTiger Users Manual).

In addition to the light tight requirement, the shutter had to also be mechanically rigid. Meaning that the forces and torques induced by the dewar does not deflect more than 0.005" or ~103μm. If the deflection were larger than the allocated value (~103μm) the image would contain bent arcs.

The filter wheel also had to be light tight and load bearing[††]. In addition, the filter wheel needed the capabilities to house six square filters, and be controlled both electronically and manually. The user had to be able to change the filters, and add additional filters to the instrument. The total allocated deflection through out WAOcam is .010" or (~200μm).

[**] Vignetting is the reduction of field size, caused by an obstruction in the light path to the active region of the CCD detector (Wu 2000).

[††] Load bearing refers to the capability of transferring torques and forces to the back of the telescope.

2.3. Requirements for Interfacing to the Telescope

2.3.1. Optical Diagram

An optical diagram of the 24" telescope was completed in *LensLab*, a *Mathematica* ray-tracing package (Mathematica: LensLab 2007). The optical model helped determine the minimum aperture size of each component to acquire an unvignetted image.

The first optics optimization for the 24" telescope at Wallace Observatory was done in 2000 by Janet Wu as part of her undergraduate thesis. Her results show the ideal location for a 2"x2" CCD detector behind the telescope back plate and the distance between the primary and secondary mirrors to be 1592.5mm equivalent to 62.697 inches (Wu 2000). In the optimizing process it was found that the ideal focal ratio lies between the f/16.6 and f/13.2 model, "the two cases revealed that as the distance between the primary and secondary mirrors increased, the resolution of the system degraded, but the unvignetted field of view increased" (Wu 2000). The instrument optimization was done by limiting the image plane behind the backplate along and imposing a resolution requirement of 1.0 arcsecond (Wu 2000). Table 1 contains the optics optimization of the 24" telescope using a 2"x 2" detector.

Table 1. 24" Optics Optimization from Janet Wu's Thesis (2000)

24" Optics Optimization from Janet Wu's Thesis Focal Ratio f/15.3		
Distance	Millimeters	Inches
Between Primary and Secondary Mirror	1592.5	62.697
Between backplate and image plane	443.4	17.457

It was found that "the distance between the primary and secondary mirror should be 1592.5mm and the distance between backplate and the image plane at 443.4 mm with a focal ratio of 15.3 .... The resolution of this system for a range of field angles from 0^{o} to 0.22^{o} [is] 1.06 arcseconds" (Wu 2000).

Using Janet Wu's thesis as a starting point, a new optical model was produced using *LensLab*. The new optical model was used to determine the apertures for the instrument that would acquire an unvignetted image at the SiTe detector. The optical model includes WAOcam and the two supporting instruments. The LensLab model, illustrated in Figure 5, contains only the optics of the Cassegrain telescope and the instruments behind the telescope backplate with rays tracing the edge of the primary mirror. For only the instrumentation behind the telescope backplate see Figure 6. The results of the model are summarized in Table 2. The code run to create the figure can be found in Appendix QQ.

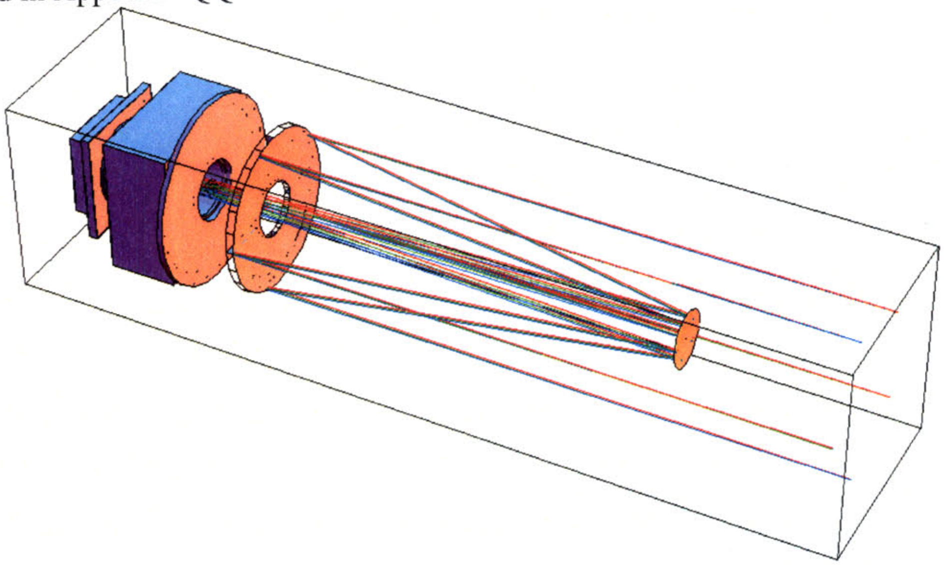


Figure 5 Cassegrain Ray Tracing for WAOcam using *LensLab*

Model of the 24" Cassegrain telescope. The light rays reflect from the primary mirror onto the secondary mirror and out the back of the telescope tube. Behind the back plate are the two support instruments and WAOcam.

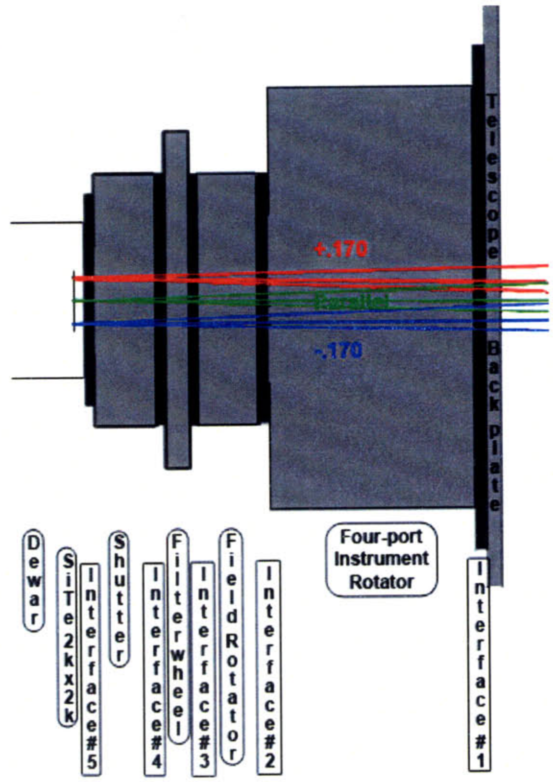


Figure 6 ***LensLab*** **Ray Tracing: Behind Telescope**

The vignetting done by projecting three sets of rays: 1) parallel to the optical axis (middle rays), 2) 0.170 degrees above the optical axis (top rays), and 3) 0.170 degrees below the optical axis (bottom rays). These rays trace out the outer limits of the SiTe 2kx2k CCD detector.

Table 2. Location of Supporting Instruments & Modules of WAOcam

LensLab: Location of Supporting Instruments & Modules of WAOcam				
Instrument	Distance from Telescope Backplate (in)	Thickness (in)	Aperture Size (in)	Description
Interface #1	0.00	0.50	8.00	Joins the four port instrument rotator to the back of the 24" telescope
Four Port Instrument Rotator	0.50	10.00	8.00 Z 4.00 X	Allows for three different instruments to be mounted simultaneously on the 24" telescope
Interface #2	10.50	0.50	7.00	Joins the four port instrument rotator to the field rotator
Field Rotator	11.00	3.00	4.75	Allows for rotation along the z axis. Needed for strip scanning.
Interface #3	14.00	0.375	6.00	Joins the field rotator to the filter wheel.

Filter Wheel	14.375	1.25	5.00	Allows for the filtering of the light path.
Interface #4	15.625	0.375	5.00	Joins the Filter Wheel to the shutter case.
Shutter Case	16.00	3.00	5.00	Light path control mechanism
Interface #5	19.00	.375	4.00	Joins the Shutter Case to the dewar
Dewar	19.375	4.45"	3.00	Holds the SiTe CCD
SiTe CCD	20.034	--	2 x 2	Active area of the CCD

The thickness of shutter and filter wheel were determined by the design of each module. The thickness of the field rotator was estimated using commercial field rotators. The remaining ten inches was allocated to the four port instrument rotator. The aperture sizes were calculated using *LensLab.* Depending on the design of the four port instrument rotator the focal plane may closer to the telescope.

The unvignetted field was calculated using a plate scale of 20.74 arcsec/mm with the 2"x 2" CCD (50.8 mm) and calculating the change in angle on the chip. The actual change on the SiTe 2kx2k chip was calculated to be 0.170 degrees. The vignetting calculation was done by projecting three sets of rays: 1) parallel to the optical tube, 2) 0.170 degrees below parallel, and 3) 0.170 degrees above parallel, illustrated in Figure 6. The diameters of each interface where made so that they did not block any of the projected rays, hence acquiring an unvignetted field of view.

2.3.2. Driver Motors

The diagrams of the 24" telescope were examined to verify that the driver motors could indeed handle an approximate eighty pound instrument. From the engineering diagrams it was determined that the telescope could handle the projected weight of WAOcam. In fact, the telescope was designed to host such an instrument. The previous Apogee camera required lead bricks to be bolted to the rear of the telescope because the camera was too light. Therefore, the WAOcam does not pose an issue to the telescopes driver motors. For the complete specifications on the 24" driver motor capabilities see Janet Wu 2002 thesis (2002).

2.3.3. Space Constraints

The size of the camera is limited by the physical constraints of the 24" dome. In order to prevent the camera from crashing against the ground or the surrounding dome, measurements were made to find the maximum dimensions of the camera that the telescope can hold. The camera length can not exceed 50" from the rear of the telescope. As the camera reached completion, the entire dome structure was modeled in SolidWorks to identify danger zones (where the WAOcam may collide into its surroundings). Figure 7 shows how WAOcam would look at the home position on the 24" telescope dome.

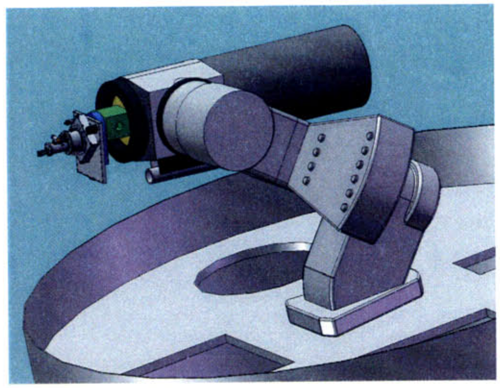


Figure 7 WAOcam on 24" Telescope at Home Position

Model of the 24" telescope environment showing how WAOcam will appear at the home position.

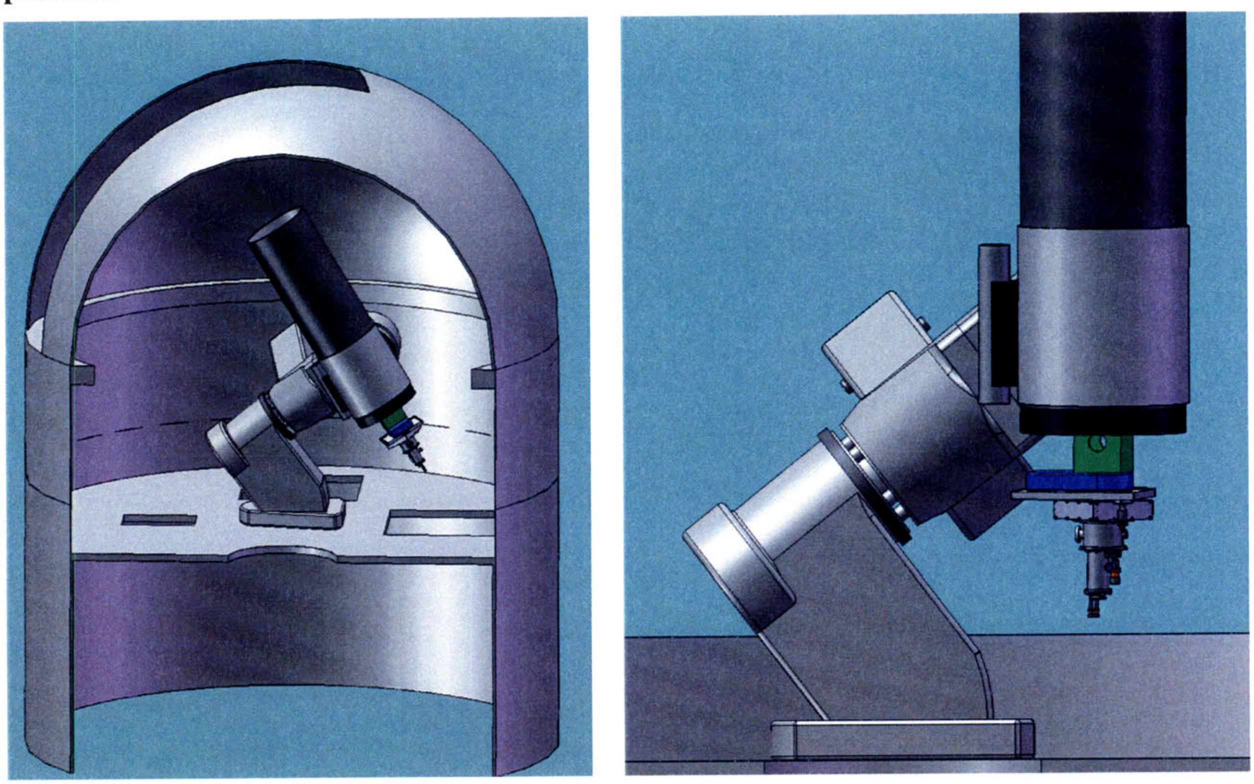


Figure 8 24" Telescope: L) Assembly Inside Dome & R) Vertical Clearance.

On the left, a cutaway view of the dome that houses the 24" telescope. The model was created to find configurations in which the camera would crash against the floor. On the right is the 24" telescope pointing vertically.

2.3.4. Balancing the Telescope

Part of the installation of WAOcam is to rebalance the telescope. The procedure for balancing the 24" telescope can be found in Janet Wu's thesis titled "Demonstration of Wallace Astrophysical Observatory's 24-Inch Telescope Upgrade" (2002).

3. Camera Components

3.1. Overview

WAOcam consists of three individual modules: 1) dewar, 2) shutter, and 3) filter wheel. The camera will be tested in the lab, and then disassembled for transport to Wallace Observatory where it will be mounted on the 24" telescope. The camera is controlled electronically via Lowell Observatory Instrument Software (LOIS) provided by Lowell Observatory. From preliminary tests it has been found that the dewar reaches the necessary –120° C, and holds a vacuum of 10^{-7} torr (1 torr = 1 mmHg). The filter wheel has not yet been interfaced with LOIS, but is currently controlled manually via a high precision rotary motion instrument from *MDC Vacuum*. A high accuracy DC stepper motor is in place for moving the filter-wheel electronically, although the automation is not yet complete. Figure 9 shows the back view of WAOcam, including the stepper motor and hand controller for the filter wheel.

There are plans to add to two additional modules: a field rotator, and instrument rotator. While the design incorporates the field rotator and the four port instrument rotator, this report does not detail their design or creation.

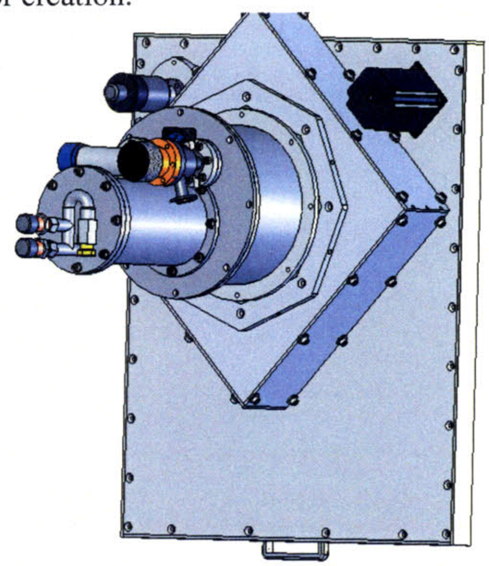


Figure 9 WAOcam Assembled

Back view of WAOcam showing the CryoTiger head, dewar, shutter, filter wheel, and the interface between modules.

3.2. Dewar

The general purpose of the dewar is to maintain the SiTe 2kx2k (2-inch square) CCD chip and electronics in a vacuum sealed environment. While at the same time operate the CCD in the range of –130 to –110° C. The dewar consists of several subcomponents: the CryoTiger head, back lid, front lid, internal electronics, and dewar case. The dewar itself was recycled from an older system and was modified to fit our needs. Figure 10 pictures the dewar during testing.

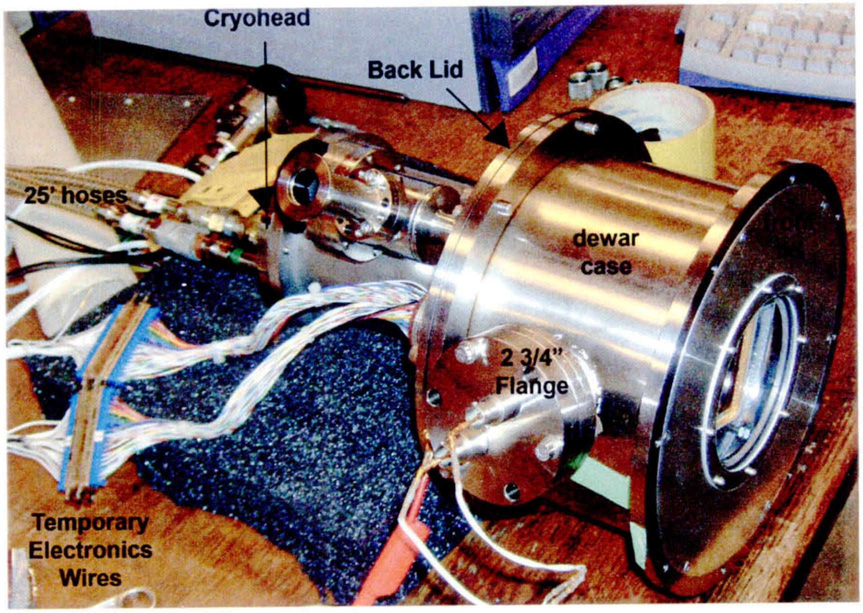


Figure 10 Dewar Assembly

Dewar assembly showing interface between front lid, dewar case, back lid, and cryohead. The CryoTiger compressor is not shown. Assembly diagrams of the dewar can be found in the WAOcam Assembly section of this paper.

3.2.1. CryoTiger

The CryoTiger consists of three parts: 1) a compressor, 2) two hoses, and 3) one cryohead. Figure 11 shows the basic layout of the CryoTiger system. The compressor is linked to the cryohead via two 25 foot hoses. The cryohead is connected by a thermal connection to the SiTe CCD.

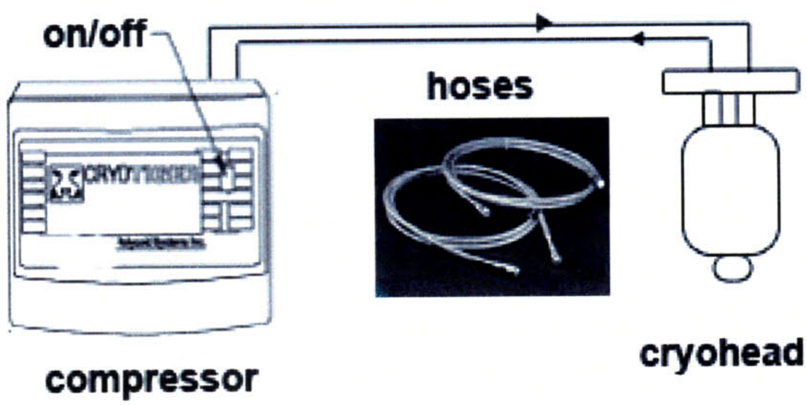


Figure 11 CryoTiger System

The compressor using PT30 as the working gas that removes the heat from the cryohead via two 25 feet hoses. The compressor runs on a wall outlet electric power. One house is assigned to be "in" to the cryohead and the other is the "out" of the cryohead. Reversing the order of the hoses breaks the cryohead.

The CryoTiger works by continually pumping PT30 to remove heat from the dewar via the cryohead. PT30 is the working gas used to remove heat from the CryoTiger head (cryohead). PT30S is a highly flammable liquefied gas made up of a mixture of Argon, Ethane, Methane, Neon, Nitrogen, and Propane. More information regarding PT30 can be found in the PT30 Datasheet (PT30 Datasheet 2000).

As it reaches steady state the CryoTiger keeps the dewar at a constant low temperature, ranging from –110 to –130ºC, to keep the dark noise down. Currently the temperature is measured using a resistor that exits through the 2.73" flange on the side of the dewar case. The goal is to measure and control the temperature of the dewar using a resistor on the thermal connection that would be controlled automatically by LOIS. The current setup does not have the means to increase the temperature. More details of the CryoTiger cooling unit can be found in the CryoTiger Technical Manual.

3.2.1.1. Cryohead

The PT30 working gas goes through coils of the cryohead to remove the heat from CCD via the thermo connection. The cryohead connects to a protective case via eight 10-32 screws at a 4" diameter spaced forty five degrees apart. Figure 12 shows the cryohead without the case. The cold end of the cryohead is a circular disk 1.25" in diameter. The disk has five holes equally spaced threaded for M3x0.5 screw at a diameter of 1.06". The inner face of the cryohead has an O-ring grove for a V70-153 O-ring. Dimensioned drawings of the cryohead can be found in Appendix B and Appendix C.

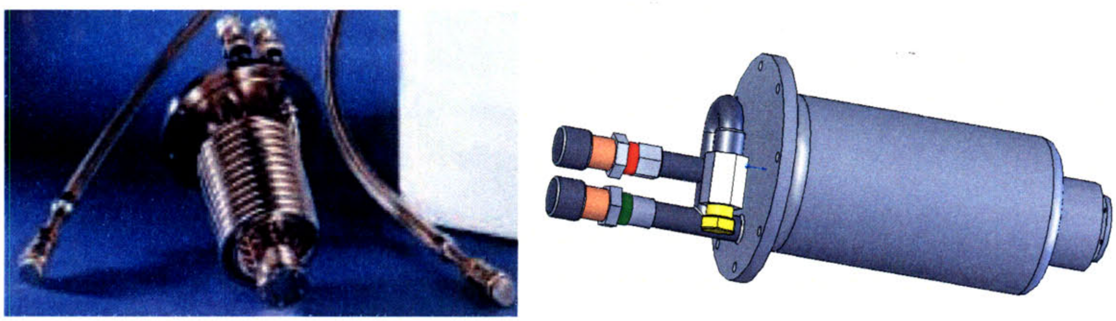


Figure 12 CryoTiger Head Thermal System

To the left is a picture of the CryoTiger head. To the right is the *SolidWorks* representation of the cryohead. The system uses PT30 as the working gas and the two interfaces are clearly labeled input and output. The desired operating temperature is – 120º C (153K). The inner surface of the cryohead as an O-ring grove for an O-ring V70-153. For the dimensions from the brochure see

3.2.1.2. Cryohead Case

The cryohead case extends the dewar to encompass the volume of the cryohead. Figure 13 shows a picture drawing of the cryohead case. One end of the cylindrical shell is threaded for 10-32 screws; this is where the cryohead connects to the case, an O-ring V70-153 secures the vacuum between the faces. The other end of the cylindrical shell has clearance holes for 10-32 screws and also has an O-ring grove for a V70-153 O-ring. Dimensioned drawings of the cryohead case can be found in Appendix D.

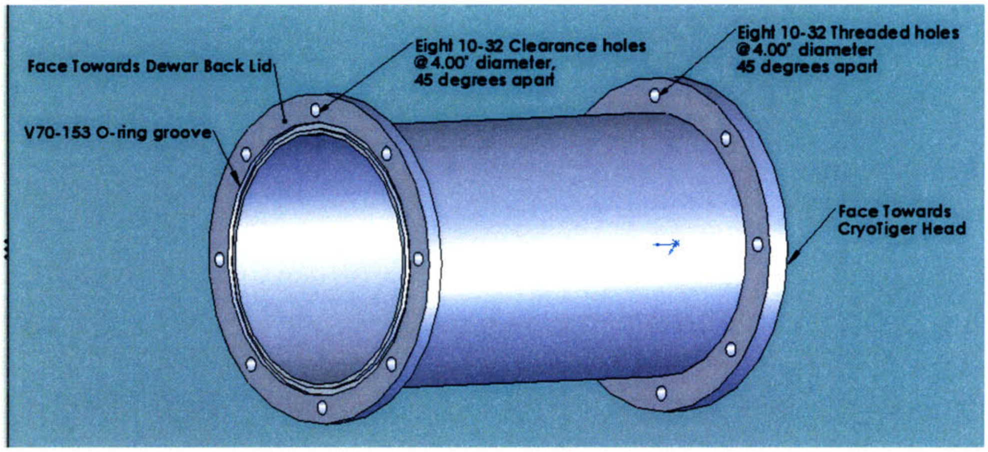


Figure 13 Cryohead Case.

One side of the cylinder has an O-ring V70-153, and threaded holes for 10-32s with forty five degrees of separation between each hole. The other side of the cylinder has clearance holes for 10-32s screws. The face with the clearance holes is connected to the back lid of the dewar, while the face with the threaded holes joins with the cryohead. Dimensioned drawings of the cryohead case can be found in Appendix D.

3.2.1.3. System Efficiency

From the four available working gases for the compressor PT30 works best in the desired temperature range. Figure 14 shows the temperature (°C) versus capacity (W) for the four available working gases. The optimal wattage/temperature for PT30 is at 27 watts at – 128° C (CryoTiger Brochure, 4).

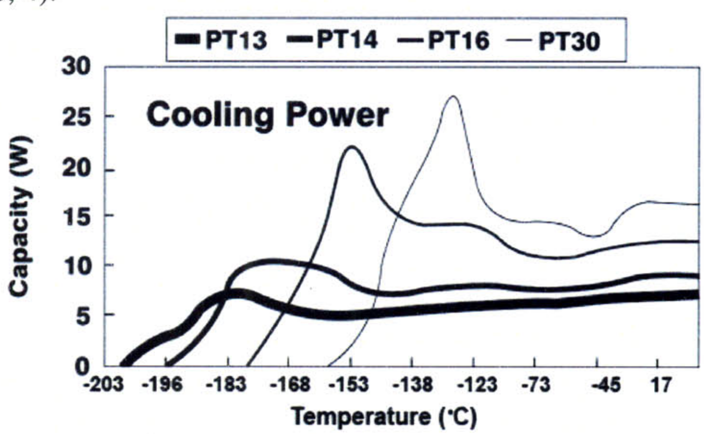


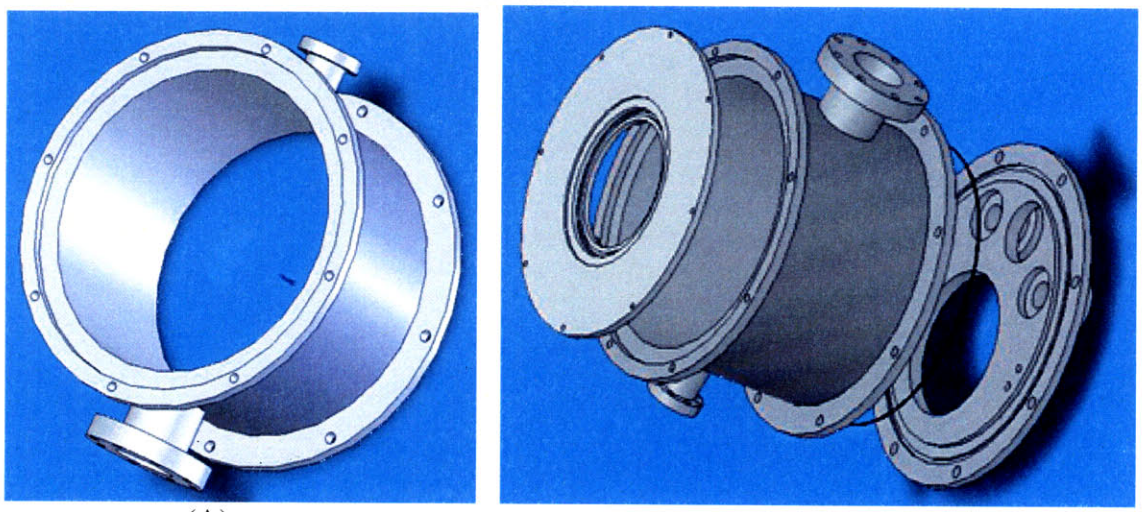
Figure 14 CryoTiger Head: Capacity (W) vs. Temperature (°C)

Power (W) versus Temperature (°C) for the high performance cold end. The capacity refers to the amount of heat that is being removed through the cryohead. Working with PT30 the optimal working wattage is estimated to 27 Watts which yields a temperature minus 128° C. From the four available working gases, PT30 is the one optimized for the range of the desired temperature for the CCD (CryoTiger Data Sheet 1994).

3.2.2. Dewar Case

The geometry of the case is cylindrical, as shown in Figure 15. Included in the case are two standard flanges. The smaller flange is a 1-1/3 flange threaded for 8-32 screws. The second flange is a 2-3/4" standard flange with clearance holes on the face. The two flanges are sealed with their respective caps and gaskets for a vacuum seal fitting. The total dimensions of the dewar are 4.5" in length and 8" in diameter. Complete dimensioned diagrams can be found in Appendix J.

The top side of the dewar holds the front lid that harbors the fused silica quartz window. The holes that surround the front lid fitting are clearance holes for 10-32 screws. The holes that are on the bottom side of the dewar are threaded holes for 1/4-20 screws. The threaded holes are where the back dewar lid connects to the dewar case.



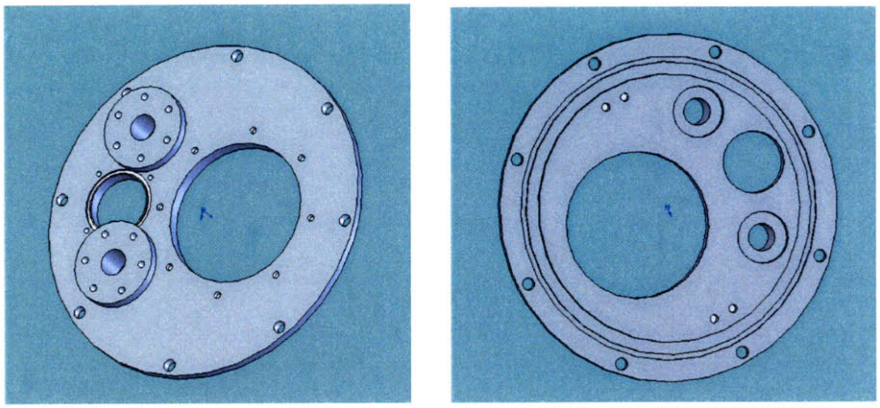
(A) (B)

Figure 15 Dewar Case & Lid Components

(A) The total length of the dewar case is 4.5" and the diameter is 8". The dewar case has two standard flanges perturbing of the side, a 1 1/3" flange and a 2 ¾" flange. (B) Shows the interface between the dewar case, front lid, and back lid. Detailed diagrams on the dewar assembly can be found in the WAOcam Assembly section of this paper. The assembly schematic for putting the dewar case is located in Appendix O.

3.2.3. Back Lid

The dewar back lid had to be designed to accommodate the CryoTiger, electronic feed-through, and two 1 1/3" flange. The back lid was manufactured by Sharon Vacuum, since the design required the welding of the two flanges, in order to fit all of the components on the back lid.



A B

Figure 16 Dewar Back Lid Design

Exterior face of the dewar back lid. This face contains the CryoTiger interface, two standard 1-1/3" flanges and the electronic feed through. To the right is the interior face of the dewar back lid that goes towards the vacuum side. This face as an O-ring grove for a 261 O-ring and four threaded 6-32 holes that are used to hold the electronics. The dimensioned diagram of the dewar back lid can be found in Appendix F.

The strengths of the design of the dewar back lid is symmetry, and space allocation. The diameter of the case was determined by the pre-existing dewar case. The dewar back lid needed to interface with the following: 1) cryohead case, 2) two flanges, and 3) the hermetic seal. It was determined that all of interfaces could not fit on the same plane. In order to fit the all of the interfaces, the 2" flanges connections were raised 0.5" above the exterior face reducing their projection on the dewar back lid to only 1". The distance between cryohead case and the hermetic connector was reduced to 0.04" (1 mm). While the design efficiently used the available space, it also determined the assembly of the dewar back lid.

The order of securing the interfaces was determined by clear access to the cap screws. The order of assembly is: 1) cryohead case, 2) hermetic connector, 3) vacuum gauge, followed by the 4) MDC valve.

On the interior side of the dewar back lid are four blind threaded 6-32 for the CCD holding mechanism. Having one the hermetic seal and the CCD holding mechanism makes it easier and safer to assemble the dewar.

3.2.3.1. Exterior Face

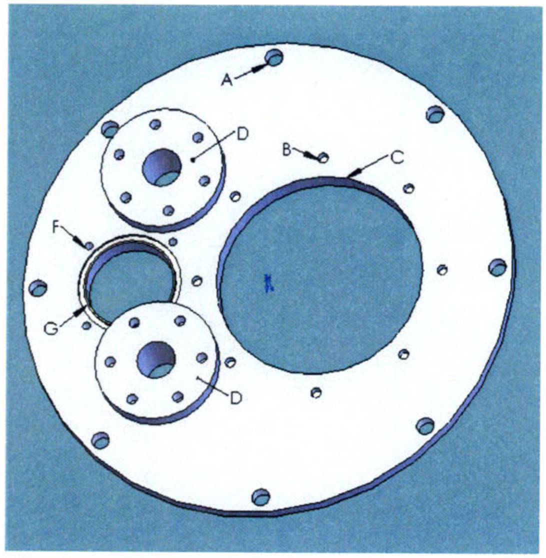


Figure 17 Dewar Back Lid Exterior Face

The exterior of the back plate is able to interface with several connections that bring the dewar together. A. One of the eight clearance holes for a 1/4-20 cap size screw. B. One of the eight threaded holes for 10-32 cap size screws. C. Clearance for CryoTiger thermo system interface. D. Standard 2" flanges, raised 1" above surface. The faces have an 8-32 threaded, six hole, bolt circle at a diameter of 1.5" E. Clearance for Electronic feed through connection. F. Threaded 4-40 holes for screws for electronic feed through. G. O-ring 029 for Electronic connection.

3.2.3.2. Interior Face

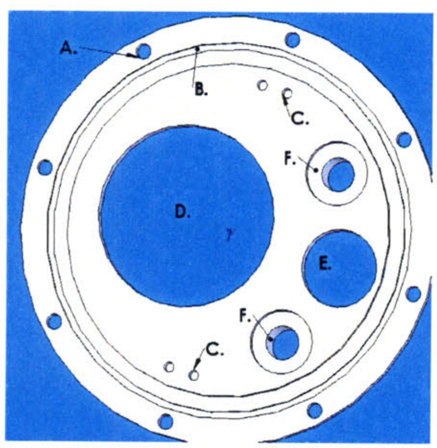


Figure 9 Dewar Back Lid Interior Face

The interior of the back plate has many features that need to be mentioned. A. One of the eight clearance holes for the 1/4-20 screws B. O-ring 261 C. Threaded 6-32 holes, depth 1/4". D. Clearance for CryoTiger interface. E. Clearance for Electronic interface. F. Clearance for 1-1/3" standard flange. See Appendix F for dimensioned drawing.

3.2.4. Electronic Connection

The electronic connection allows the transfer of information through the back plate into the vacuum-sealed environment. The electronic connection through the dewar back lid is a glass sealed insulator MIL-DTL-38999 series II circular hermetic connector (part # MS27476Y24E) with 128 pins, ordered from ITT Cannon™ (ITT Cannon Website 2008). The geometry and pin numbering can be found in Figure 18 below. On the inside of the dewar the pins are soldered to the wires that connect to the SiTe circuit board. Four 4-40 screws secure the hermetic seal to the dewar back lid. A 029 O-ring secures the vacuum integrity of the dewar.

The wiring of the electronics was done by Dr. Steve Kissel, a CCD specialist. The wiring diagram of the electronic feed through can be found in Appendix I.

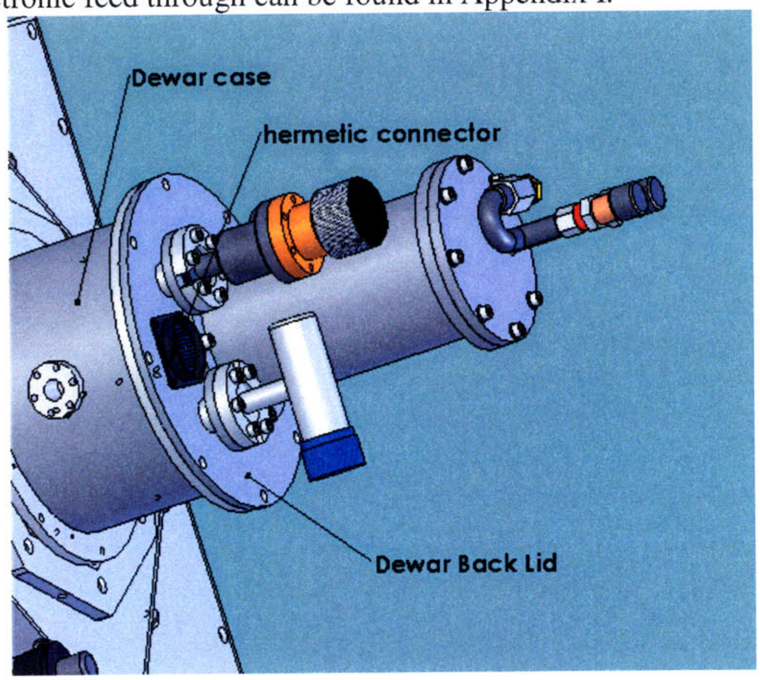


Figure 18 Electronic Feed Through.

The top right hand side shows a zoomed out image of the locations of the electronic feed through. The electronic connection through the dewar back lid is a glass sealed insulator MIL-DTL-38999 series II circular hermetic connector (part # MS27476Y24E) with 128 pins, ordered from ITT Cannon™ (ITT Cannon Website 2008). Four 4-40 screws connect the electronic feed through to the back lid. A 029 O-ring seal maintain the vacuum integrity of the dewar. The layout of the pins is located in Appendix H. The dimensions of the SolidWorks model can be found in Appendix G.

3.2.5. Front Lid

The purpose of the lid is to hold the dewar window while at the same time keeping the dewar vacuum sealed. The front lid is made of aluminum 6061 because of its low cost, and ability to be formed. Al 6061 is a standard alloy used in a variety of applications; hence it is also readily acquired. The total size of the lid is 7 ¼" in diameter with a 3" clearance hole in the center. The window is held in place on a counter hole pocket with a O-ring grove, Figure 20 illustrates the window holder mechanism.

The front lid fits into topside of the dewar and has distinct exterior and interior surfaces. The exterior surface has a ring mechanism that holds the window and the interior surface has an O-ring 165 grove size or inner diameter of 6.5" and thickness 3/32" See Appendix K for dimensioned drawings of the front lid.

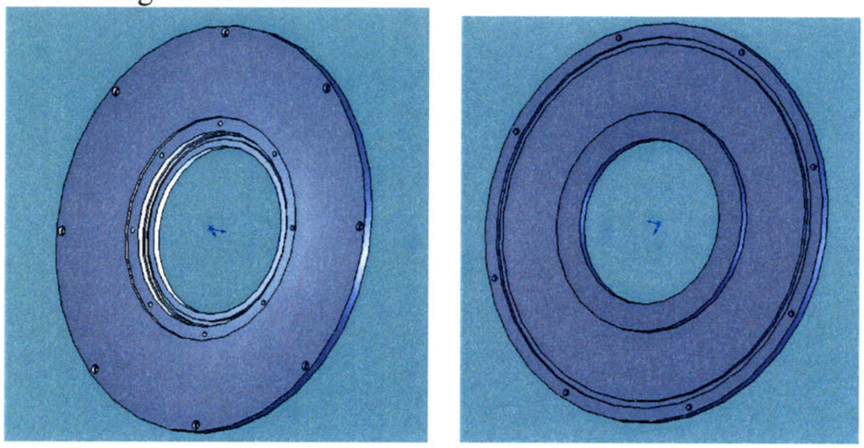


Figure 19 Dewar Front Lid

To the left is the top of the front lid. The holes in the perimeter are clearance holes for 4-40 cap screws. The ring mechanism is better illustrated in Figure 20. To the right is the interior of the front lid. The grove is for a 165 O-ring.

The window fits into place in the front lid. A disk with an inner diameter of 3" and an outer diameter of 4" secures the window to the front lid with six screws size 2-56. An O-ring size 042 between the window and the front lid ensures that the vacuum in the dewar is maintained. The O-ring has an inner diameter of 3.250" and a thickness of 1/16". The design for the dewar front lid is a reproduction of a smaller window design from an old dewar case.

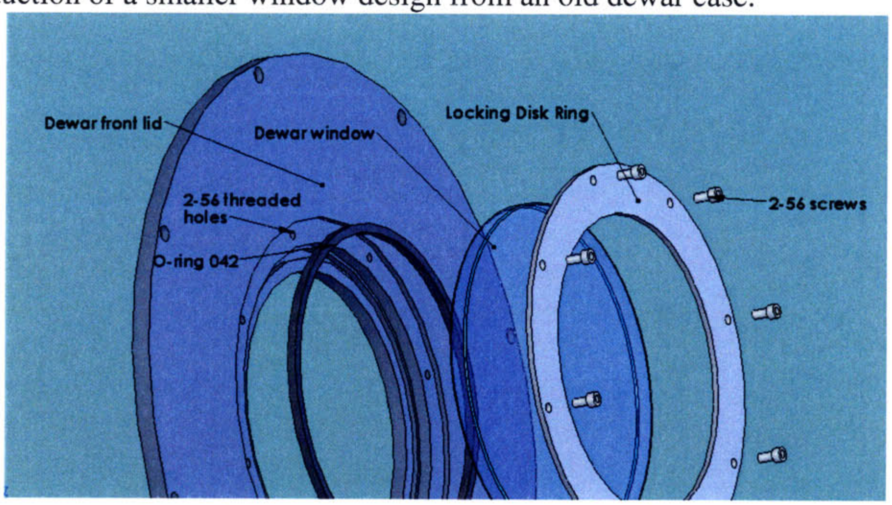


Figure 20 Dewar Window Holding Mechanism.

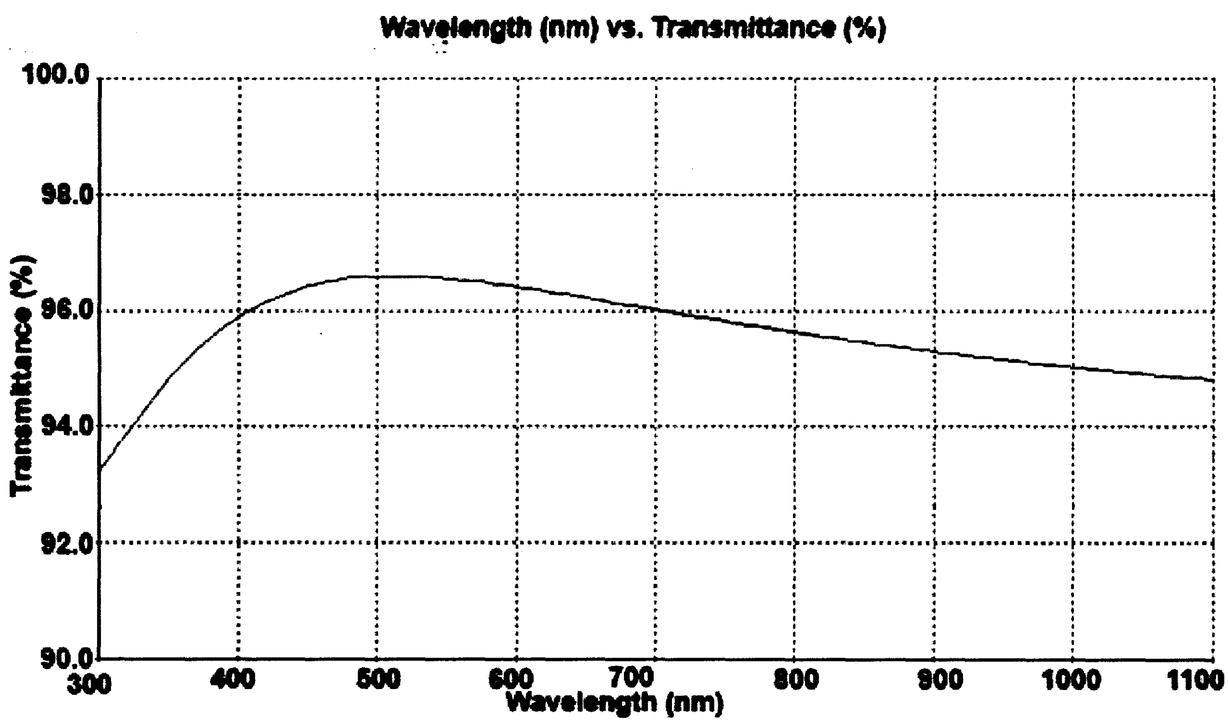
The dewar window is pressed onto the front lid by locking disk rink. An O-ring (size 042) between the dewar window and front lid secures the dewar vacuum. The 3.5" groove on the front lid holds the dewar window from shifting sideways. The locking disk ring has inner diameter of 3" and outer diameter of 4", it is securely fastened to the front lid by six 2-56 screws. The diagram for the front lid can be found in Appendix K. The diagram for the front lid lock can be found in Appendix L.

3.2.6. Dewar Window

The dewar window allows light to pass into the vacuum-sealed dewar; it is the final optical surface before the CCD detector (Wu 2000). Poor quality windows can introduce aberrations, hence affecting the quality of the images. For astronomical observations the key specifications of the dewar window are: 1) index of refraction, 2) transmission, and 3) coating. The transmission through the window must be above ninety percent. The window has to be thick in order to reduce concavity created by the pressure difference between the inside and outside of the dewar. An anti-reflective coating is often applied to reduce the amount of reflected light that is removed from the light beam before hitting the detector.

The window for WAOcam is made of fused silica, ordered as a precision window from Esco products‡‡. It was purchased with an anti-reflective MgF_2 coating. The window's diameter is 3.5" ± .005" and the thickness is 3/16" (diagram located in Appendix M). The diameter of the window was determined using the optical diagram and getting an unvignetted field of view for the SiTe 2kx2k. The window thickness was determined both the change in pressures created by the vacuum and the manufacturing standards. The window also has a one-quarter wave flatness per surface coating, and a 60/40 scratch/dig surface quality§§. The parallelism is better then 10 arc minutes. The edges of the glass are beveled for nominal safety in handling the window. The wave flatness, coating, surface quality, and parallelism where determined based on the scientific objectives for the WAOcam.

From the transmission curve in Figure 21, it can be concluded that for u, v, r', i' wavelengths the glass has over a ninety-two percent transmission, which is satisfactory for astrometry and photometry.



‡‡ Window Specifics:

§§ A surface quality of 60/40 implies that the: 1) maximum width of an allowable scratch is 60 microns, and 2) maximum dig diameter is 400 microns. Scratch: (60 microns = 0.0024"). Dig diameter (400 micron = 0.0158").

Figure 21 Dewar Window Transmission Curve

Transmission curve from Esco Products for the fused quartz glass Silica. A) Illuminant: white. B) Medium: air. C) Substrate: Fused Silica. D) Exit: Air. E) Detector. Ideal. F) Angle: 0.0 (deg). G) Reference: 525.0 (nm).

3.2.7. Internal Components

3.2.7.1. SiTe 2kx2K CCD Detector

The SiTe 2kx2k (SI424A) CCD is a "silicon charge-coupled device designed to efficiently image scenes at low light levels from UV to near infrared" (SiTe 2kx2k 1994). Some features of the SiTe CCD "include a buried channel with a mini-channel for high transfer efficiency, multiphase pinned (MPP) operation for low dark current, and lightly doped drain (LDD) output amplifiers for low read noise" (SiTe 2kx2k 1994). The CCD imager is mounted in a non-hermetic metal package without a window.

The detector is 2.50" x 2.50" with 0.60" radius on the edges. The height of the CCD casing is 0.165" with pins extruding an additional 0.25", see Appendix S for the drawing of the manufacturer and Appendix R for the SolidWorks model representation. The size of the detector is 2048 pixels x 2048 pixels, with each pixel being 24 microns x 24 microns. The detector is divided into four equal sections each with its own amplifier. The readout time using the four amplifiers un-binned mode is 25 seconds. For additional device specifications see Table 3 below. The graphs of quantum efficiency versus wavelength and dark current versus temperature can be found in Appendix LL and Appendix MM. The appendix section also contains more information of the SiTe CCD supplied by the manufacturer.

Table 3. SiTe CCD Specifications

DEVICE SPECIFICATIONS

Measured at -45 deg. C, unless otherwise indicated, 45 kpixels/sec and standard voltages using a dual slope CDS circuit (8 μs integration time)

		Minimum	Typical	Maximum
Format			2048 x 2049 pixels	
Pixel Size			24 μm x 24 μm	
Imaging Area			49 mm x 49 mm	
Dark current (MPP), 20°C equivalent			50 pa/cm²	100 pa/cm²
NON-MPP (non inverted)			250 pa/cm²	500 pa/cm²
Readout noise	Front		5 electrons	10 electrons
	Back		7 electrons	10 electrons
Full Well signal		150,000 electrons	200,000 electrons	
Dynamic Range (relative to readout noise)		15,000:1	28,000-40,000:1	
Output gain		1.0 μV/ electron	1.3 μV/ electron	
CTE per pixel		0.99998	0.99999	
Output Amplifier Power Dissipation (each)			7 mW	
Clockline Capacitance[1]	parallel		230,000 pF	
	serial		600 pF	
Clockline Resistance[2]	front illuminated	phase 1	75 ohms	
		phase 2	55 ohms	
		phase 3	45 ohms	
	back illuminated	phase 1	185 ohms	
		phase 2	400 ohms	
		phase 3	460 ohms	
Clock Rise and Fall Times		Reset	0.2 μsec	
		Serial	0.2 μsec	
		Parallel	5.0 μsec	
Minimum Clock Overlap		Parallels	0.8 msec	
Quantum Efficiency			see Figure 7	

[1]These are estimated values per phase for the entire array, and include phase to phase and phase to substrate capacitances.
[2]These values are obtained with Pxa and Pxc connected together and with Pxb/Pxd connected together. Resistance is measured from Pxa to Pxb. It includes metal buss resistance and poly gate resistance in a series-parallel combination.

The table summarizes the specifications for the SiTe 2kx2k CCD. This information was obtained from SiTe 2kx2k (1994).

3.2.7.2. CCD Holding Mechanism

The mechanism for holding the SiTe CCD chip changed several times in order to meet specifications. The first design held the CCD using two 0.125" Aluminum plates raised by four 6-32 threaded rods, shown in Figure 22. The CCD was pressed between the top plate and the thermal connection. Although the tilt test did not show that there was a significant problem, it was decided to develop a better holding mechanism based on the MagIC II*** design and a thermal insulation analysis.

*** MagIC II is the MagIC camera after the summer 2007 upgrade

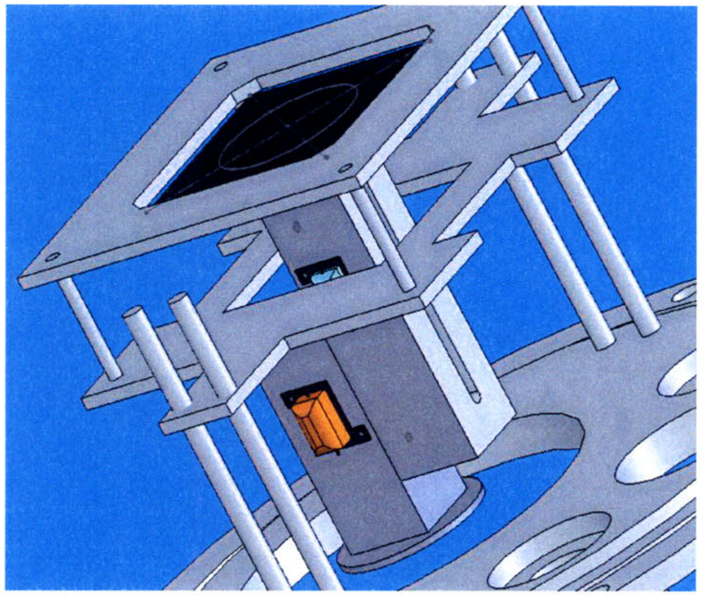
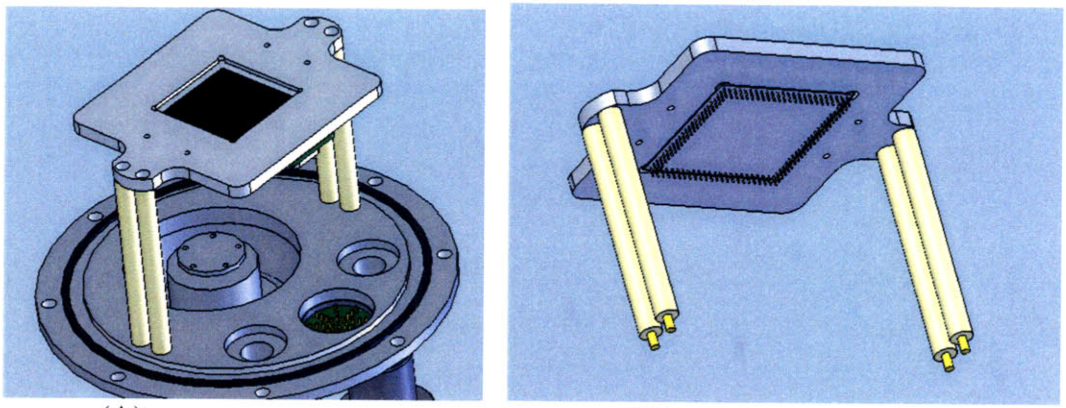


Figure 22 First CCD Mount Design

The CCD chip is the black block in the image. The rods that are holding the main plate are 6-32 threaded rods. The CCD chip was held in place by pressure between the top plate and the thermal connection coming from CryoTiger head. The second design for holding the CCD is with a custom made CCD stand which is a one solid piece of 0.375" thick Al 6061 with a pocket for the CCD. The CCD stand is raised towards the dewar window by four 3.625" ABS plastic rods, threaded for 6-32s on both ends. One end of each isolating rods has a brass threaded rod screwed into the rod until only 0.25" of the threaded region remains exposed. Figure 23 shows the SiTe CCD mounted and the four plastic rods that raise the stand from the dewar back lid. The same figure also shows the bottom of the CCD mount with only the four plastic rods, showing the brass threaded region exposed .25" at the bottom.

The improved design for holding the CCD is illustrated in Figure 23. The new design not only improved the tilt of the CCD, but also improved the concentricity (centering the CCD with the center of the dewar) of camera and the thermal insulation of the CCD. In the previous design (using threaded rods) it was difficult to acquire a parallel setup between the dewar window and the CCD stand. The new design uses four plastic stands that are all the same size within 0.005", which means that across a 5" length the maximum tilt is 0.057°. In the previous design the concentricity was obtained by centering the CCD by hand on what appeared to be the center of the stand. The new CCD mount has a pocket where the CCD fits tightly. The concentricity of the SiTe 2kx2k to the dewar is within 0.003". The third improvement in the new design was the thermal insulation. Since the previous design used threaded rods to hold the CCD stand, the CCD stand was not thermally insulated from the rest of the dewar; hence, the cryohead was not only cooling the CCD but the entire dewar case. Since the new design uses plastic stands, the CCD mount is thermally isolated from the rest of the dewar.



(A) (B)

Figure 23 SiTe CCD Holding Mechanism

To the left is the CCD in the holding plate supported by four plastic rods with an inserted thread 6-32 brass rod .5" in length. The dimensions of each plastic stand are 3.625" long by 0.375" in diameter. Four 6-32 cap head screws secure the CCD mount to the four raisers. The CCD is held using the thermal connection to press it against the mounting plate. To the right is the CCD mount and with the plastic rods from the bottom to show how the CCD fits into the pocket on the CCD mount. The diagrams for the raiser can be found in Appendix P. Appendix Q contains the diagram for the final CCD mount.

3.2.7.3. Thermal Connection

The thermal system allows the cryohead to remove heat from CCD by conduction. Like the CCD mount the thermal connection has undergone several changes. In the first design, shown in Figure 24, the thermal connection was composed of two pieces of aluminum that adjust between 3" and 5" via a 1.5" 8-32 cap screw that pressed both pieces together. Mounted on the thermal connection was a resistor intended to prevent temperature fluctuations.

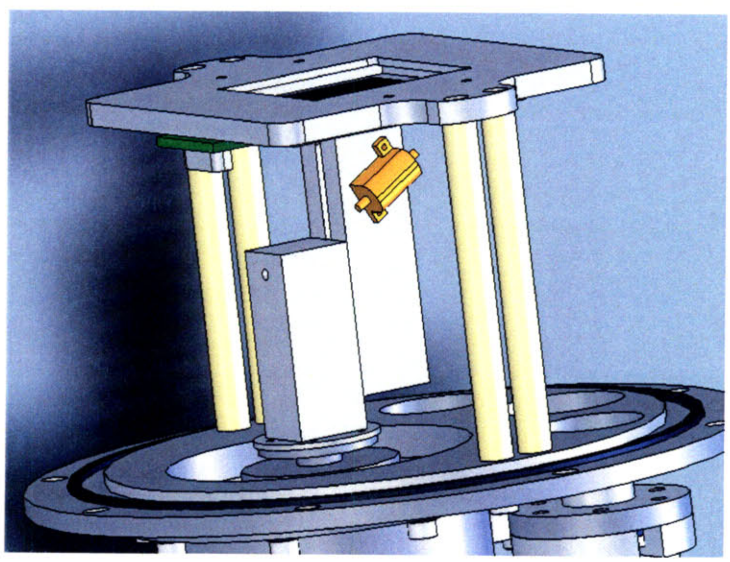


Figure 24 First Thermal Connection Design

The first thermal connection design was composed of two solid pieces of Aluminum. The problem with this design is that as the temperature decreases to –120° C a gap develops

between the CCD backplate and the aluminum thermal connection due to the change in temperature. The as the aluminum thermal connection contracted the pressed fit loosened to the point that the thermal connection was no longer in contact with the back of the CCD, so the minimum temperature was not achieved.

Modifications had to be made to the first design to account for contraction of metal under cold temperatures. As the Al thermal connection cooled a gap developed between the CCD and thermal interface which rendered the thermal connection incapable of both removing heat from the CCD and pressing the CCD against the mount. The new thermal connection is made up of three independent components, illustrated in Figure 25 below. The first part presses the CCD onto the CCD mount using four 6-32 screws with wave washers, commonly known as spring washers[†††]. The washers act as a preloaded springs, as the thermal connection cools the washers provide a force upwards. The second part (not shown in the image below) is a copper ribbon, one end is held by clamp #1 the other end is held by clamp #2. The third part is the cryohead connection, which has five clearance holes for M3.5 screws evenly spaced at a 1.06" diameter. The cryohead has connection region is threaded for M3.5 screws.

The new design allows for flexibility and it has been proven to work efficiently with the MagIC II camera.

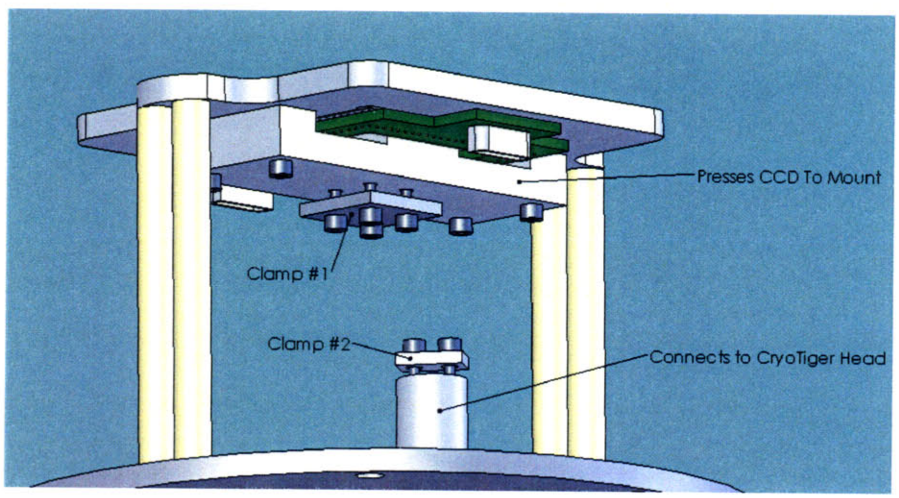


Figure 25 Final Thermal Connection from Cryohead to SiTe

The thermal connection is composed of three parts. The first part is presses the CCD onto the CCD mount using four 6-32 screws with wave washers. The second part (not shown in image) is a copper ribbon that is pressed between clamp #1 and clamp #2. The ribbon provides the flexibility, this idea originated from the original MagIC design. The third part, the connection to the cryohead, is a solid piece of aluminum with five clearance holes for 3.5 metric screws at 1.06" diameter. The diagram for the thermal connection can be found in Appendix T and Appendix U.

[†††] "Spring washers are disks of metal that are formed in an irregular shape so that when the washer is loaded it deflects, acts like a spring, and provides a preload between two surfaces" (Global Spec)

3.3. Shutter

The purpose of the shutter is to accurately control the exposure time. The shutter mechanism, shown in Figure 26 is identical to that of the MagIC Camera chosen for both availability and familiarity. Unlike the MagIC shutter, which is incorporated into the filter wheel, the WAOcam shutter is an independent module. In order to make the shutter mechanism usable for WAOcam it needed to be enclosed in a light tight case. The shutter case serves three purposes: 1) house the shutter mechanism, 2) prevent ambient light from interfering with the scientific data, and 3) load bearing.

3.3.1. Shutter Mechanism

The shutter mechanism dimensions are 11.5" x 11.5" x 2" with a 5.90" diameter iris. The shutter is naturally closed, a piston motor (labeled in Figure 26) opens the 5.90" iris. The power for the shutter mechanism comes from a large power converter, which is just a transformer (mounted on the side of the telescope). The shutter mechanism requires 25 volts of DC current, three amps are needed to open the shutter and one amp to hold it open. For a complete description of the electronics that control the shutter mechanism see Appendix OO.

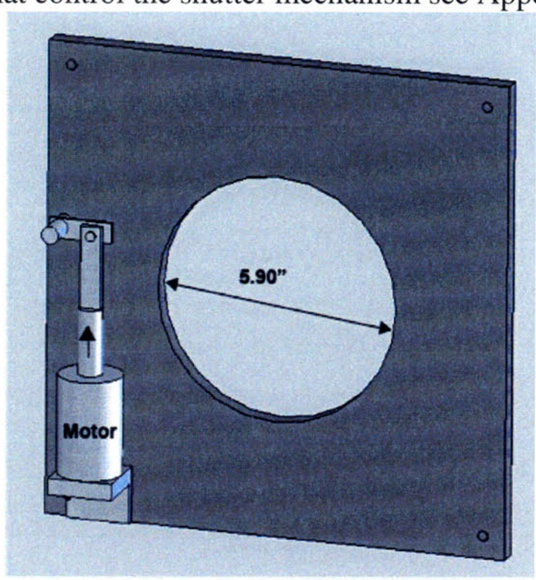


Figure 26 Shutter Mechanism

The iris size is 5.90" in diameter. Both the length and width of the shutter are 11.41", while the depth is roughly 2.50" including the motor. The piston motor to the left of the image controls the opening and closing of the shutter. The shutter is naturally closed and the motor upon receiving the signal will engage and open the shutter. The motor upon receiving (from U25 pin 15) the signal moves the shaft upwards (labeled with an arrow) and opens up the aperture. While three amps are needed to open the shutter only one amp is needed to keep it open. The diagram for the shutter mechanism can be found in Appendix V. For more information regarding shutter mechanism electronics and operations see Appendix PP.

3.3.2. Casing

The shutter casing, shown in Figure 27, provides housing for the shutter mechanism. The case, made of ¼" thick Al 6061, was designed with overlapping joints to reduce light leakage, illustrated in Figure 28. The shutter mechanism is held inside the casing by a tight fit within five thousands of an inch. The casing is held together via thirty-six 8-32 cap head screws. The two faces perpendicular to the light path have 10-32 octagonal threaded holes at diameters 7.5" and 9.00", to connect the shutter case to the module interfaces.

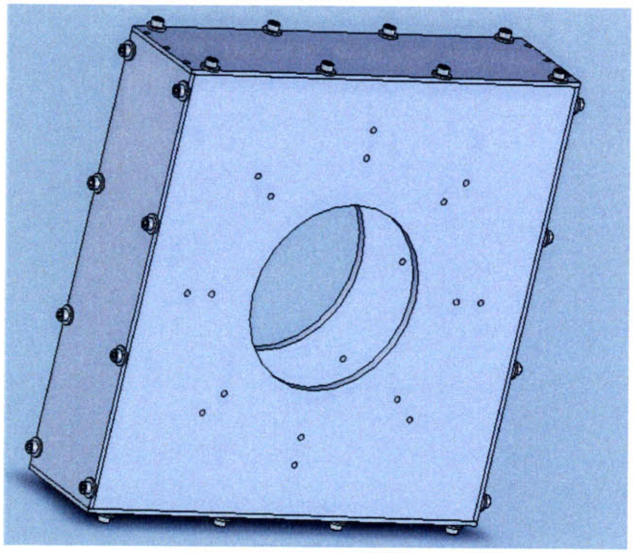


Figure 27 Shutter Casing

The shutter casing is composed of six parts held together by thirty six 8-32x¾" long screws. All of the faces are ¼" thick Al 6061. Both the front and back face have 10-32 octagonal threaded holes at a diameter of 7.5" and 9.00", to connect the shutter case to the module interfaces, and blind 8-32 threaded holes along each edge. One side plate has two connections (one red, one black) for powering the shutter mechanism. The power supply of the shutter will be mounted on the side of the telescope tube. The diagrams for the six parts of the shutter casing are located in Appendix W, Appendix X, Appendix Y, and Appendix Z.

The overlapping joints shown in Figure 28 provide a light tight environment to first order approximation. The overlapping depth is one eighth of an inch. Figure 29 shows how the shutter mechanism is held in the shutter case. For an assembly image of the shutter module see Appendix AA.

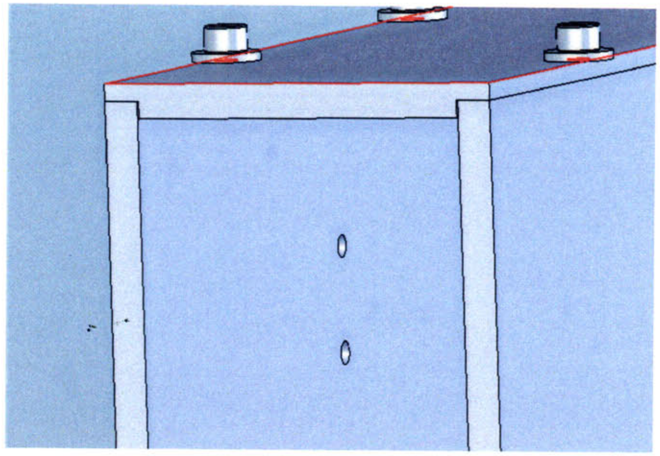


Figure 28 Shutter Casing Overlapping Joints.

The overlapping joints provide a first order light tight environment. The depth of joint is 1/8".

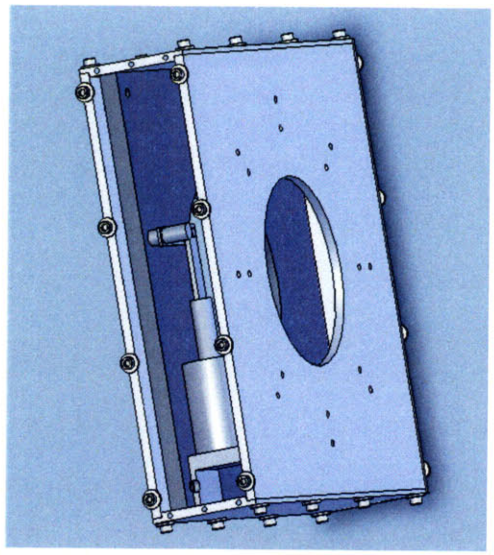


Figure 29 Shutter Casing with Shutter Mechanism Inside.

3.4. Filter Wheel

The filter-wheel has been custom designed to meet the scientific objectives of future projects using the 24" telescope. The filter-wheel design had to fulfill the following criteria: 1) light tight, 2) load bearing, 3) allocate space for six 3"-square filters, 4) provide means for changing filters (in and out of the filter wheel), and 5) ability to rotate between filters using both electronic and manual controls. In order to reduce the amount of reflected light, all of the components inside the wheel will be black anodized.

The filter wheel was manufactured using Al 6061 for its strength and machinability. The dimensions of the filter wheel are 17.59x20.92x1.25[‡‡‡] inches. The filter-wheel is subdivided into four main sections: 1) filter holders, 2) carousel, 3) casing, and 4) filter rotation. There are two designs for the filter wheel case. A comparison between the two designs is located in Table

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‡‡‡ Not including: 1) the handle at the bottom of the case, 2) stepper motor, or 3) manual control

4. The second design is a result from improvements for the first design. These improvements were made for ease of machining, reliability and making the filter wheel light tight.

The strength of the filter wheel design lies in its symmetry and ease of machining. The less complex the better the design. Many of the filter wheel parts were manufactured by WaterJet.

3.4.1. Filter Holders

The filter wheel carousel can hold up to six filters at any given time. The filter holder consists of three main parts 1) clearance plate, 2) frame, and 3) threaded plate. The frame of the filter holders provides the support necessary to hold the filter from shifting, while the two plates sandwich the filters by a 1/8" overlap on the corners. The frame is 0.25" thick with squared clearance holes for 2-56 screws. The top of the frame also has two clearance holes for 4-40 screws that hold the filter holder to the carousel. The bottom of the frame has a 0.125" dowel pin for aligning the filter holder to the carousel. The two plates that sandwich the filters are 0.032" thick. The plate is threaded for 2-56 screws. Figure 30 shows the main parts of the filter holder and how all of parts fit together. Figure 31 shows how the assembled filter holder fits in the carousel. Figure 32 shows the overlap corners of the filter holder assembly that secure the filters to their holders.

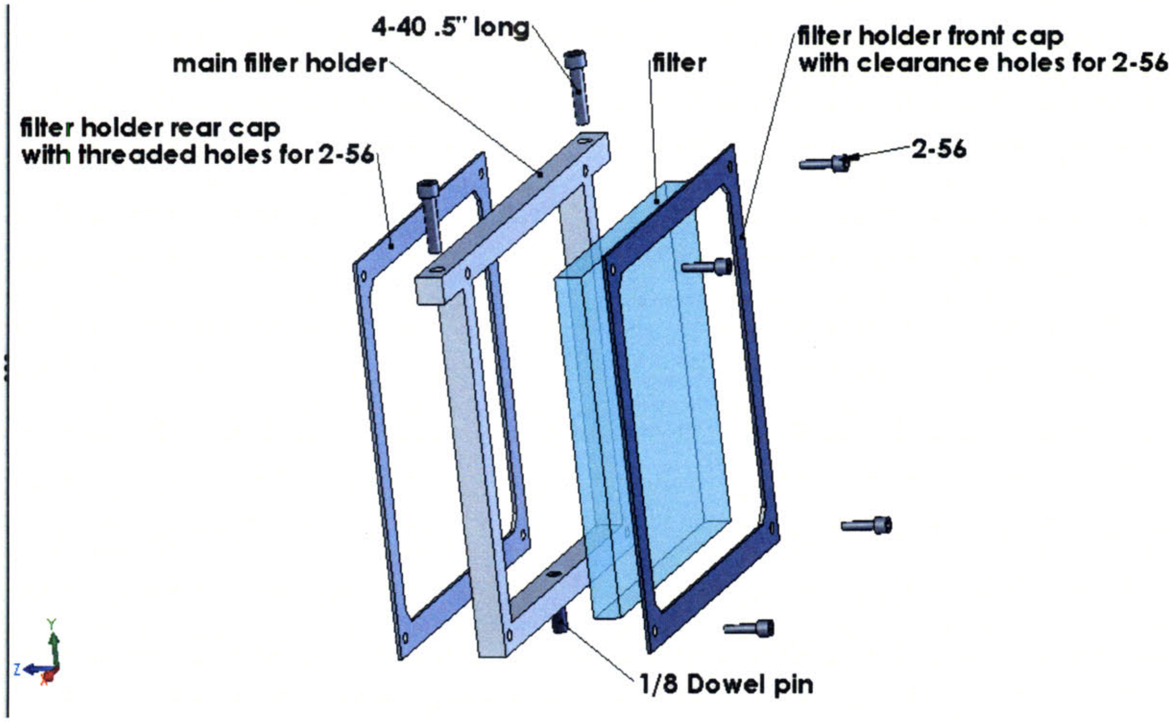


Figure 30 Filter Holder Assembly

The frame is 0.25" thick with squared clearance holes for 2-56 screws. The top of the frame also has two clearance holes for 4-40 screws that hold the filter holder to the carousel. The bottom of the frame has a 0.125" dowel pin for aligning the filter holder to the carousel. The two plates are 0.032" thick, the plate is threaded for 2-56 screws. For the dimensioned drawings refer to the appendix section.

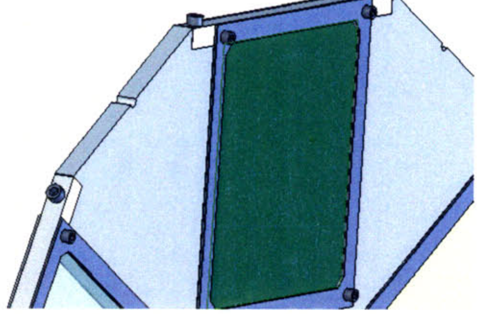


Figure 31 Filter Holder in Carousel

The Carousel can hold up to six filters at one time. The filter holders are held on the carousel via two 4-40 screws and positioned with a 0.125" dowel pin.

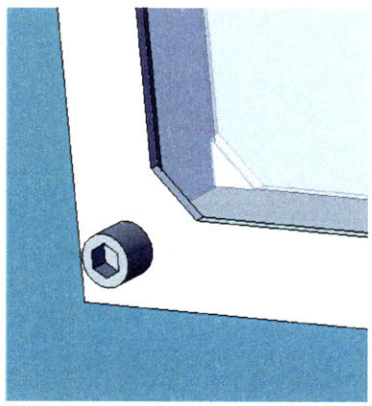


Figure 32 Corner of Filter Holder

Corner of filter holders that secure each filter to its holder.

3.4.2. Carousel

The filter-wheel carousel can hold up to six filter holders at one time. The frame of the carousel is 0.25" thick. At the center of the carousel there is a 1.125" clearance hole for a smooth ball bearing. The ball bearing is 0.25" thick with an outer diameter of 1.125" and an inner diameter of 0.50". Concentric with the ball bearing is an XL series gear 0.3" thick. The XL series is defined has having a pitch of 0.2". The gear has thirty two teeth at a pitch diameter of 2.032". The gear is held to the carousel via two 8-32 (0.375" long) flat head screws. The gear has the clearance holes, while the carousel frame has the two threaded holes 1.5" apart. Each of the filter holder slots has at the bottom an alignment hole for the 0.125" dowel pin of the filter holder and the threaded holes for the 4-40 screws that hold the filter holders to the carousel.

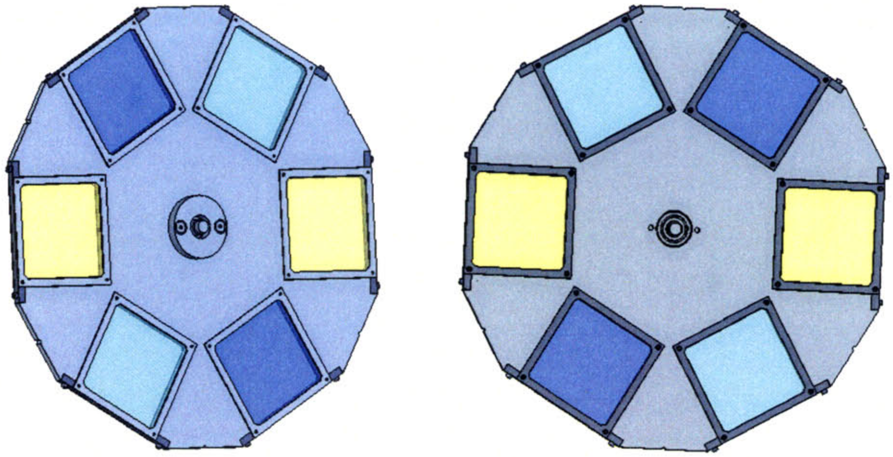


Figure 33 Filter-wheel Carousel

The filter-wheel carousel can hold up to six filter holders at one time. The frame of the carousel is made of 1/4" Al 6061. The center of the frame has a 1.125" clearance hole where a smooth ball bearing is pressed fit. The ball bearing is 0.25" thick, outer diameter of 1.125", inner diameter of 0.5". Concentric to the ball bearing is a 2.032" pitch diameter gear with a 0.2" pitch, better known as the XL series. The gear is held via two 8-32 flat head screws. The gear has the clearance holes, while the carousel frame has the two threaded holes 1.5" apart.

3.4.3. Casing

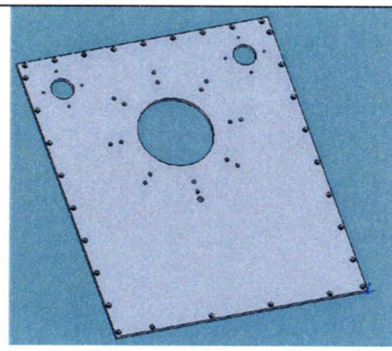
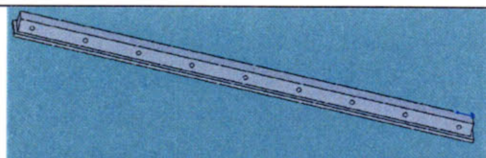
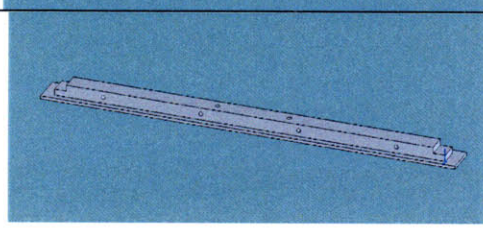
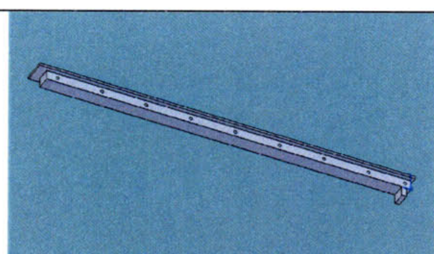
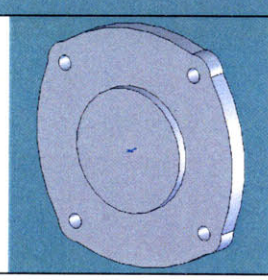
The final filter wheel case has not been manufactured. Table 4 compares the old case design to the new design with the justification for improvements. The design information and the drawings for the filter-wheel case found in this document are for the design of the new case.

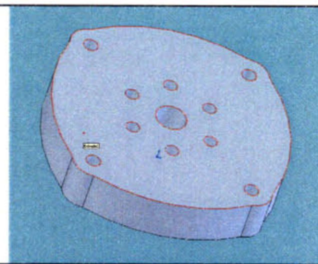
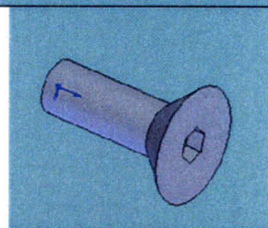
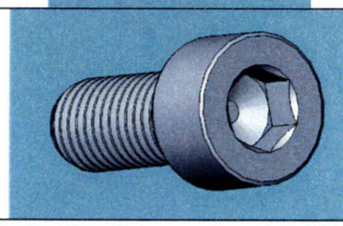
Table 4 Improvement for new Filter-Wheel Case

	Old Case	New Case	Justification
Main Plate: Corners	Rounded	Straight	Minimize complexity
Main Plate: Bolt Circle	30 degrees apart	45 degrees apart	Standardize to the rest of the camera
Main Plate: Control Ports	Several types	Only one type all symmetrical	Minimize complexity
Side Bars	Multi parts for each face	Single part for each face	Light tight and minimize complexity
Side Bars	No overlap main plates	0.125" Overlap with plates	Light tight
Side Bars	Clearance holes	Threaded holes	Easier to assemble and maintain.
Side Bars	Machined with Waterjet	Machine with CNC mill	Obtain clean faces that will prevent light leakage into the filter-wheel

The improved filter-wheel case consists of nine pieces described in Table 5. Figure 34 shows the front and rear view of the filter wheel fully assembled. The strength of the case design is its symmetry. The ports for the control mechanism are all identical, hence we can switch the side in which the motor go in order to avoid interference between modules.

Table 5. Filter Wheel Case Assembly Pieces

Name	Picture	Qt	Description
Main faces Al 6061 17.34x20.70x0.25		2	• One 5.00” clear aperture. • Two 1.50” automation control access ports • Eight threaded 10-32 holes at a diameter of 7.5” around the 5.00 clear aperture. • Eight Threaded 10-32 holes at a diameter of 9.0” around the 5.00 clear aperture • 0.40” rotation axis clearance hole • Around the edge a counter sink 8-32 clearance holes.
Top Bar Al 6061 17.59x1.25x0.625		1	• Nine 8-32 threaded holes, to join the two main faces.
Bottom Bar Al 6061		1	• Four 8-32 threaded holes, to join the two main faces. • Two 8-32 clearance holes, to grab on to a handle
Right & Left Bar Al 6061		2	• Nine 8-32 threaded holes, to join the two main faces. • One end has a 0.5” overlapping region for the bottom bar.
Closing Cap Al 6061 Max 3.15” diameter circle 0.375” thick		2	• Four 8-32 clearance holes • 1.50” diameter raised 0.125”

Joining Cap Al 6061 Max 3.15" diameter circle 0.375" thick		1	• Four 8-32 clearance holes • 0.5" through hole • Six 8-32 threaded holes at 1.06" diameter • 1.50" diameter raised 0.125"
8-32x0.5" Flat Head Screws Stainless Steel		62	McMaster Part # 90585A228
8-32x0.5" Cap Head Screws Stainless Steel		16	McMaster Part # 91251A194

Filter wheel case assembly pieces. Each piece has a short description of its features. Dimensioned drawings for each piece can be found in the appendix section.

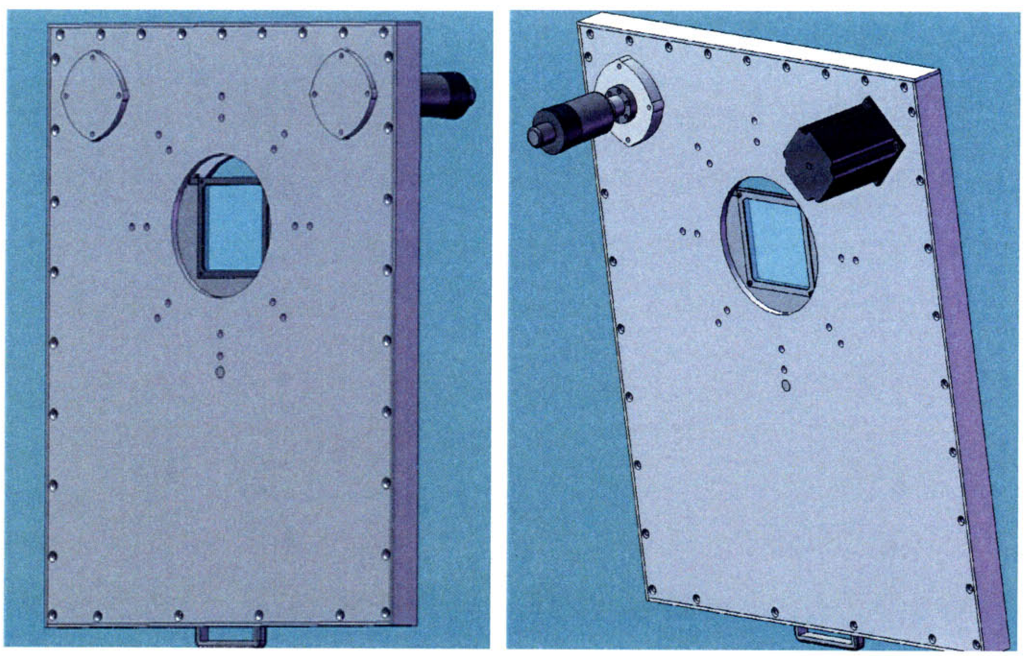


Figure 34 Filter Wheel Fully Assembled Front and Rear View

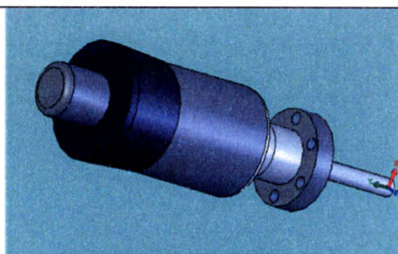
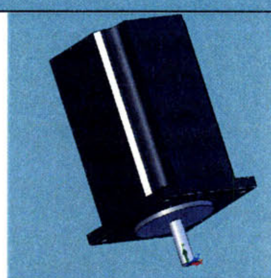
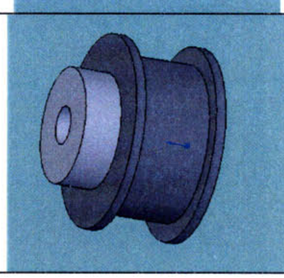
The left image shows the face of the filter wheel that faces the 24" telescope. The right image shows the face of the filter wheel towards the dewar and the two control mechanisms for rotating between filters.

3.4.4. Filter Rotating

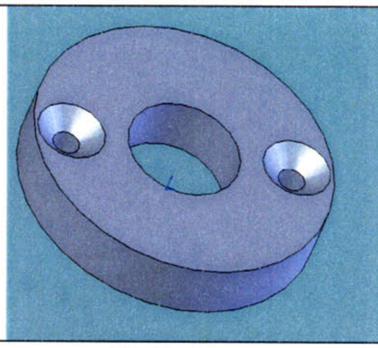
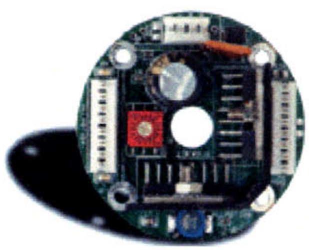
There are two ways of changing the filter on the optical axis. The first method is by using a MDC Direct hand dial which is accurate within ¼ of a degree depending on the user. The second method of changing filters is through a DC stepper motor. One pulse by the driver is equivalent to 0.9° degrees of revolution. The goal is to interface the stepper motor with LOIS[§§§] in order to change filters at the click of a button. Table 6 lists the parts needed for the controlling the filter rotation

The rotation of the filters is done using a 42" XL series timing belt that links the steeper motor, manual dial, and carousel together. Currently the gear ratio between the carousel and controls is one to two. Therefore, one full revolution of the stepper motor is only half a revolution for the carousel. Part of the design also allows for changing the gear ratio. The carousel gear must be at most ¼" thick with an inner diameter (ID) of 0.5", and also have the two 8-32 clearance holes for connecting the gear to the carousel. The gears for the hand dial and the stepper motor must have an ID of ¼".

Table 6 Filter-Wheel: Filter Control Parts

Name	Picture	Qt	Description
MDC Direct Hand Dial		1	MDC Direct hand dial control Part # 670000 REF# BRM-133
DC Stepper Motor		1	Lin Engineering 5718L-03S 2.1A (All Motion 2008) See Appendix II for datasheet.
XL Series 1.019 Pitch diameter gear		2	McMaster Part # 57105K16

[§§§] Camera control software

XL Series 2.017 Pitch diameter gear		1	McMaster Part # 6495K725 With minor modification to join to car
XL Timing belt 42" long	 Image from McMaster.com	1	McMaster Part # 6484K514
DC Motor Drivers		1	All Motion Driver http://www.allmotion.com/EZHR17Description.htm **2 Amp NEMA 17 High Resolution** **Intelligent Motion Encoder Feedback** Stepper Controller + Driver 10V - 40V 2Amp 1.6" x 1.6" Size 1/256th Step

The filter rotation is controlled by two driving pulleys (only one activated at a time), one driven pulley (on the carousel), one spring loaded tension mechanism (maintains the tension on the timing belt), all connected by one 42" XL timing belt (links all the driver pulleys and the driven pulley). Figure 35 shows the how the timing belt goes on the pulleys, carousel, and tension mechanism.

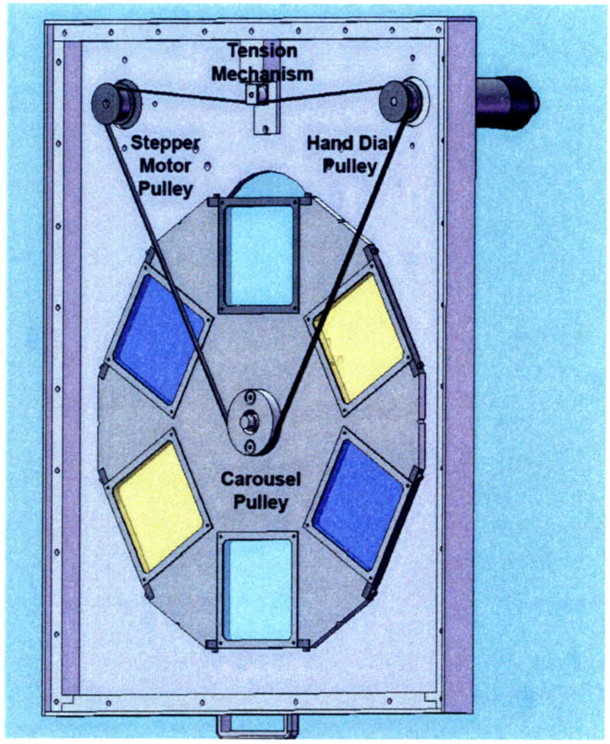


Figure 35 Filter Wheel Rotation Mechanism

The 42" XL timing belts connects: 1) hand dial pulley, 2) tension mechanism, 3) stepper motor pulley, and 4 carousel pulley. The current gear ratio of carousel to driving pulleys is one to two, respectively. The tension mechanism is a spring loaded piston with two ball bearings that press down on the timing belt but still allowing for the timing belt to rotate.

3.4.5. Removing and Adding Filters

Prior to Opening Filter Wheel

The tools required for changing filters is an English Allen key set.

- Align the filter wheel such that the filter that will be changed is at the bottom of the filter wheel carousel.

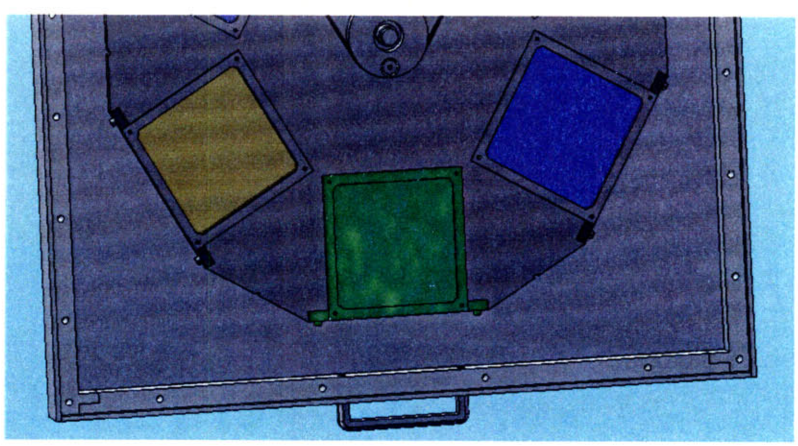


Figure 36 Filter Wheel Removal Alignment

Aligning a filter into the removal location.

• Lock the hand dial control by turning the small knob (behind the degrees dial) clockwise. The degrees dial will no longer rotate freely.
• Place the new filter in a filter holder. See Figure 30 for holder assembly layout.

Procedure

1. Remove the eight 8-32 cap head screws (9/64 Allen key) that hold bottom of the filter-wheel case. This is the section of the filter-wheel that has a handle.
    a. At no point during the filter changing process is there a need to remove the front or back panels. Leave those connected. The figures below don't have the front panel showing in order to show the location of the filters relative to the case.
2. Pull the bottom section out by the handle.

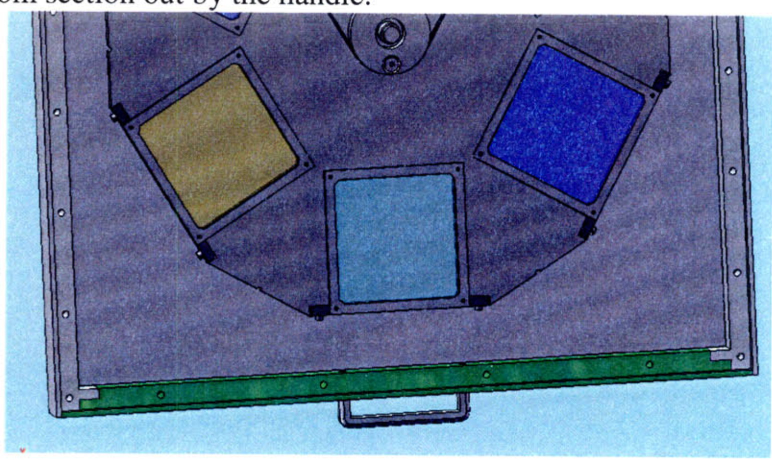


Figure 37 Filter Wheel Removal Handle.

Shows the filter wheel handle to remove when replacing a filter.

3. Using an 3/32" Allen key remove the two 4-40 screws that hold the filter holder to the carousel.
4. Holding the new filter holder by the sides guide the filter into place using the 1/8" dowel pin at the bottom of the holder. Also notice the alignment of the 2-56 cap screws. The caps of the 2-56 are on the opposite side of the timing belt.

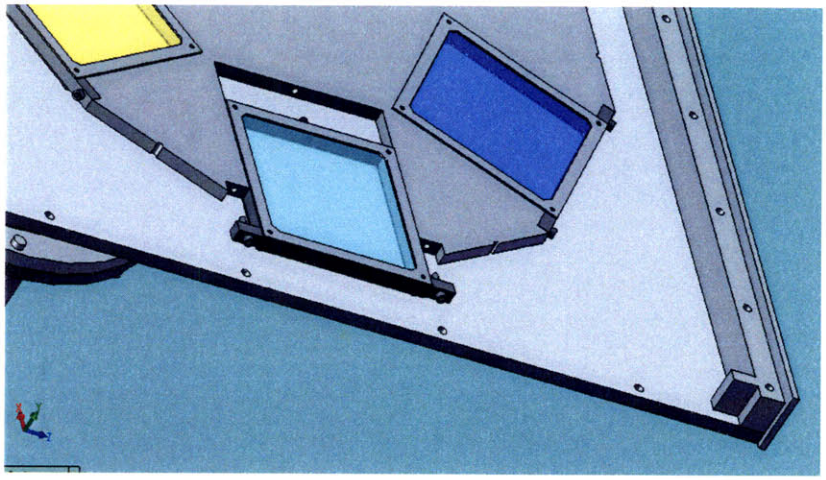


Figure 38 Filter Wheel Sliding.

Shows the sliding motion of the filter as it is removed from the carousel. The front plate is not shown in the image.

5. Secure the new filter holder to the carousel. The 1/8" dowel pin and the edges of the filter holder are used to align the filter to the carousel.
6. Place bottom section of the filter case back on and secure via the 8-32 screws.
7. Make the change in LOIS of the new filter.

3.5. Instrument Interfaces

The purpose of the instrument interfaces is to bring the different camera components together into one light tight assembly. The interfaces also serve to separate the camera into modules that can be easily replaced. If there are no replacements, for example the filter wheel, then that module is removed the camera can continue to be used without the filter wheel. Not only do the instrument interfaces have to be light tight, but they also have to be load bearing.

The interfaces allow for modules to be removed with minimal impact to the rest of the camera. The design is based on a lock and key system. Each plate is 0.375" thick or 0.5" thick depending on the shear stress that it has to withstand. Interface one and two are 0.5" thick and interfaces three to five are 0.375" thick. While the clearance aperture in the key changes for each interface, the bolt circle diameter does not change. Figure 39 shows how the lock and key design work with a hexagonal shape that allows us to rotate each module independently. Figure 40 shows the lock and key alone.

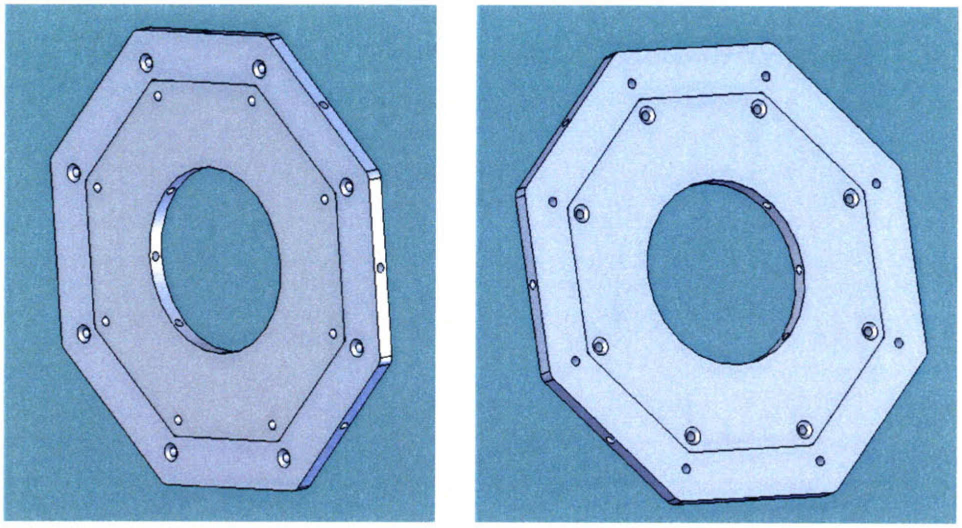


Figure 39 Module Interface Assembly

Front and back view of a module interface assembly.

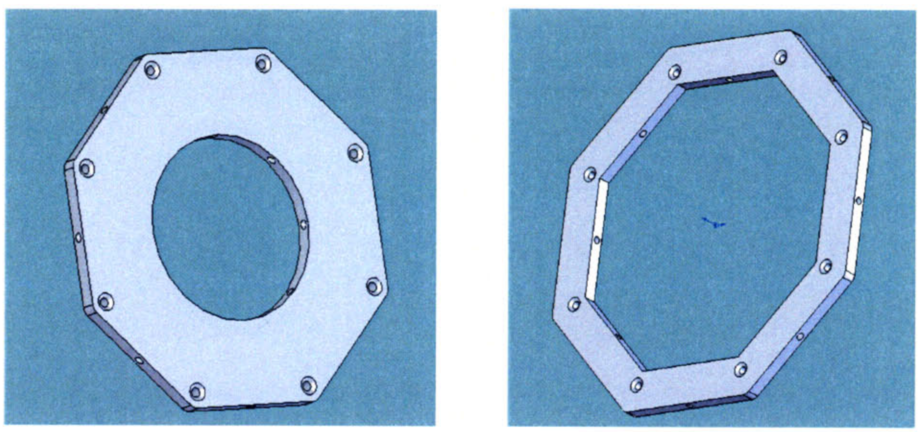


Figure 40 Interface: Lock and Key

The image on the left is the key. The image on the right is the lock. They connect via eight 10-32 screws that run parallel to the faces.

3.6. Field Rotator

The purpose of the field rotator is to allow for accurate alignment of the CCD with celestial coordinates such as needed for strip scanning surveys. The field rotator in mind is three inches thick with a clear focal path of 4.75 inches. RC Optical Systems makes the field rotator that meets the needs for the 24" telescope (RC Optical Systems 2008), see Figure 41.

Figure 41 RC Optical System Inc. Field Rotator

The image is a field rotator from RC Optical Systems. The aperture size is 4.75". It weights ten pounds. Features include: tapped 5.125" bolt circle for 10-32, less than 3" profile, and a robotic control system. Image is from RC Optical Systems Website.

3.7. Four Port Instrument Rotator

The four port instrument rotator will allow for the changing of instruments by the flip of a mirror. The three detectors that will go on the instrument rotator are: 1) WAOcam, 2) POETS, and 3) 1" eye piece. The space allocated for the four port instrument rotator is 10", not including the interfaces. The estimated weight of the instrument rotator is 25 pounds, from a preliminary design project.

4. Camera Specification

The operational temperature of the WAOcam detector is minus 120° Celsius. The camera is currently being tested and is not operational on the 24" telescope. The dewar and shutter are complete, but the new redesigned filter-wheel case is awaiting manufacturing.

The active area of the detector is 2"x 2" but the total detector size is 2.5" x 2.5". Each pixel is 24 microns x 24 microns, relating it to the size of the active area yields a 2048 pixels x 2048 pixel per image. The detector is divided into four equal sections each with its own amplifier. The readout time using the four amplifiers un-binned mode is 25 seconds. Through LOIS, the detector can be binned in 2x2, 3x3, and 4x4 modes.

A leak of the PT30 working gas has prevented any additional testing on WAOcam, for a period of a month. Currently, the repair of the CryoTiger has been completed. The next step in the project is to modify the LOIS software to control the SiTe 2kx2k CCD. Preliminary test in spring 2007 show that the SITe 2kx2k CCD is functional, but there is a problem with the bias levels in the four amplification mode, an issue that can be fixed through LOIS.

5. Current Status

WAOcam is currently not operational. The original circuit boards created for MagIC were not all identical, additional changes must be made to LOIS before running WAOcam after the November 2007 re-wiring. Dr. Michael J. Person is in charge of taking care of all of the software development for the LOIS version for WAOcam. Matt Lockhart has been put in charged of interfacing the filter wheel controls to LOIS. All of the mechanical aspects of WAOcam are functional, the only tasks remaining are fixing the software interface with LOIS and testing.

6. Conclusion

The objective of this project was to improve the scientific capabilities of the George R. Wallace, Jr. Astrophysical Observatory by designing and manufacturing WAOcam, a new CCD camera designed specifically for the 24" telescope at Wallace Observatory. WAOcam consists of three modules:1) dewar, 2) shutter, and 3) filter-wheel. All of the components are in accordance with the requisite set by the scientific objectives, designed to avoid stray light leakage into the optical path. Each module was designed to function independently. All of the components are within the acceptable tolerances. With the exception of machining a new filter-wheel case, all of the mechanical components for WAOcam have been created.

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8. Appendices

The appendix section contains engineering diagrams, assembly illustrations, wiring diagrams, and relevant data sheets for WAOcam. The drawings were generated using SolidWorks.

Appendix A WAOcam Parts List

Item	Assembly	Quantity	Description
CryoTiger			
CryoTiger	CryoTiger	1	Pump. Order from Brooks Automation.
CryoTiger Hoses	CryoTiger	2	25 feet long CryoTiger Hoses. Order from Brooks Automation
Dewar:Cryohead Appendix E			
Cryohead	Cryohead	1	Cooling Unit Drawing: W_C_H_v1 Appendix B and Appendix C
CryoTiger Extender	Cryohead	2	Connect to cryohead to Protect the spring loaded seals. Order from Brooks Automation: Part #
Cryohead case	Cryohead	1	Encloses the cryohead into the dewar. Drawing: W_C_Case_v1 Appendix D
CryoTiger Head Harness	Cryohead	1	Manufactured to protect the feeds to the cryohead. Drawing: Pending Manufacture
10-32x0.5 Hex Socket Cap Screws & Washers	Cryohead	16	Eight join the cryohead to the cryohead case. The other eight join the case to the dewar back lid. McMaster Part 92200A342.
O-ring 153 Viton	Cryohead	2	Secures interface between cryohead and case. Another O-ring is used between the case and the dewar back lid. McMaster Part 1201T823.
Dewar:Backlid			
Backlid	Dewar Back Lid	1	Manufactured. Drawing: W_D_BL_v1 Appendix F
O-ring 261 Viton	Dewar Back Lid	1	Secures interface between dewar case and back lid. McMaster Part 1201T894
¼-20x.05 Hex Socket Cap Screws & Washers	Dewar Back Lid	8	Unites the dewar back lid to the dewar case. McMaster Part
Glass Hermetic Connector	Dewar Back Lid Hermetic	1	ITT Cannon Part Drawing: W_D_E1_V1 Simple Model Appendix G
O-ring 128 Viton	Dewar Back Lid	1	Secures interface between hermetic connector and dewar back lid.

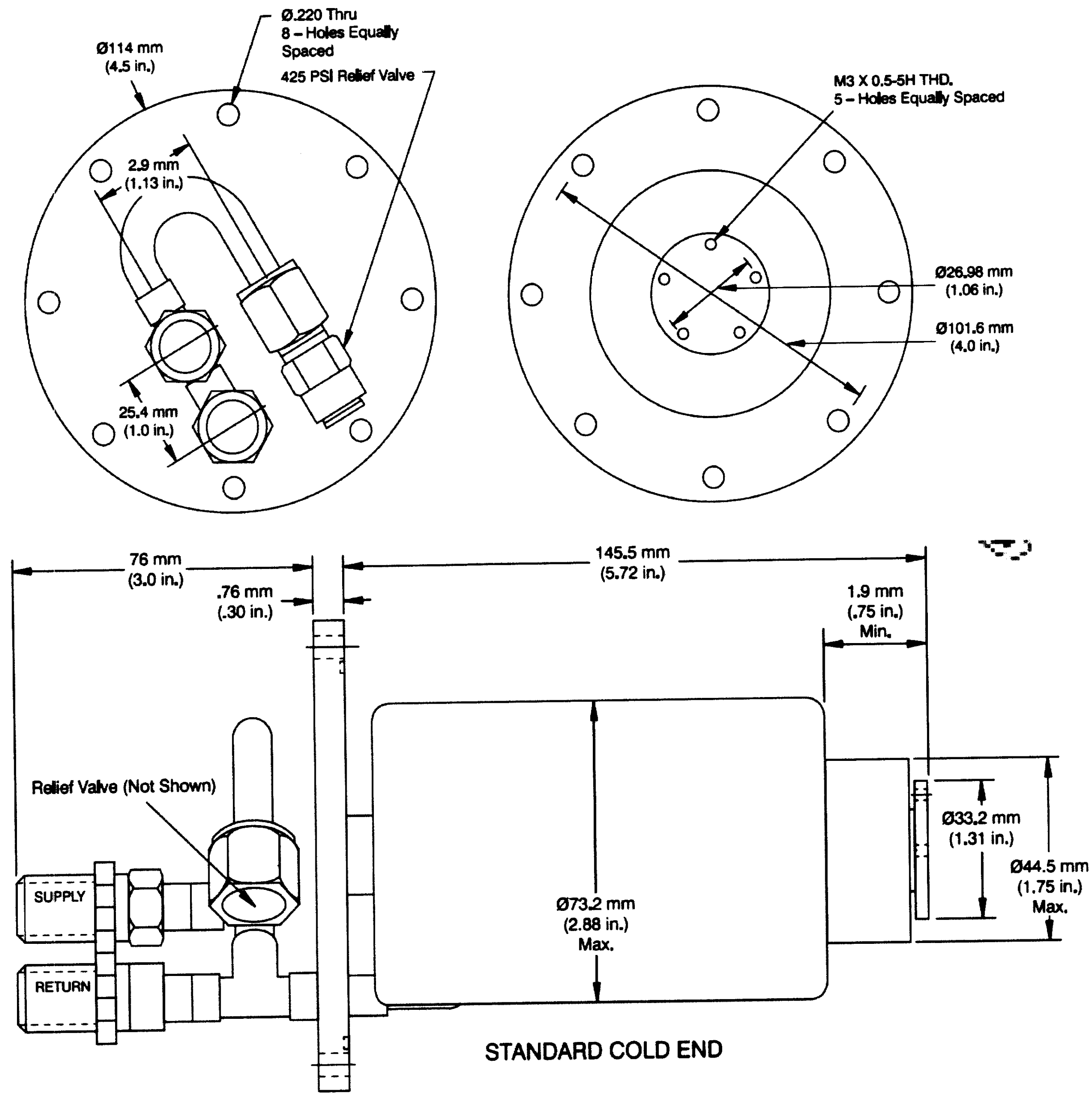
	Hermetic		McMaster Part 1201T787
4-40x0.25" Hex Socket Cap Screws	Dewar Back Lid Hermetic	4	Unites the glass hermetic connector to the dewar back lid.
Pressure gauge	Dewar Back Lid Gauge	1	Obtained
Valve	Dewar Back Lid Valve	1	½" Valve size Reference AV-050M MDC Vacuum Products Part # 312055
Bulkhead Clamp with 10-32 screws	Dewar Back Lid Flanges	4	Used to join the pressure gauge and the valve to the two standard flanges on the dewar back lid. NW16, 6 bolts, BC 1.50", THK 0.36" MDC Vacuum Products Part # 716000
Centering Rings	Dewar Back Lid Flanges	2	Keep the vacuum between the pressure gauge and back lid, and the valve and the back lid. NW16, ID 0.63", O-ring ID 0.73" MDC Vacuum Products Part # 710000
Dewar: Case Appendix O			
Case	Dewar Case	1	Manufacture Drawing: W_D_C1_v2 Appendix J
Seal Flange OD 1.33" with Gasket & Screws	Dewar Case	1	Closes the standard flange on one side of the dewar case. MDC Vacuum Products: Part # 110000 Flange Part # 191001 Gasket Part # 190000 Socket Head Screw
Seal Flange OD with Gasket & Screws	Dewar Case	1	Closes the standard flange on one side of the dewar case. MDC Vacuum Products: Part # 110008 Flange Part # 191005 Gasket Part # 190040 12-PT Bolts
Dewar: Front Lid			
Front Lid	Dewar Front Lid	1	Manufacture Holds the window. Drawing: W_D_FL_v1 Appendix K
Front Lid Lock	Dewar Front Lid	1	Manufacture Drawing: W_D_FL_clamp v1 Appendix L
Fused Quartz Window	Dewar Front Lid	1	Dewar window Order from Esco Products Drawing: W_D_FL_G_v1

			Appendix M
O-ring 152 Viton	Dewar Front Lid	1	Secures the vacuum interface between the window and the front lid. McMaster Part # 1201T822
O-ring 260 Viton	Dewar Front Lid	1	Secures the vacuum interface between front lid and the dewar case McMaster Part # 1201T893
Eight 2-56x0.25 Cap Head Screws	Dewar Front Lid	8	Presses the Front Lid lock to the front lid, holding the dewar window. McMaster Part # 92196A074
Eight 4-40x0.25 Cap Head Screws	Dewar Front Lid	8	Join the front lid to the dewar case. McMaster Part # 92185A106
Dewar:Interior			
Brass Threaded Rod (6-32x0.5")			Manufacture Drawing: W_D_Interior_rods v1 Appendix P
ABS Plastic Raisers (0.375 D x 6.625" L)			Manufacture Drawing: W_D_Interior_rods v1 Appendix P
CCD Mount			Manufacture Drawing: W_D_H2_v1 Appendix Q
6-32x 0.375 Hex Socket Cap Screw		14	McMaster Part #
SiTe 2kx2k		1	Obtained Drawing: W_D_E_SiTe Appendix R and Appendix S
Thermal Connection Part 1: CCD Mount		1	Manufacture Drawing: W_D_TC_CM_v1 Appendix T
Thermal Connection Part 2: Copper Ribbon		1	Manufacture No drawing available. The part consist of four layers 0.035" thick, ½" wide and 4" long.
Thermal Connection Part 3: Cryohead		1	Manufacture Drawing: W_D_TC_C1_v1 Appendix U
Shutter Appendix AA			

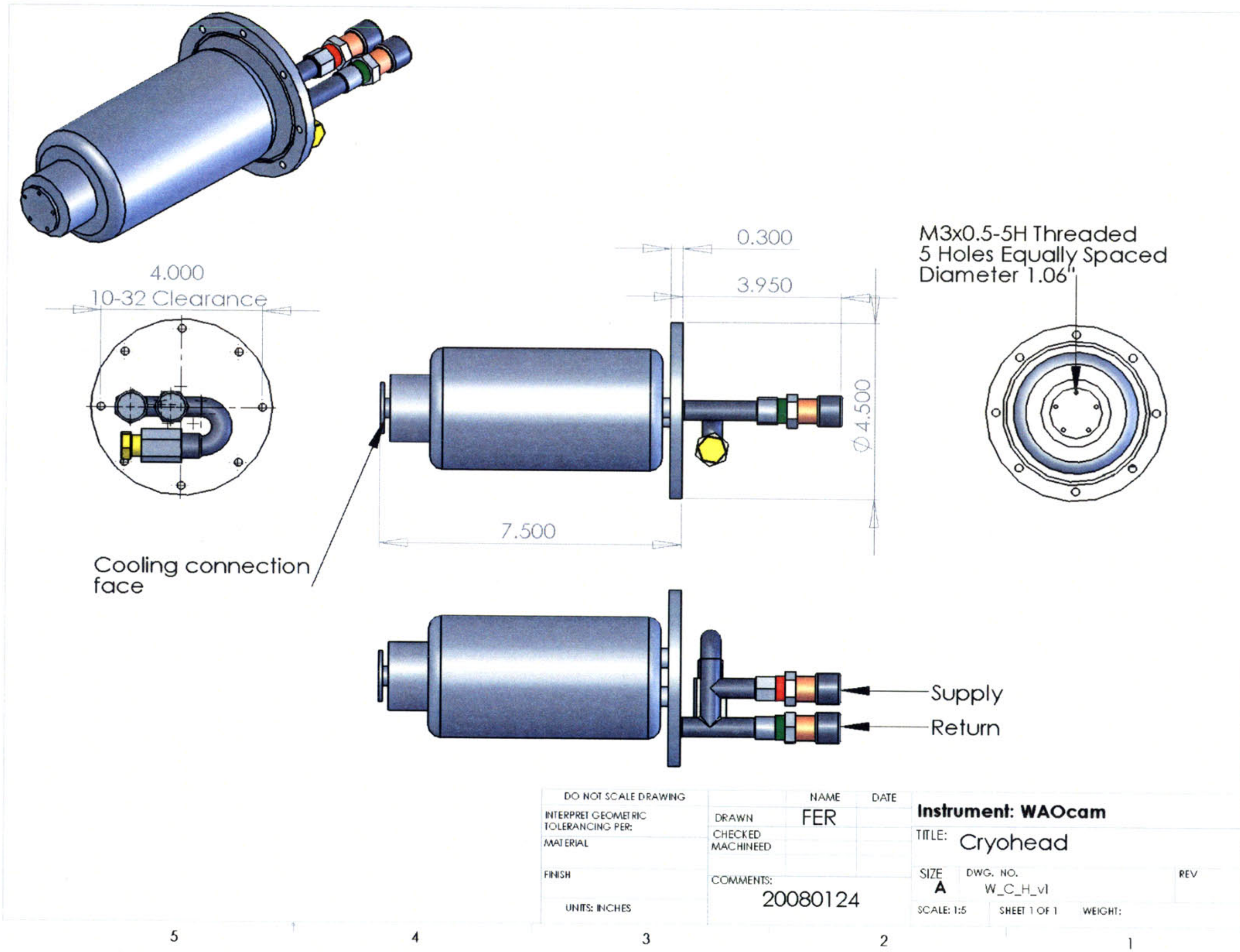
Shutter Mechanism	Shutter	1	Obtained. Drawing: W_SC_Shutter Assembly Appendix V
Shutter: Case			
Front & Back Panels		1	Manufacture Drawing: W_SC_FB Parts Appendix W
Top Panel		1	Manufacture Drawing:W_S_Top v1 Appendix X
Right & Left Panels		1	Manufacture Drawings: W_SC_RL Parts V2 Appendix Z
Bottom Panel (Power)		1	Manufacture Drawing: W_SC_TB_power part v1 Appendix Y

** For Filter Wheel parts see Filter Wheel section.

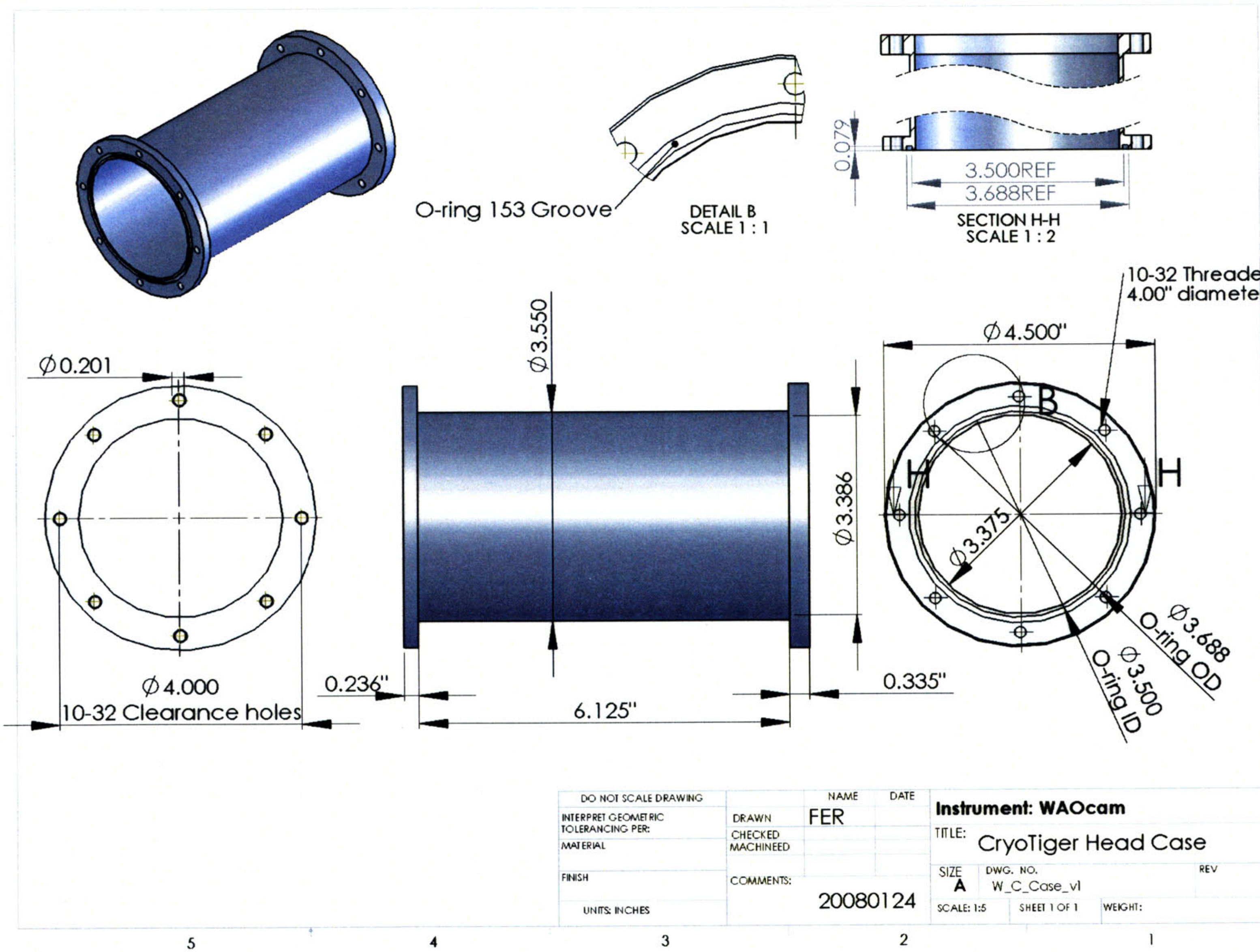
Appendix B Cryohead Drawings (CryoTiger Info Sheet)



Appendix C Cryohead (Drawing: W_D_H_v1)



Appendix D Cryohead Case (Drawing: W_D_Case v1)



Appendix E Cryohead Assembly Schematic

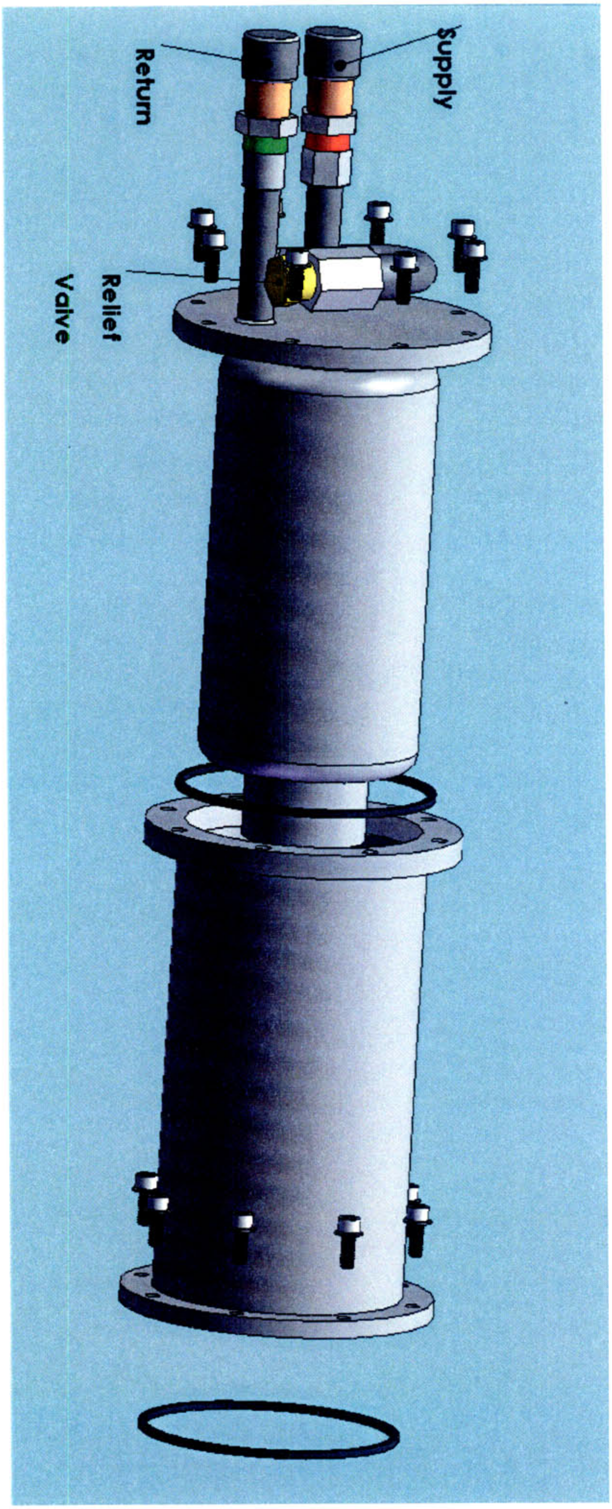


Figure 42 Dewar Cryohead Assembly

Appendix F Dewar Back Lid (Drawing: W_D_BL_v1)

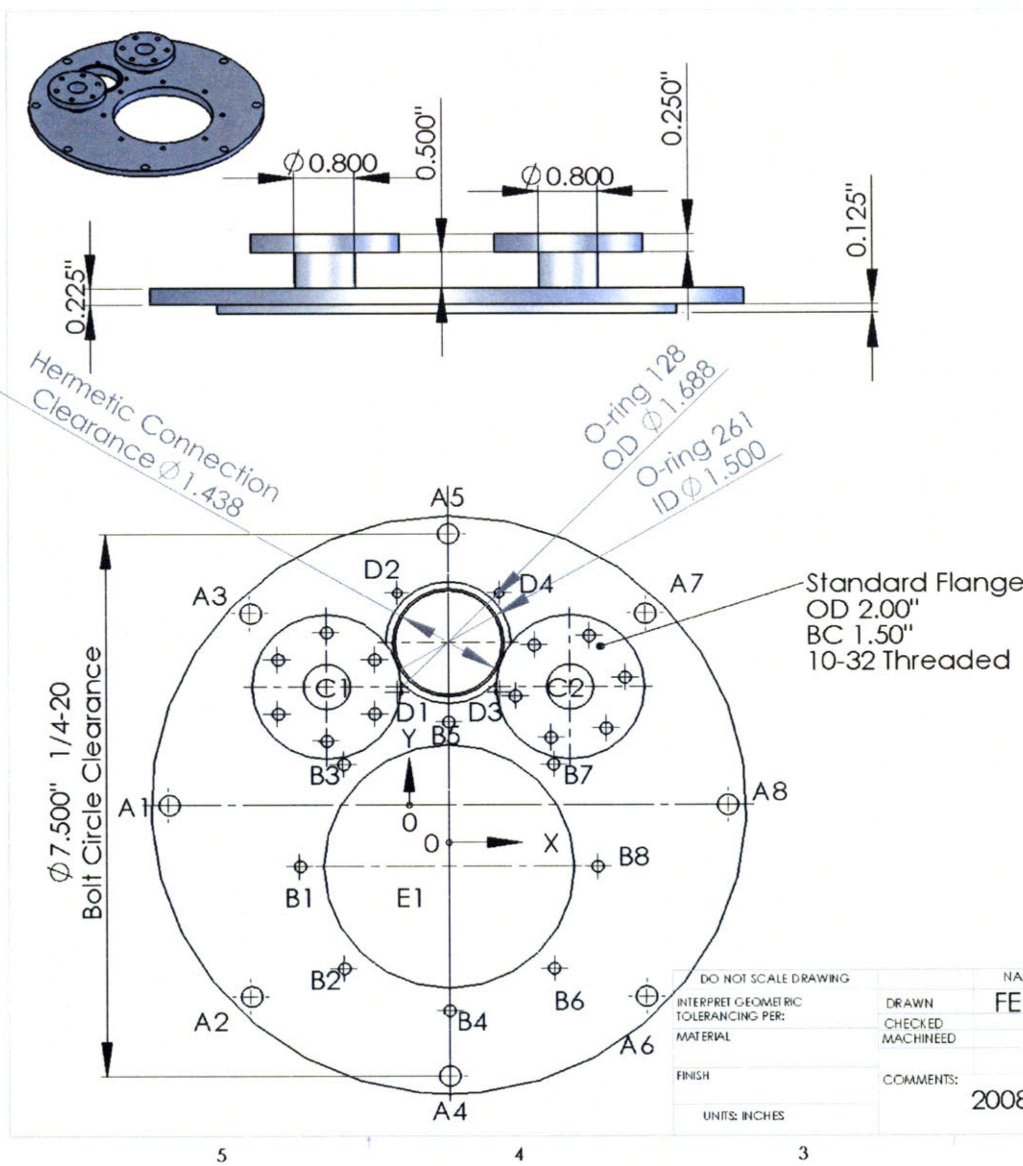
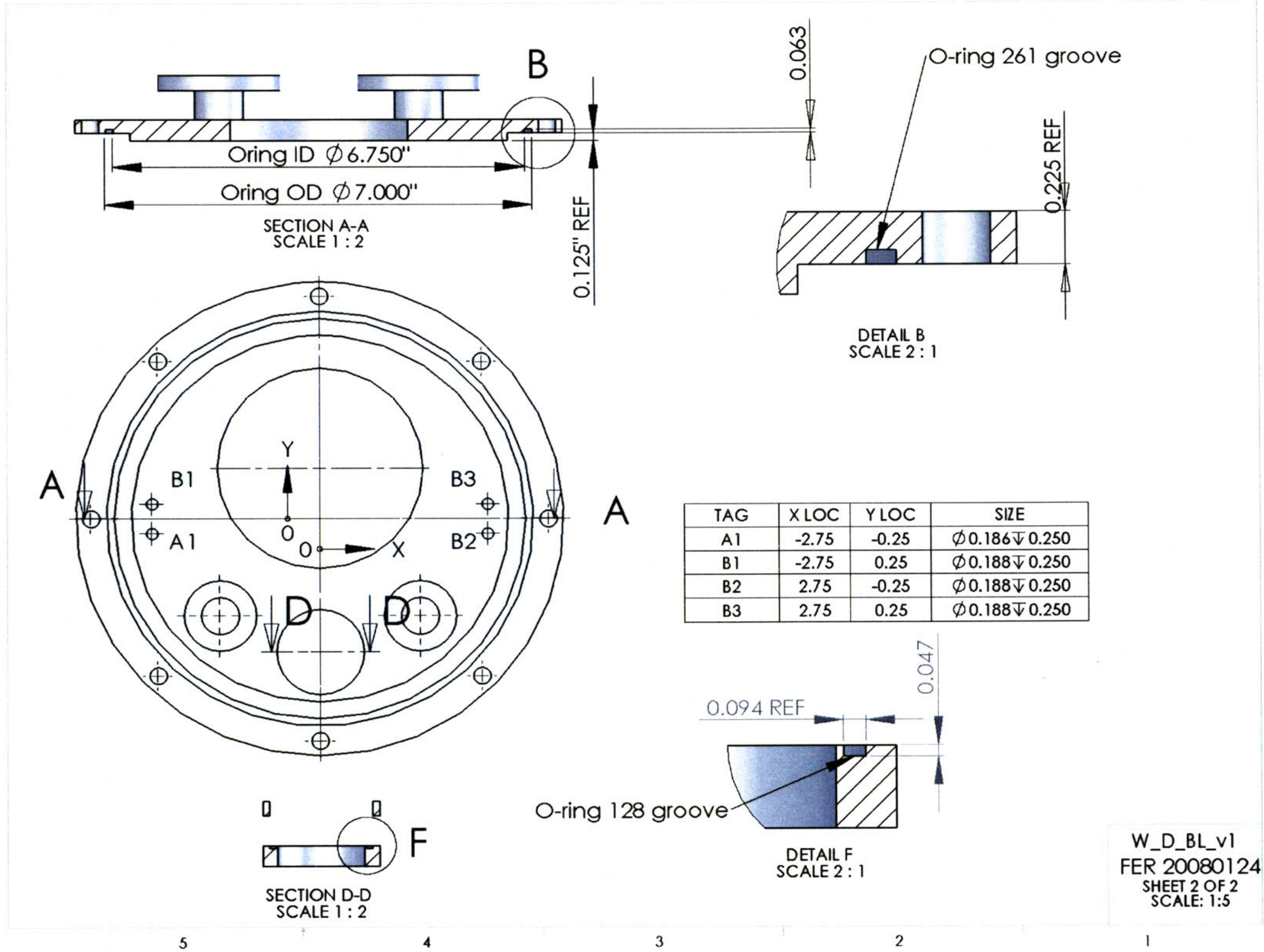


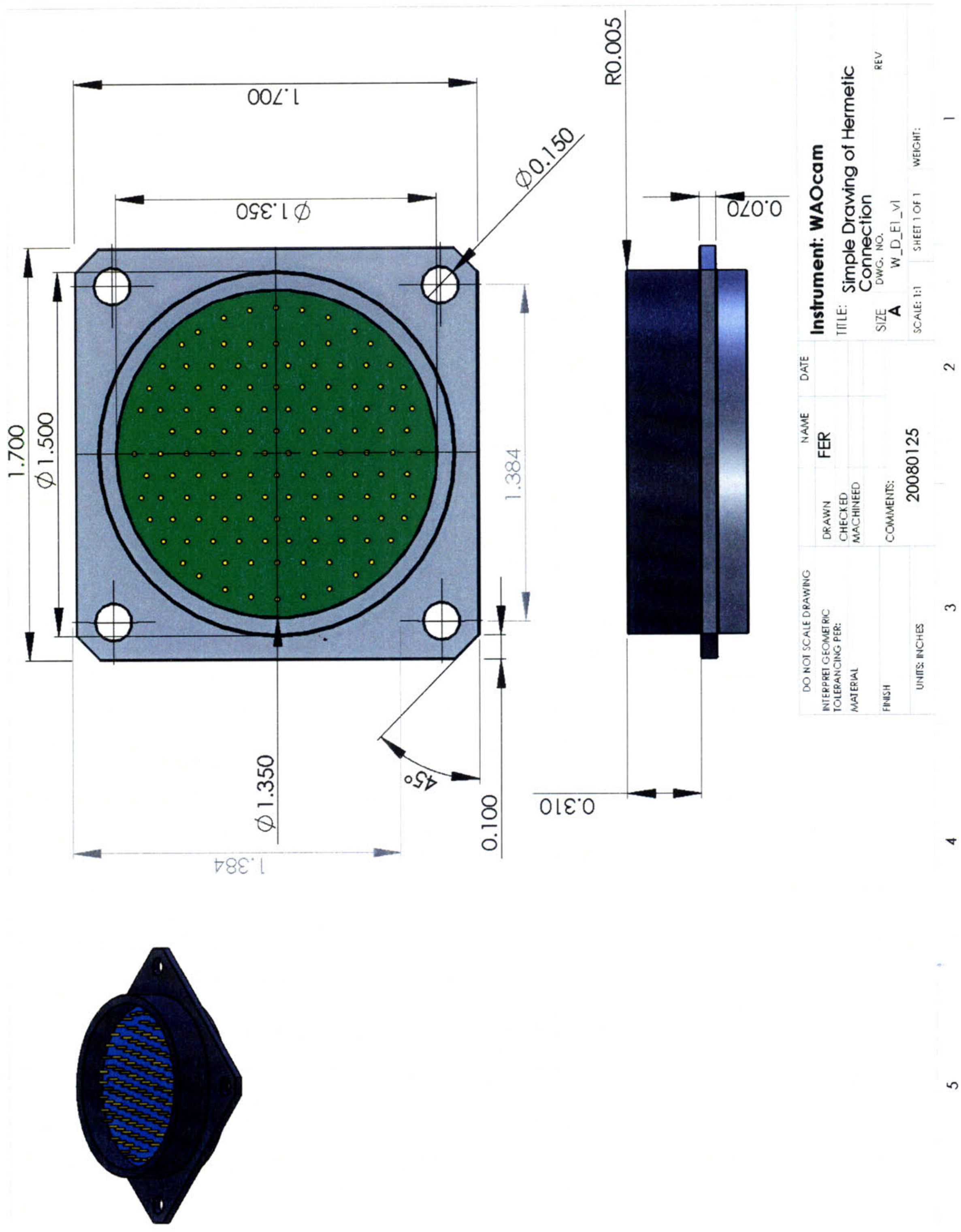
Table of Holes for exterior face

TAG	X LOC	Y LOC	SIZE
A1	-3.75	0.00	∅0.281 THRU
A2	-2.65	-2.65	∅0.281 THRU
A3	-2.65	2.65	∅0.281 THRU
A4	0.00	-3.75	∅0.281 THRU
A5	0.00	3.75	∅0.281 THRU
A6	2.65	-2.65	∅0.281 THRU
A7	2.65	2.65	∅0.281 THRU
A8	3.75	0.00	∅0.281 THRU
B1	-2.00	-0.85	∅0.159↧0.125
B2	-1.41	-2.26	∅0.159↧0.125
B3	-1.41	0.56	∅0.159↧0.125
B4	0.00	-2.85	∅0.159↧0.125
B5	0.00	1.15	∅0.159↧0.125
B6	1.41	-2.26	∅0.159↧0.125
B7	1.41	0.56	∅0.159↧0.125
B8	2.00	-0.85	∅0.159↧0.125
C1	-1.64	1.64	0.800 THRU
C2	1.64	1.64	0.800 THRU
D1	-0.69	1.56	∅0.125↧0.250
D2	-0.69	2.94	∅0.125↧0.250
D3	0.69	1.56	∅0.125↧0.250
D4	0.69	2.94	∅0.125↧0.250
E1	0.00	-0.85	∅3.375 THRU



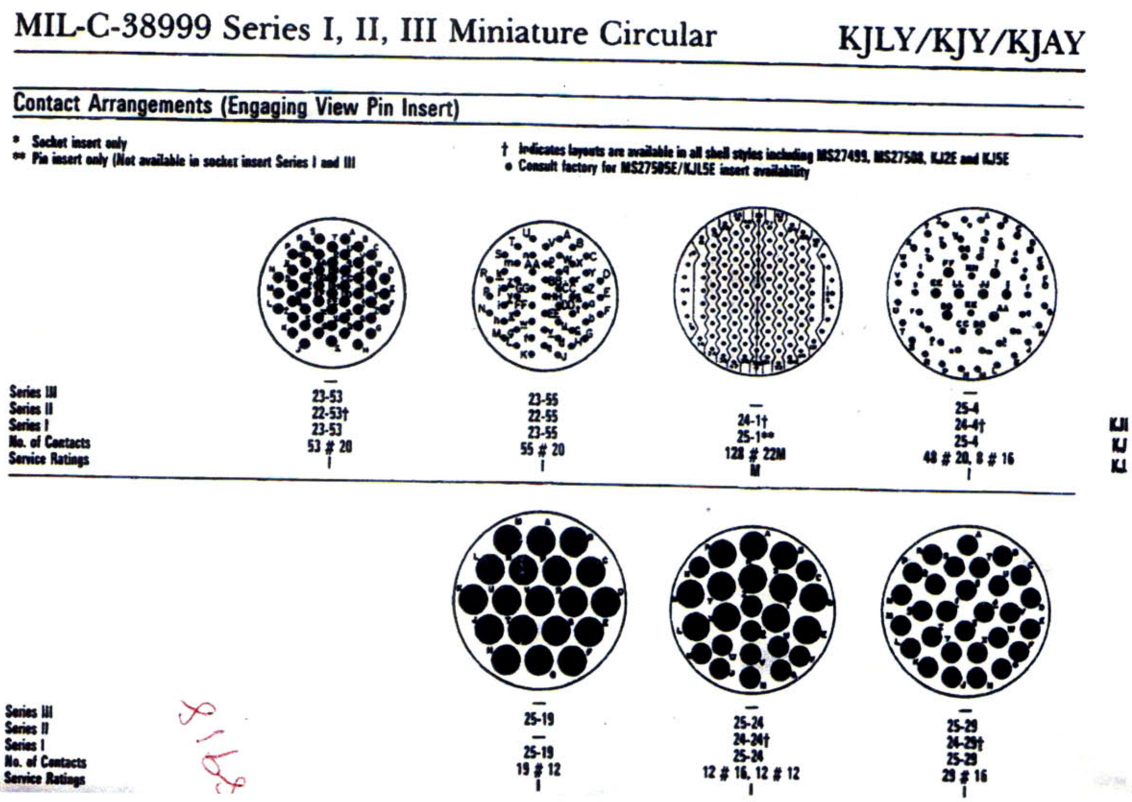
TAG	X LOC	Y LOC	SIZE
A1	-2.75	-0.25	∅0.186↧0.250
B1	-2.75	0.25	∅0.188↧0.250
B2	2.75	-0.25	∅0.188↧0.250
B3	2.75	0.25	∅0.188↧0.250

Appendix G Hermetic Connection (Drawing: W_D_EI_v1)



Appendix H Hermetic Connection Pin Layout

The hermetic connector used for WAOcam is the third connector on the first row. It is the only 128 pin connector on the diagram.



MIL-C-38999 Series I, II, III Miniature Circular KJLY/KJY/KJAY

Contact Arrangements (Engaging View Pin Insert)

* Socket insert only
** Pin insert only (Not available in socket insert Series I and III

† Indicates layouts are available in all shell styles including MS27499, MS27508, KJ2E and KJ5E
• Consult factory for MS27505E/KJL5E insert availability

Series III	23-53	23-55	—	25-4
Series II	22-53†	22-55	24-1†	24-4†
Series I	23-53	23-55	25-1**	25-4
No. of Contacts	53 # 20	55 # 20	128 # 22M	48 # 20, 8 # 16
Service Ratings	I	I	M	I

KJL
KJ
KJ

Series III	25-19	25-24	25-29
Series II	—	24-24†	24-29†
Series I	25-19	25-24	25-29
No. of Contacts	19 # 12	12 # 16, 12 # 12	29 # 16
Service Ratings	I	I	I

Appendix I Hermetic Connection Wiring

Provided by Steve Kissel

External J1 (37 dsub pin)   Circular 128 socket

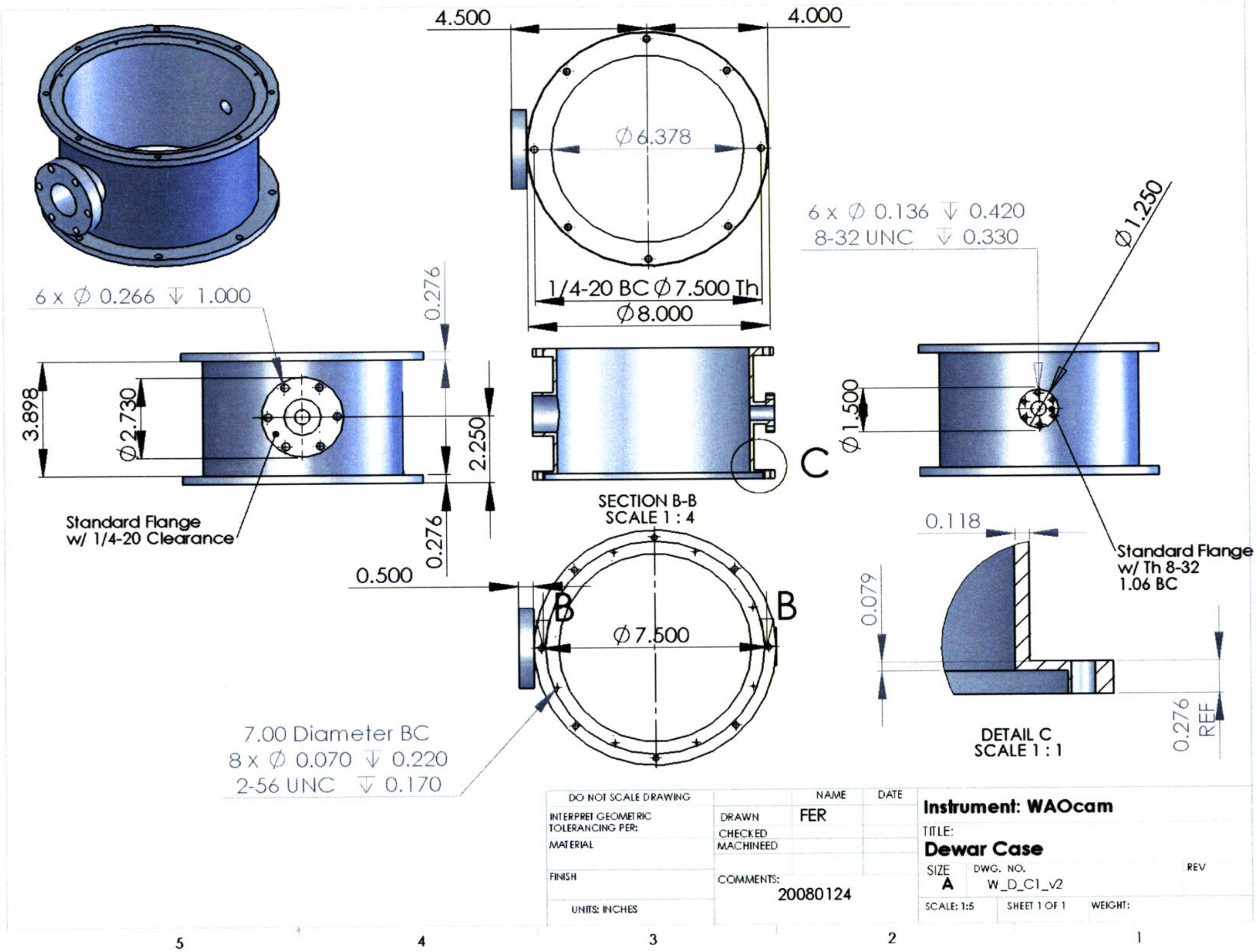
1 35
. .
. .
11 25
12 47
. .
. .
23 36
24 58
. .
. .
34 48
35 61
36 60
37 59

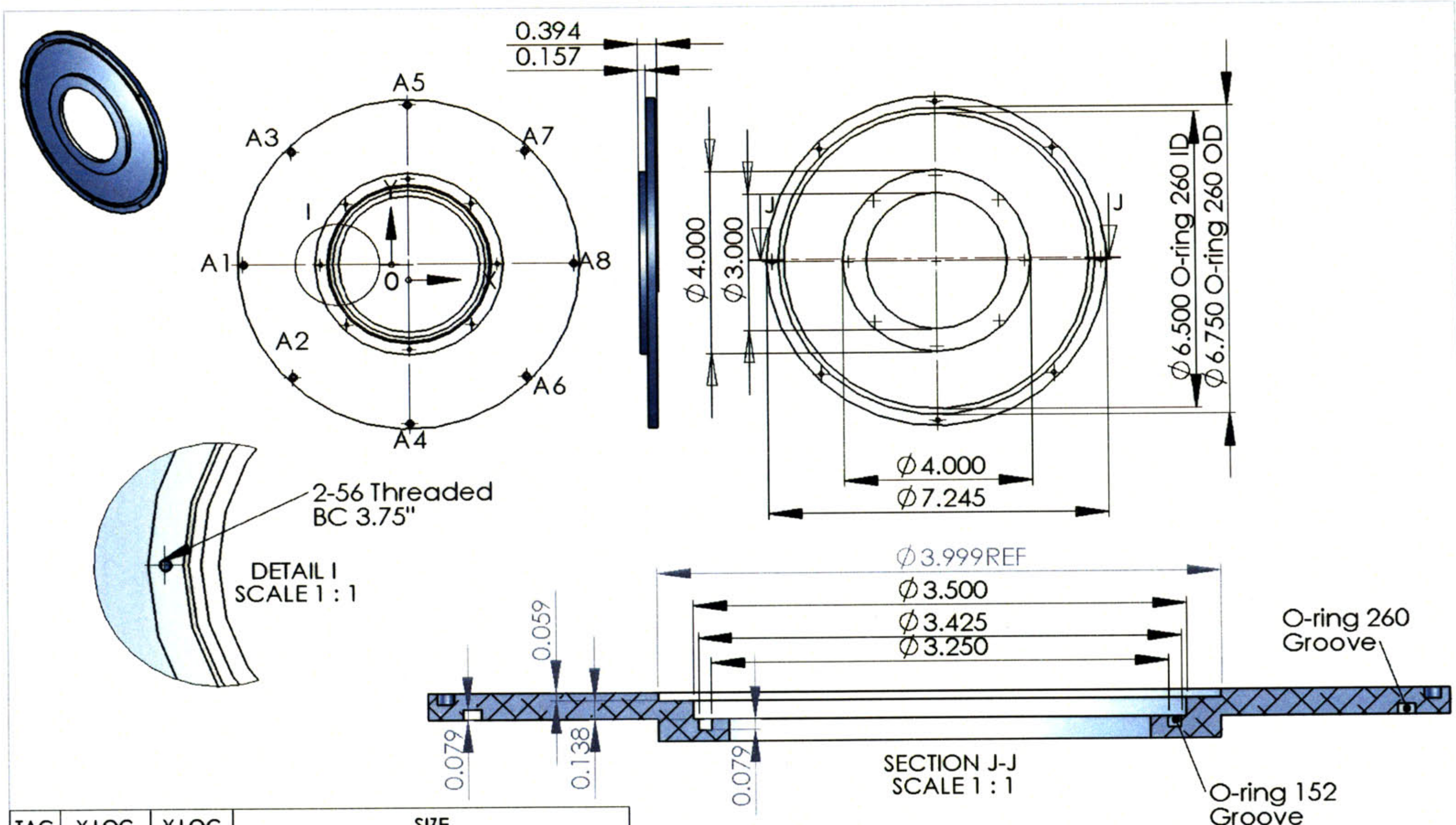
External J2 (37 dsub pin)

1 94
. .
. .
11 104
12 82
. .
. .
23 93
24 71
. .
. .
34   81
35 68
36 69
37 70

The internal portion just duplicates this so the end result of the assembly is 2x 37p wired pin-to-pin from outside to inside.

Appendix J Dewar Case (Drawing: W_D_C1_v2)





TAG	X LOC	Y LOC	SIZE
A1	-3.50	0.00	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A2	-2.47	-2.47	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A3	-2.47	2.47	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A4	0.00	-3.50	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A5	0.00	3.50	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A6	2.47	-2.47	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A7	2.47	2.47	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083
A8	3.50	0.00	Ø 0.096 THRU ALL ⌴ Ø 0.156 ↧ 0.083

DO NOT SCALE DRAWING
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		

COMMENTS: 20080125

Instrument: WAOcam

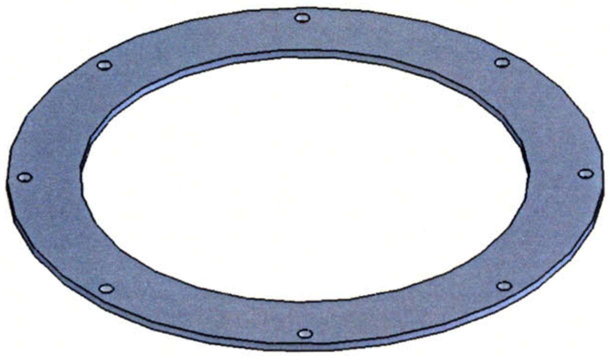
TITLE: **Dewar Front Lid**

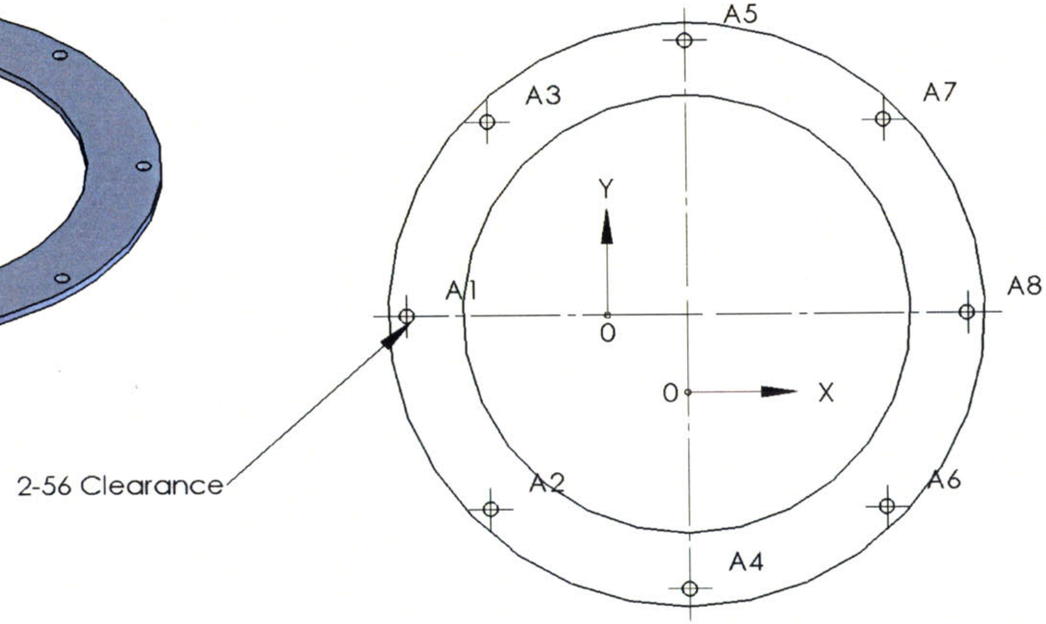
SIZE A | DWG. NO. W_D_FL1_vl | REV

SCALE: 1:5 | SHEET 1 OF 1 | WEIGHT:

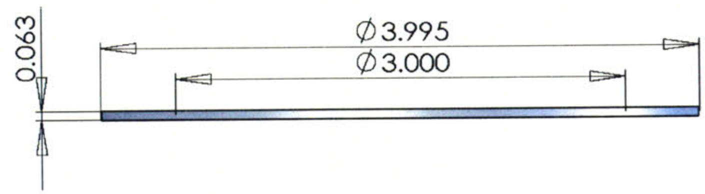
5 4 3 2 1

Appendix L Dewar Front Lid Lock (Drawing W_D_FL_clamp_v1)





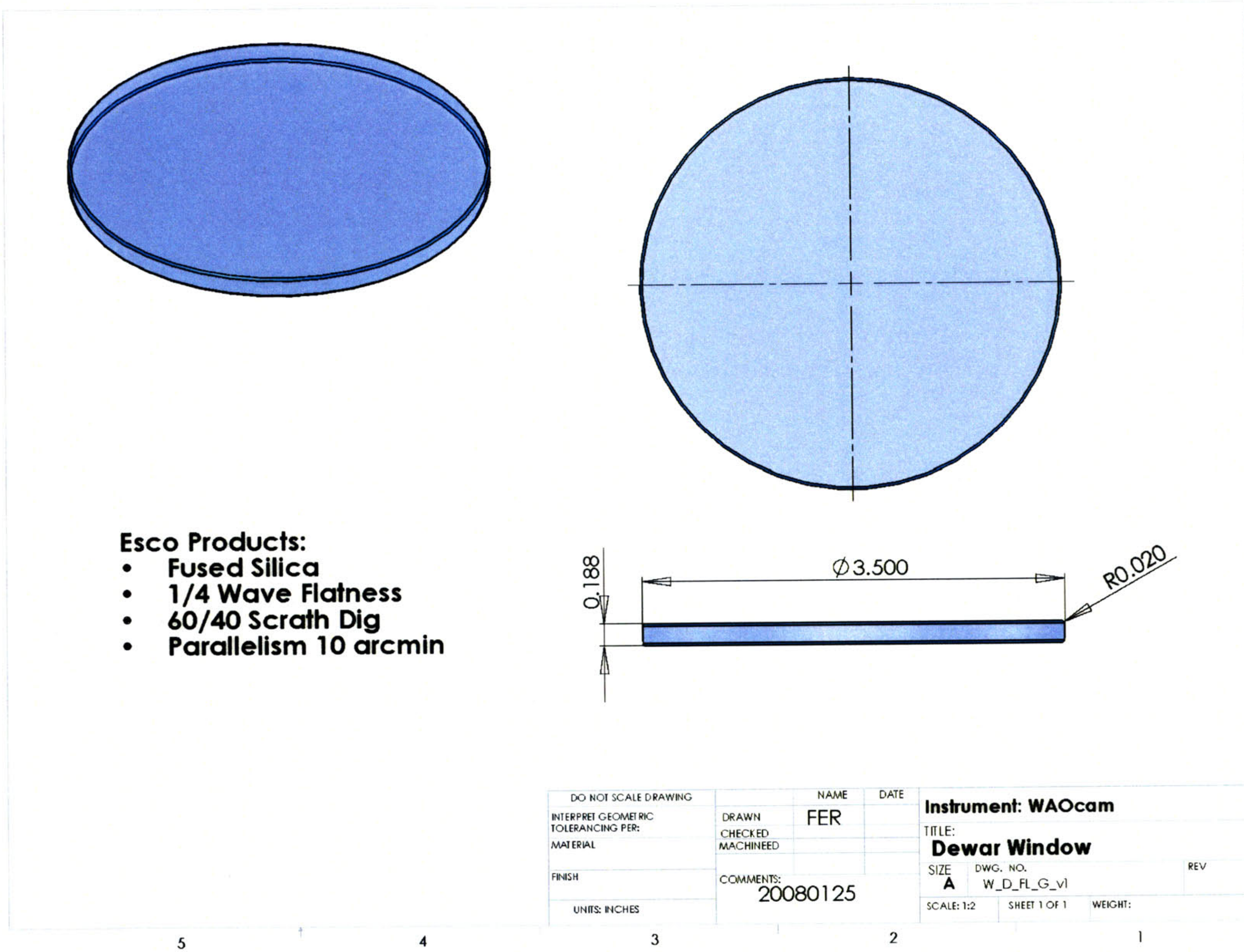
TAG	X LOC	Y LOC	SIZE
A1	-1.87	0.00	∅ 0.096 ↧ 1.000
A2	-1.33	-1.33	∅ 0.096 ↧ 1.000
A3	-1.33	1.33	∅ 0.096 ↧ 1.000
A4	0.00	-1.87	∅ 0.096 ↧ 1.000
A5	0.00	1.88	∅ 0.096 ↧ 1.000
A6	1.33	-1.33	∅ 0.096 ↧ 1.000
A7	1.33	1.33	∅ 0.096 ↧ 1.000
A8	1.88	0.00	∅ 0.096 ↧ 1.000



DO NOT SCALE DRAWING		NAME	DATE	Instrument: WAOcam
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER		TITLE:
MATERIAL	CHECKED MACHINEED			**Front Lid Lock**
FINISH	COMMENTS:			SIZE A · DWG. NO. W_D_FL_clamp_v1 · REV
UNITS: INCHES	20080125			SCALE: 1:2 · SHEET 1 OF 1 · WEIGHT:

5 4 3 2 1

Appendix M Dewar Window (Drawing: W_D_FL_G_v1)



Appendix N Front Lid Assembly

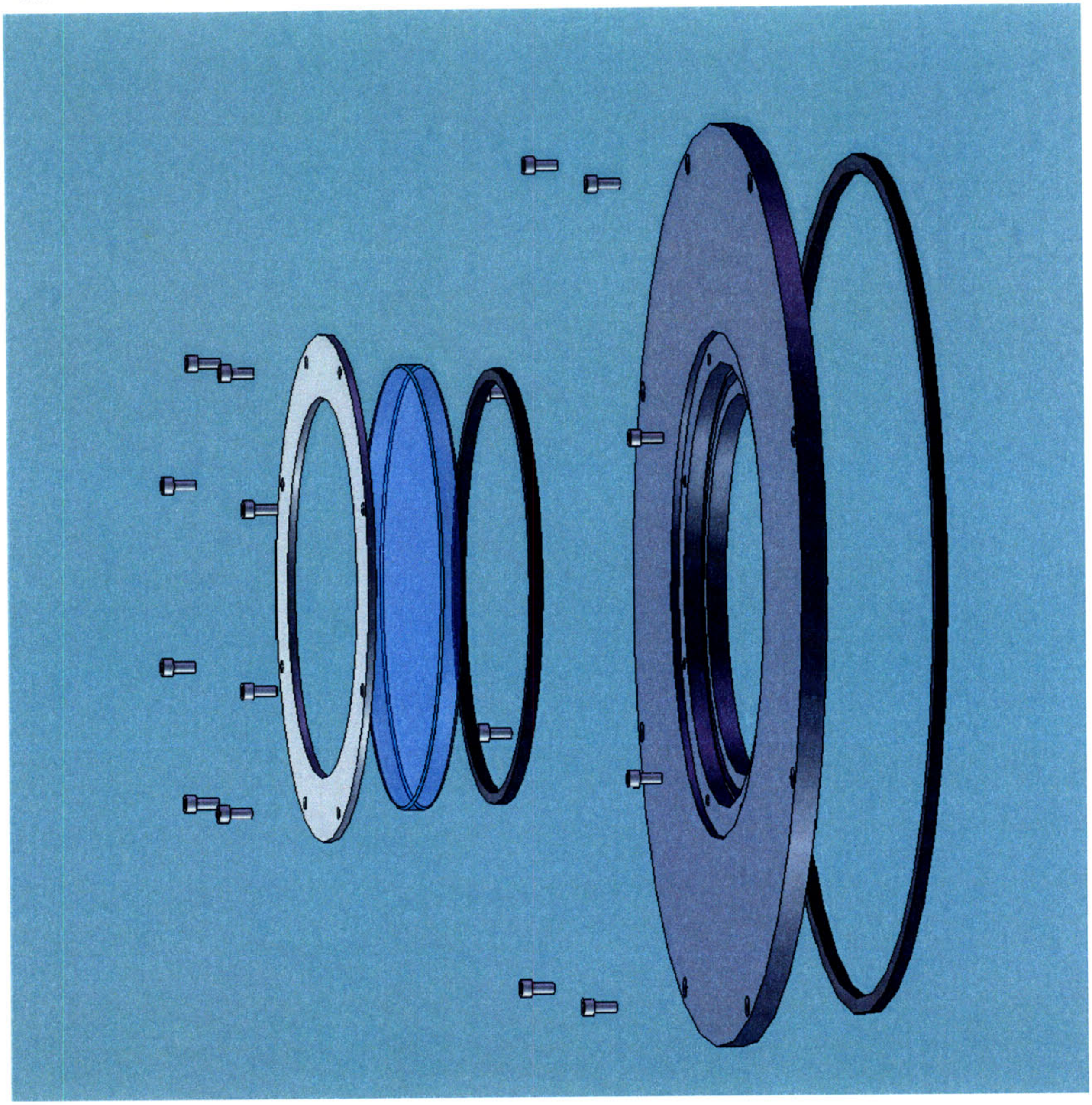


Figure 43 Dewar: Front Lid Assembly Layout

Appendix O Dewar Case Assembly

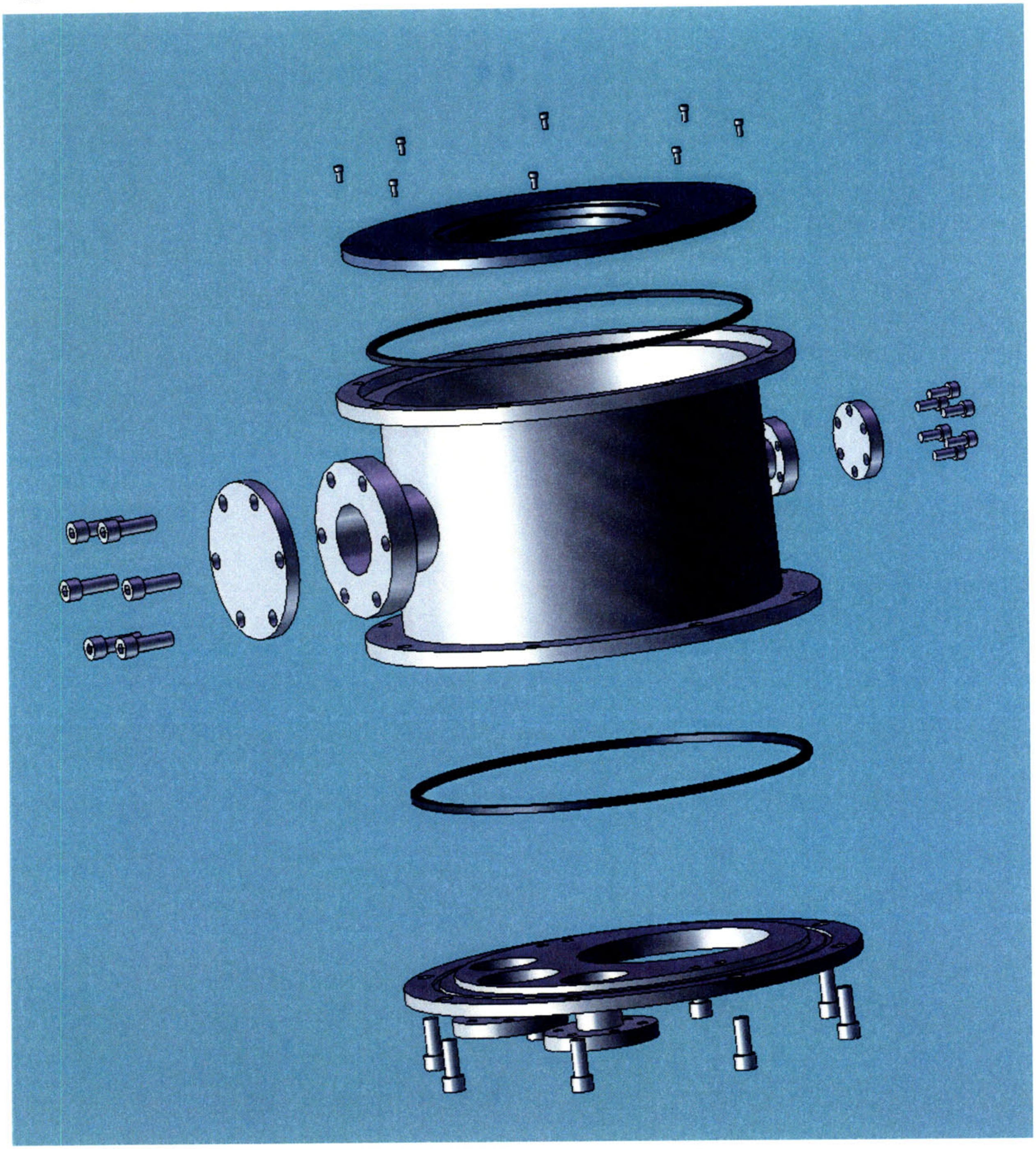
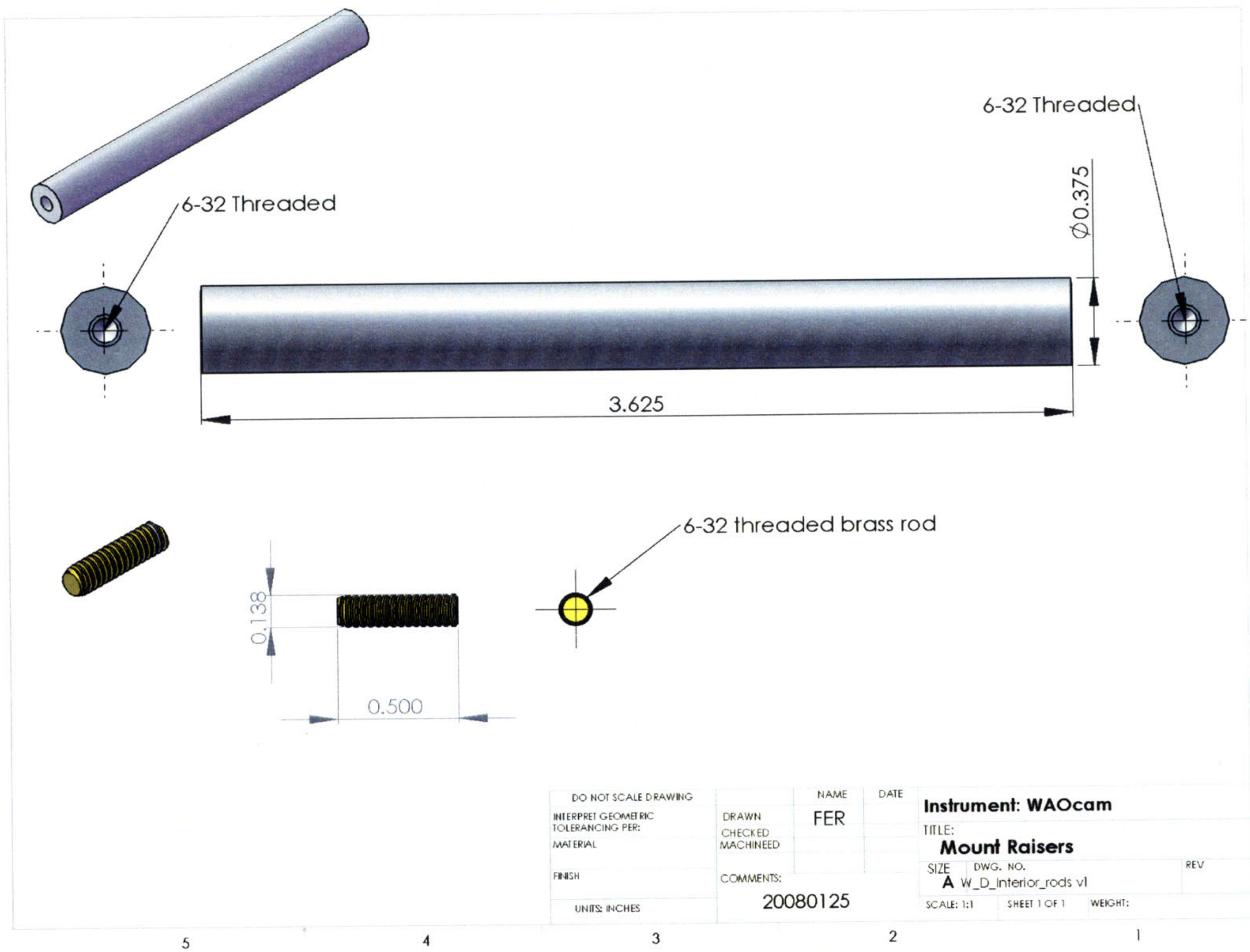
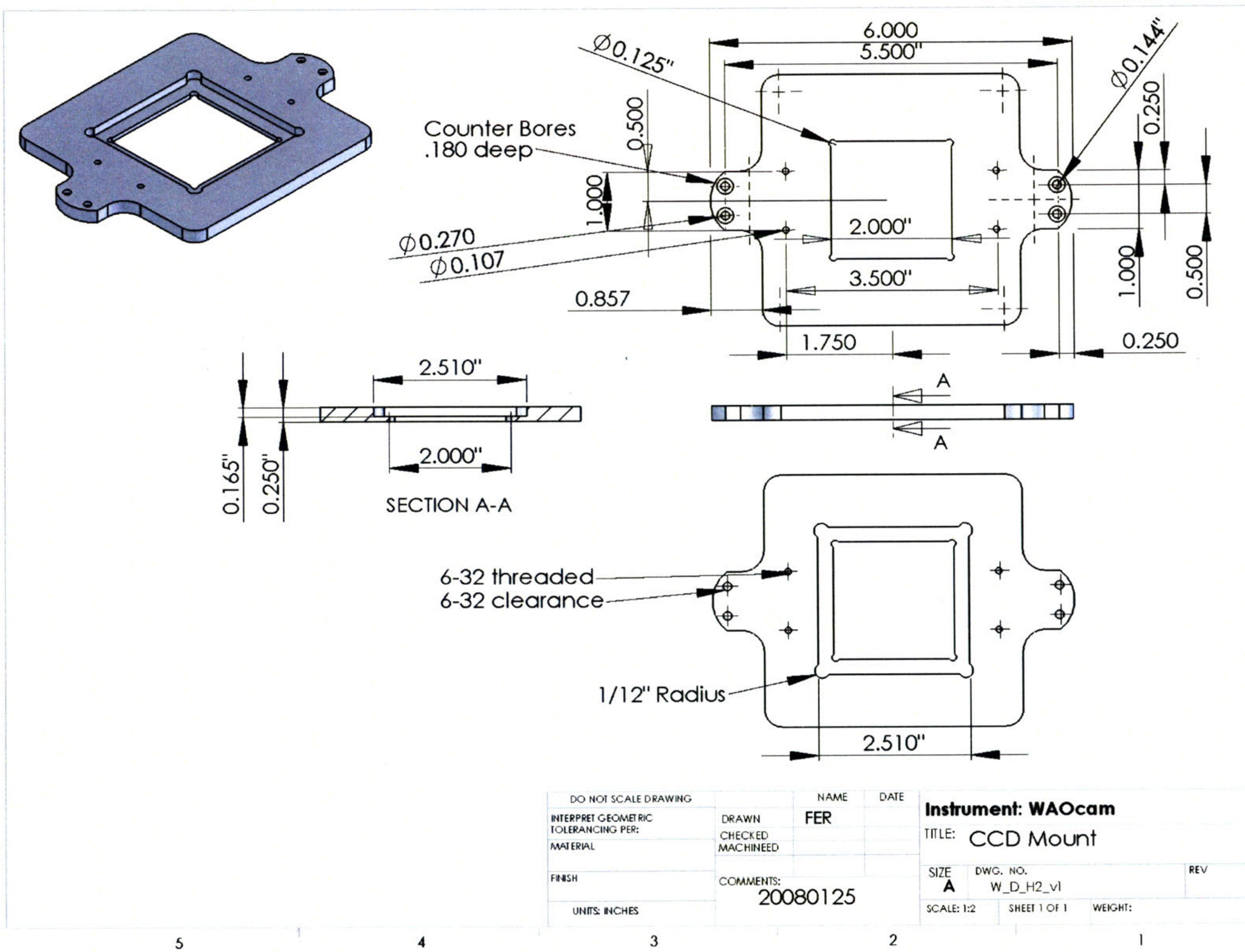


Figure 44 Dewar: Case Assembly Layout

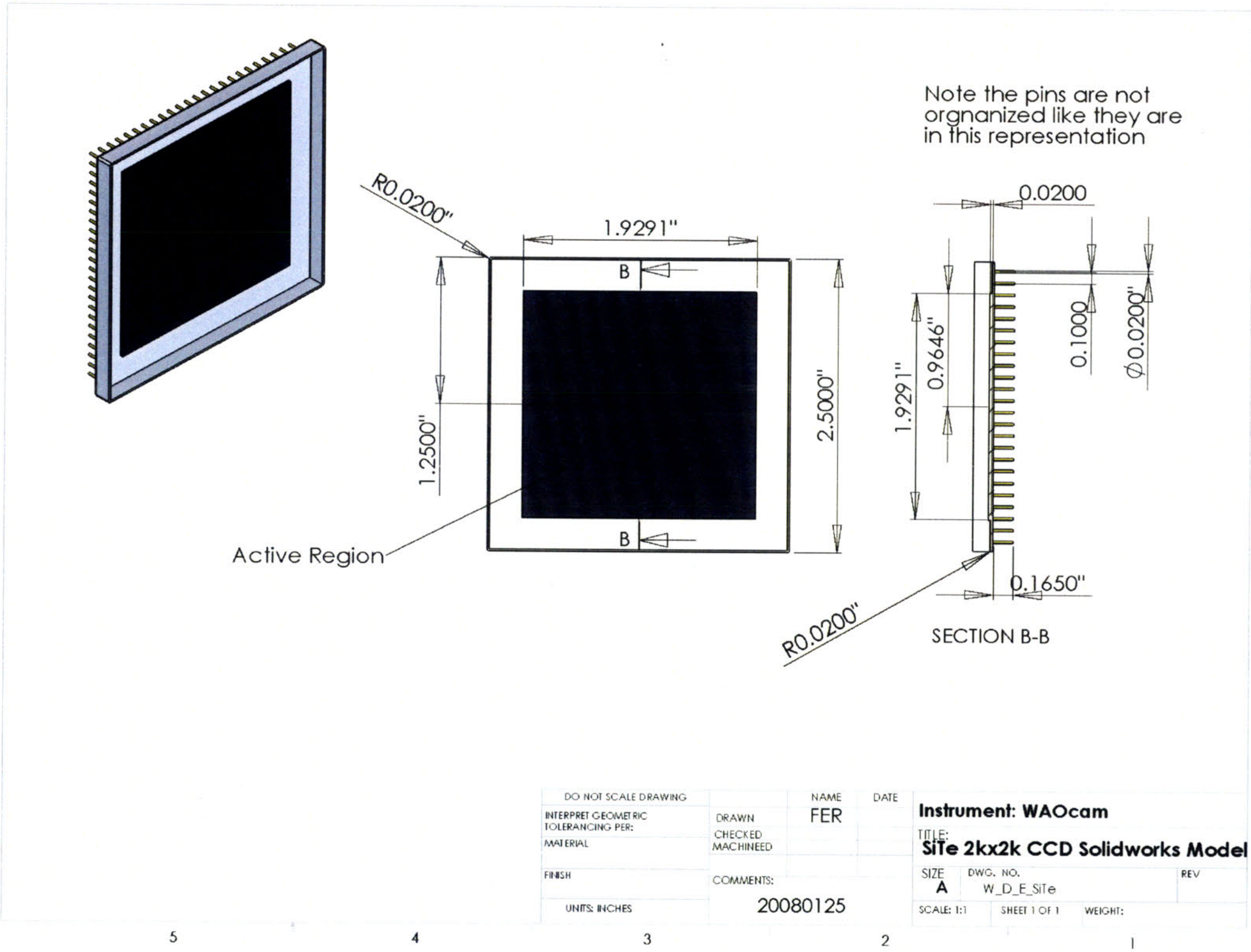
Appendix P Dewar Internal: ABS Plastic Raisers (Drawing: W_D_Interior_rods v1)



Appendix Q Dewar Internal: CCD Mount (Drawing: W_D_H2_v1)



Appendix R Dewar Internal: SiTe 2kx2k CCD (Drawing: W_D_E_SiTe)



Appendix S Dewar Internal: SiTe 2kx2k Manufacture Dimensions (SiTe 2kx2k 1994)

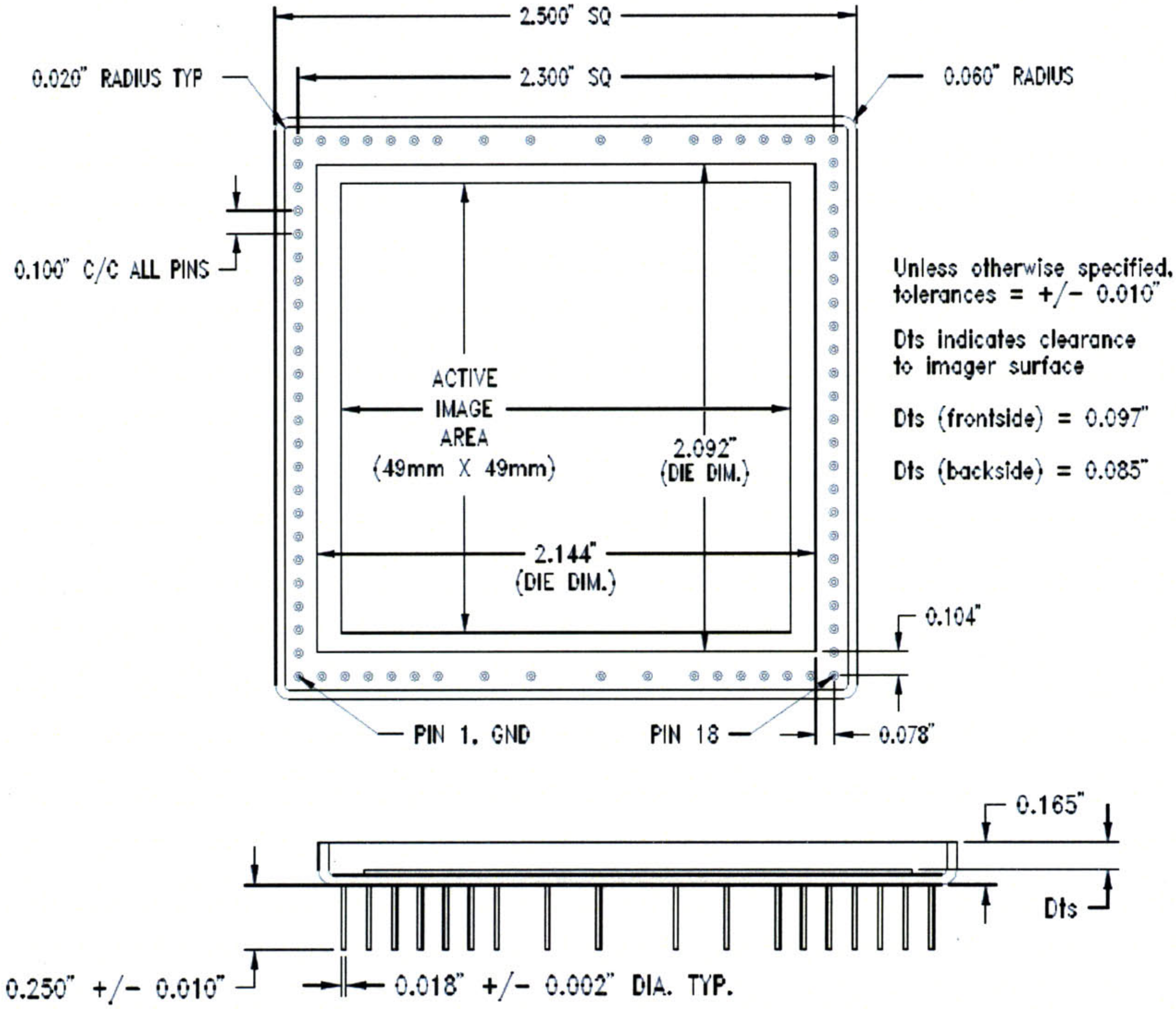
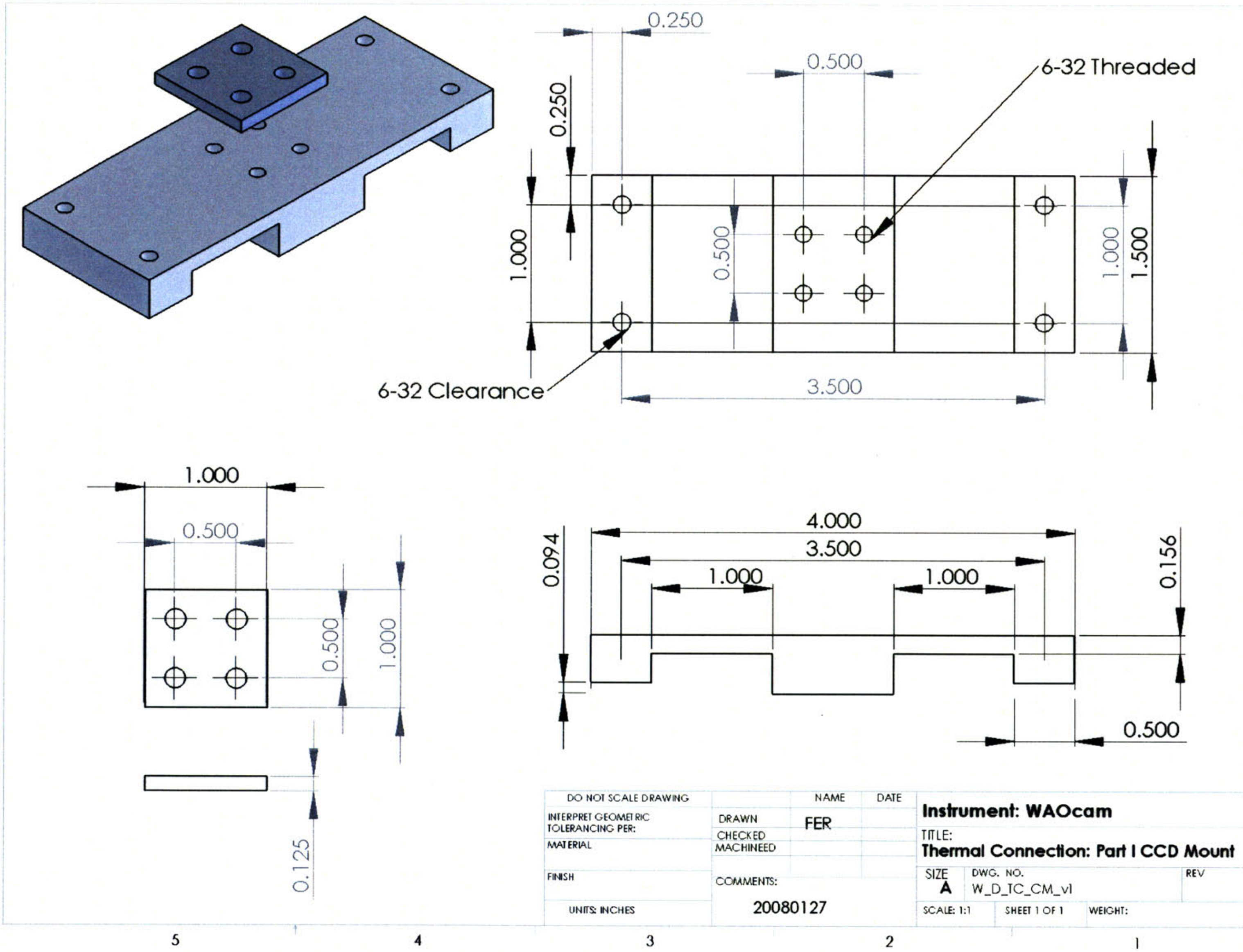
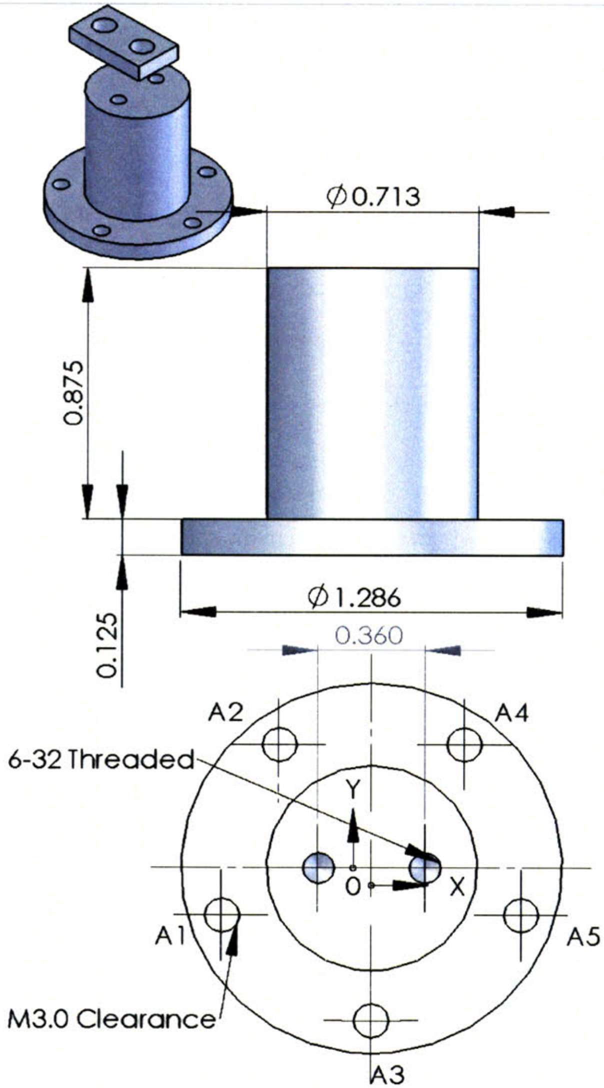


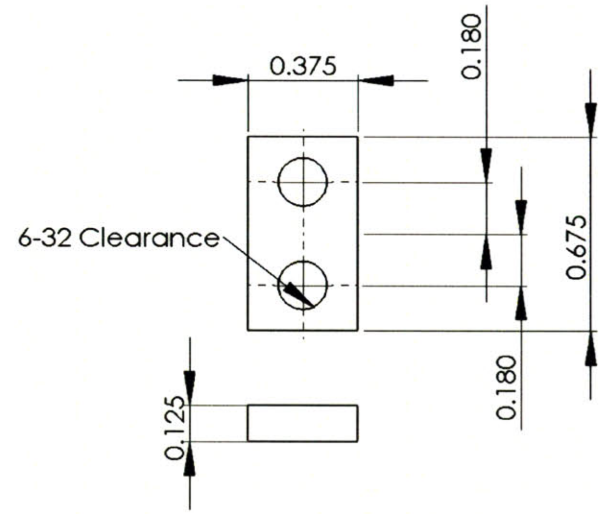
FIGURE 7 SI424A *package configuration*

Appendix T Thermal Control: CCD Press (Drawing: W_D_TC_CM_v1)



Appendix U Thermal Connection: Cryohead Connection (Drawing: W_D_TC_C1_v1)



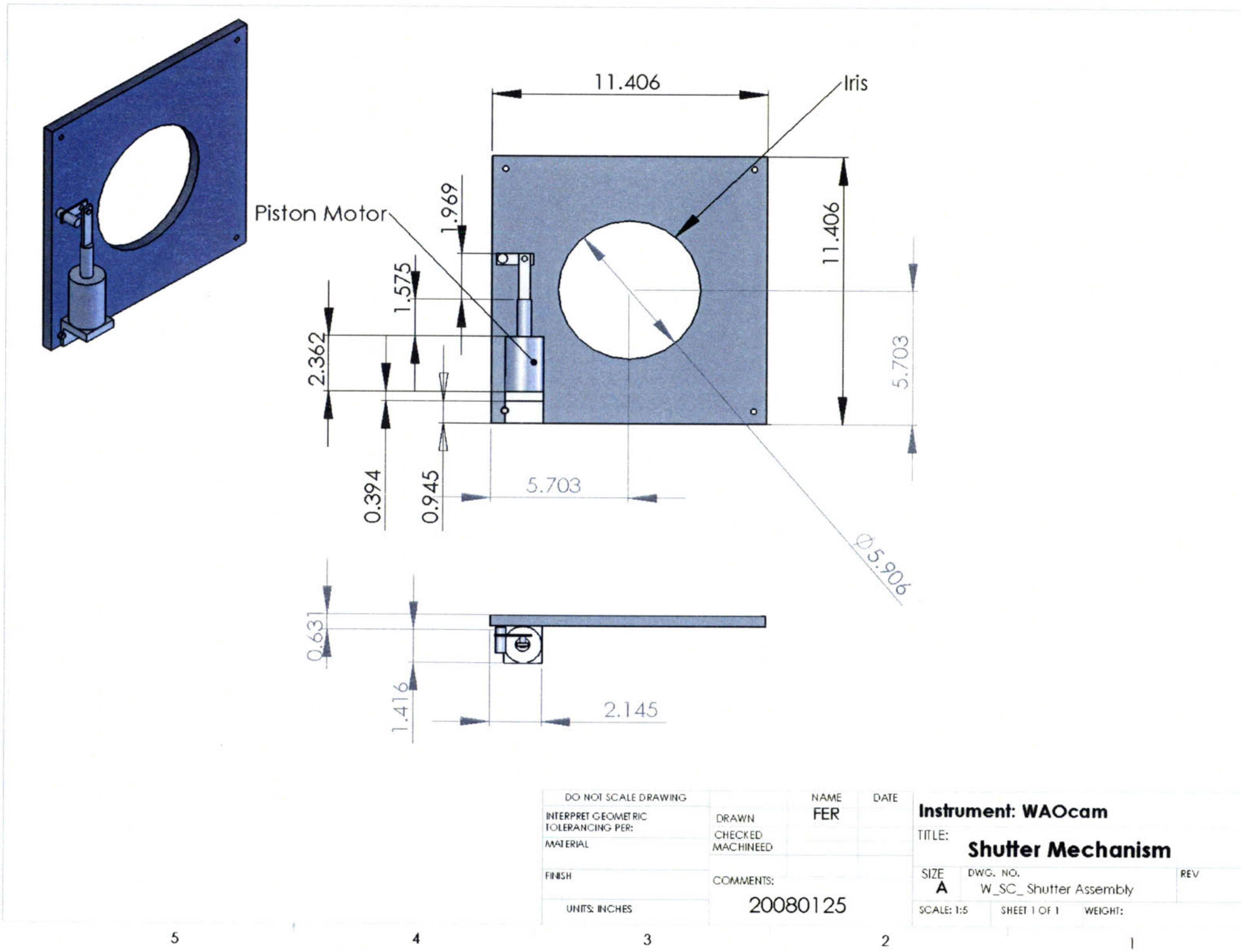


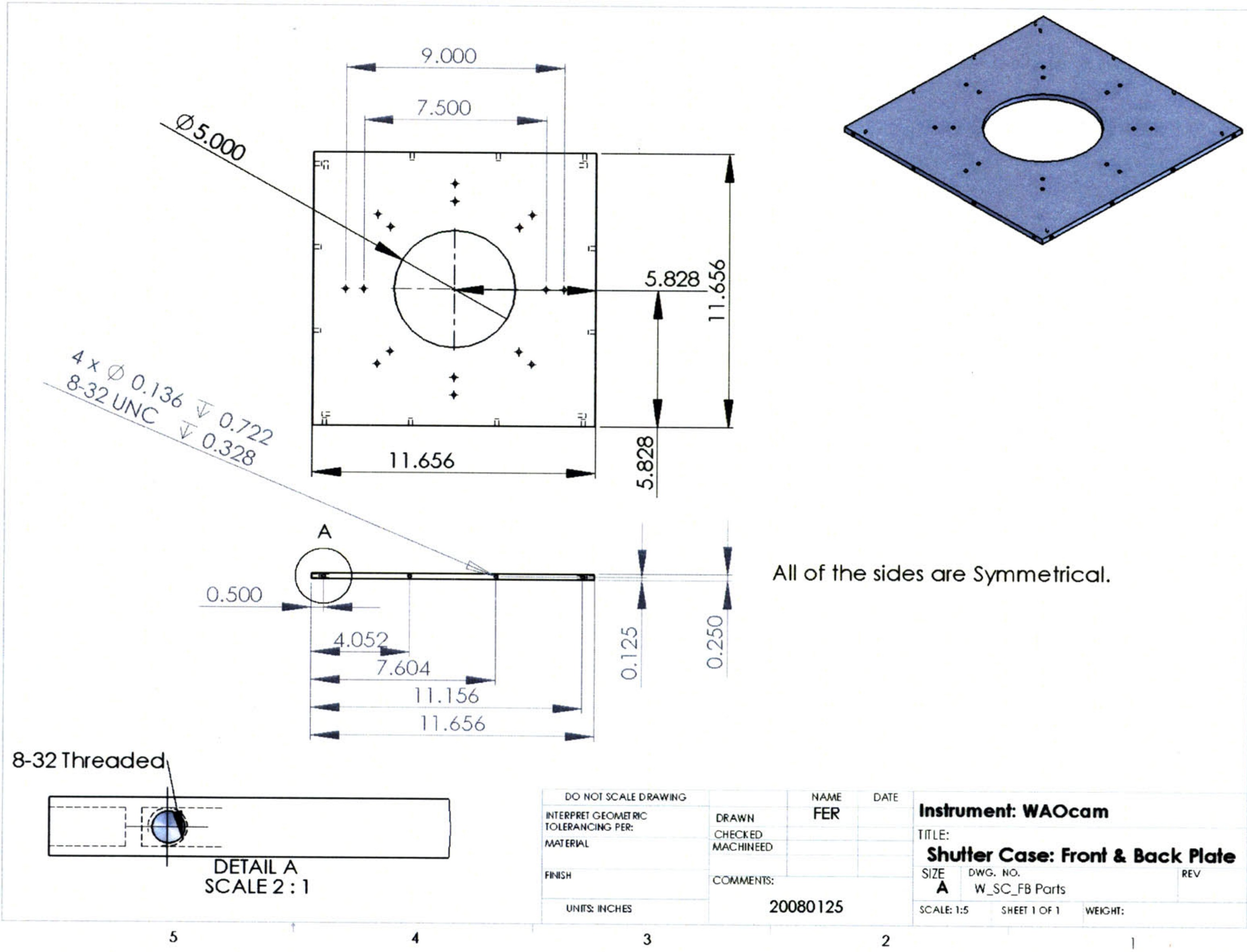
TAG	X LOC	Y LOC	SIZE
A1	-0.50	-0.16	Ø 0.118 ↧ 1.000
A2	-0.31	0.43	Ø 0.118 ↧ 1.000
A3	0.00	-0.53	Ø 0.118 ↧ 1.000
A4	0.31	0.43	Ø 0.118 ↧ 1.000
A5	0.50	-0.16	Ø 0.118 ↧ 1.000

DO NOT SCALE DRAWING		NAME	DATE	
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER		**Instrument: WAOcam**
MATERIAL	CHECKED MACHINEED			TITLE: **Thermal Connection: Cryohead**
FINISH	COMMENTS:			SIZE **A** DWG. NO. W_D_TC_CT_vl REV
UNITS: INCHES	20080125			SCALE: 2:1 SHEET 1 OF 1 WEIGHT:

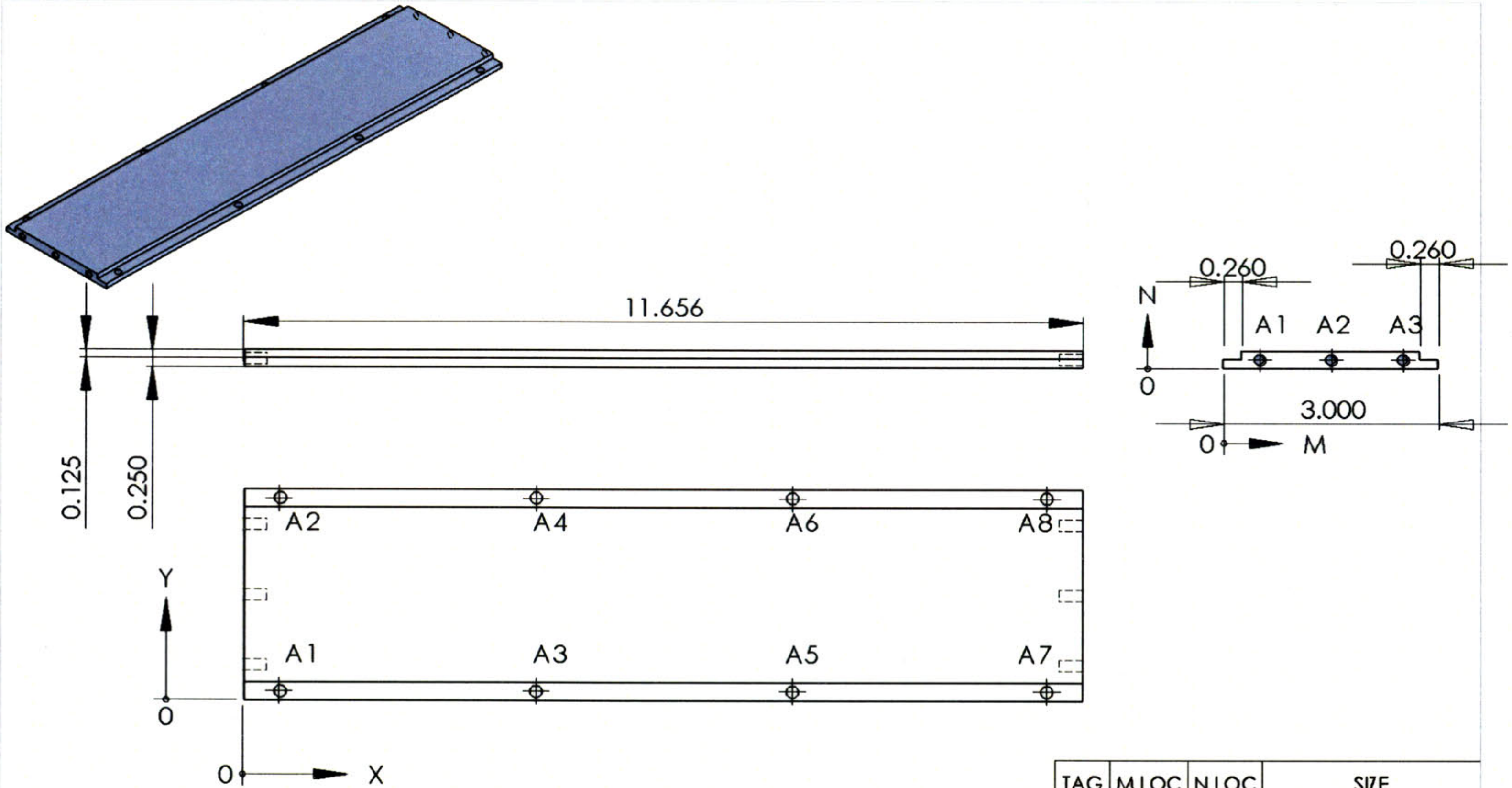
5 4 3 2 1

Appendix V Shutter Mechanism (Drawing: W_SC_Shutter Assembly)




9.000
7.500
Ø5.000
5.828
11.656
4 x Ø 0.136 ↧ 0.722
8-32 UNC ↧ 0.328
11.656
5.828
A
0.500
4.052
7.604
11.156
11.656
0.125
0.250
All of the sides are Symmetrical.
8-32 Threaded
DETAIL A
SCALE 2 : 1
DO NOT SCALE DRAWING
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNITS: INCHES
NAME
DATE
DRAWN
FER
CHECKED
MACHINEED
COMMENTS:
20080125
Instrument: WAOcam
TITLE:
Shutter Case: Front & Back Plate
SIZE
A
DWG. NO.
W_SC_FB Parts
REV
SCALE: 1:5
SHEET 1 OF 1
WEIGHT:
5
4
3
2
1

Appendix X Shutter Case: Top (Drawing: W_SC_Top v1)



TAG	M LOC	N LOC	SIZE
A1	0.50	0.13	Ø 0.136 ↧ 0.720 8-32 UNC ↧ 0.330
A2	1.50	0.13	Ø 0.136 ↧ 0.720 8-32 UNC ↧ 0.330
A3	2.50	0.13	Ø 0.136 ↧ 0.720 8-32 UNC ↧ 0.330

TAG	X LOC	Y LOC	SIZE
A1	0.500	0.125	Ø 0.170 ↧ 1.000
A2	0.500	2.875	Ø 0.170 ↧ 1.000
A3	4.052	0.125	Ø 0.170 ↧ 1.000
A4	4.052	2.875	Ø 0.170 ↧ 1.000
A5	7.604	0.125	Ø 0.170 ↧ 1.000
A6	7.604	2.875	Ø 0.170 ↧ 1.000
A7	11.156	0.125	Ø 0.170 ↧ 1.000
A8	11.156	2.875	Ø 0.170 ↧ 1.000

DO NOT SCALE DRAWING
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		

COMMENTS:
20080125

Instrument: WAOcam

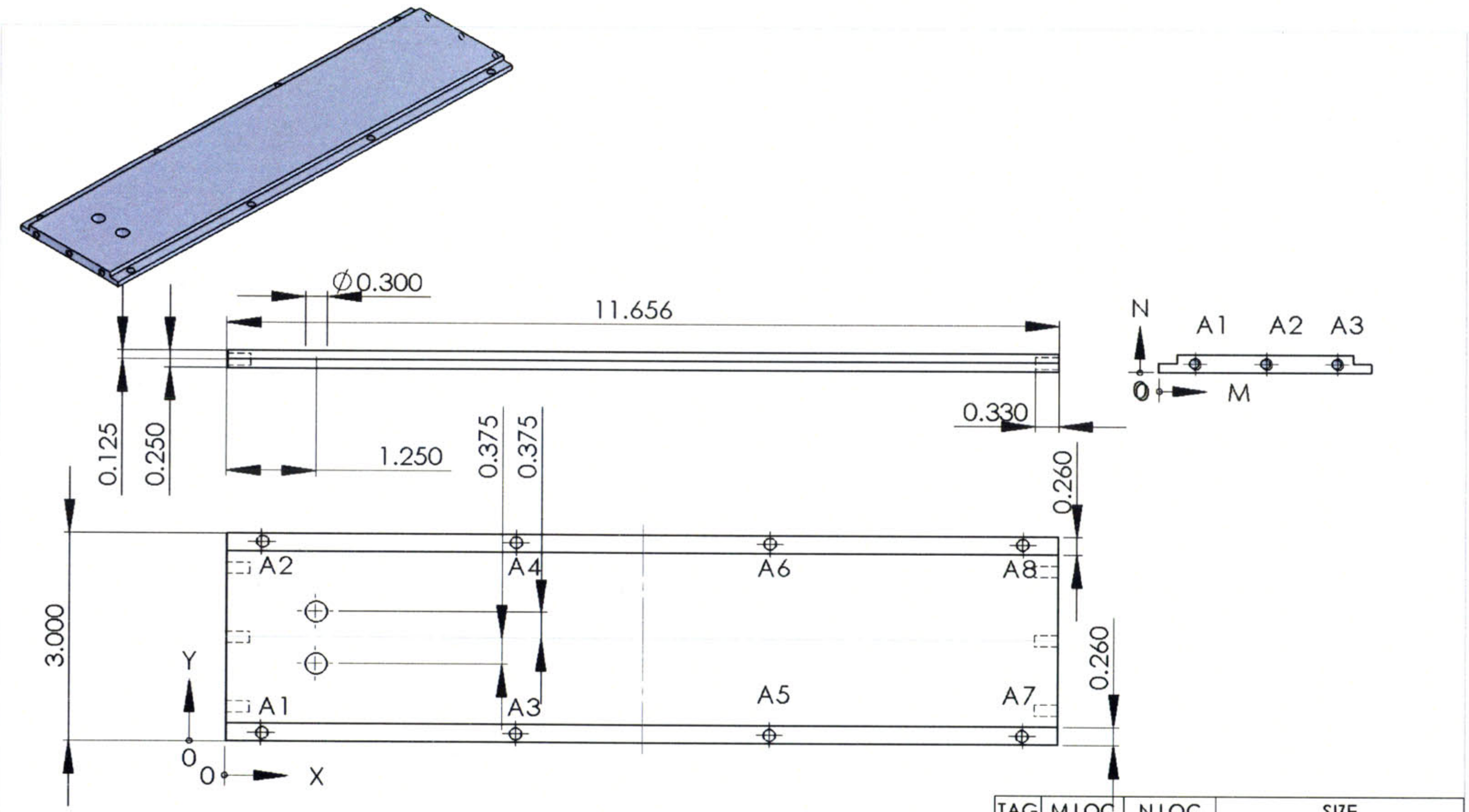
TITLE: **Shutter Case: Top**

SIZE **A** DWG. NO. W_SC_Top v1 REV

SCALE: 1:5 SHEET 1 OF 1 WEIGHT:

5 4 3 2 1

Appendix Y Shutter Case: Top/Power (Drawing: W_SC_TB_power part v1)



TAG	X LOC	Y LOC	SIZE
A1	0.500	0.125	∅ 0.170 ↧ 1.000
A2	0.500	2.875	∅ 0.170 ↧ 1.000
A3	4.052	0.125	∅ 0.170 ↧ 1.000
A4	4.052	2.875	∅ 0.170 ↧ 1.000
A5	7.604	0.125	∅ 0.170 ↧ 1.000
A6	7.604	2.875	∅ 0.170 ↧ 1.000
A7	11.156	0.125	∅ 0.170 ↧ 1.000
A8	11.156	2.875	∅ 0.170 ↧ 1.000

TAG	M LOC	N LOC	SIZE
A1	0.500	0.125	∅ 0.136 ↧ 0.720 8-32 UNC ↧ 0.330
A2	1.500	0.125	∅ 0.136 ↧ 0.720 8-32 UNC ↧ 0.330
A3	2.500	0.125	∅ 0.136 ↧ 0.720 8-32 UNC ↧ 0.330

DO NOT SCALE DRAWING
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		
COMMENTS:		

20080125

Instrument: WAOcam

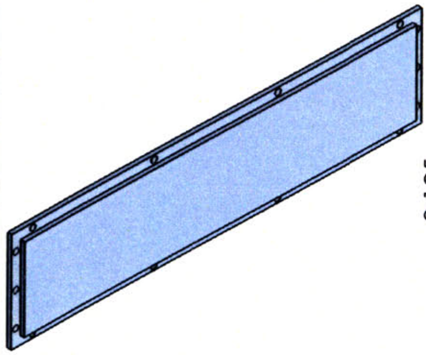
TITLE:
Shutter Case: Bottom/Power

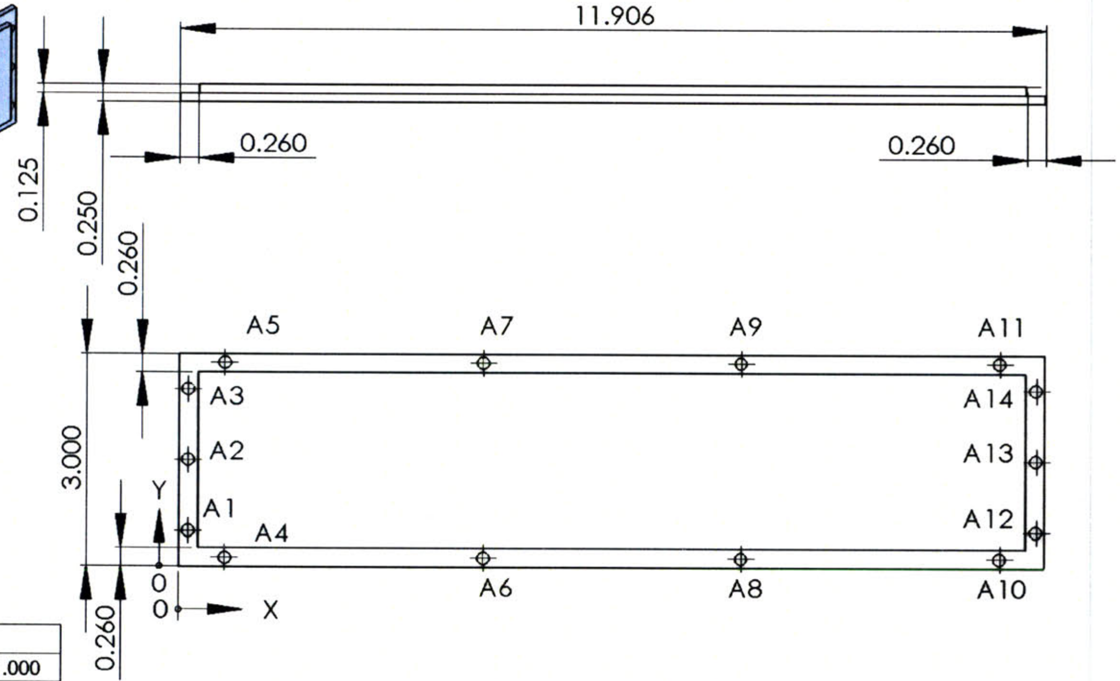
SIZE A DWG. NO. W_SC_TB_power Parts V1 REV

SCALE: 1:5 SHEET 1 OF 1 WEIGHT:

5 4 3 2 1

Appendix Z Shutter Case: Right & Left Plate (Drawing: W_SC_RL Parts V2)





TAG	X LOC	Y LOC	SIZE
A1	0.125	0.500	⌀ 0.170 ↧ 1.000
A2	0.125	1.500	⌀ 0.170 ↧ 1.000
A3	0.125	2.500	⌀ 0.170 ↧ 1.000
A4	0.625	0.125	⌀ 0.170 ↧ 1.000
A5	0.625	2.875	⌀ 0.170 ↧ 1.000
A6	4.177	0.125	⌀ 0.170 ↧ 1.000
A7	4.177	2.875	⌀ 0.170 ↧ 1.000
A8	7.729	0.125	⌀ 0.170 ↧ 1.000
A9	7.729	2.875	⌀ 0.170 ↧ 1.000
A10	11.281	0.125	⌀ 0.170 ↧ 1.000
A11	11.281	2.875	⌀ 0.170 ↧ 1.000
A12	11.781	0.500	⌀ 0.170 ↧ 1.000
A13	11.781	1.500	⌀ 0.170 ↧ 1.000
A14	11.781	2.500	⌀ 0.170 ↧ 1.000

DO NOT SCALE DRAWING
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		

COMMENTS:
20080125

Instrument: WAOcam

TITLE:
Shutter Casing: Right & Left Plate

SIZE A | DWG. NO. W_SC_RL Parts V2 | REV

SCALE: 1:5 | SHEET 1 OF 1 | WEIGHT:

5 4 3 2 1

Appendix AA Shutter Assembly (Drawing: W_D_C)

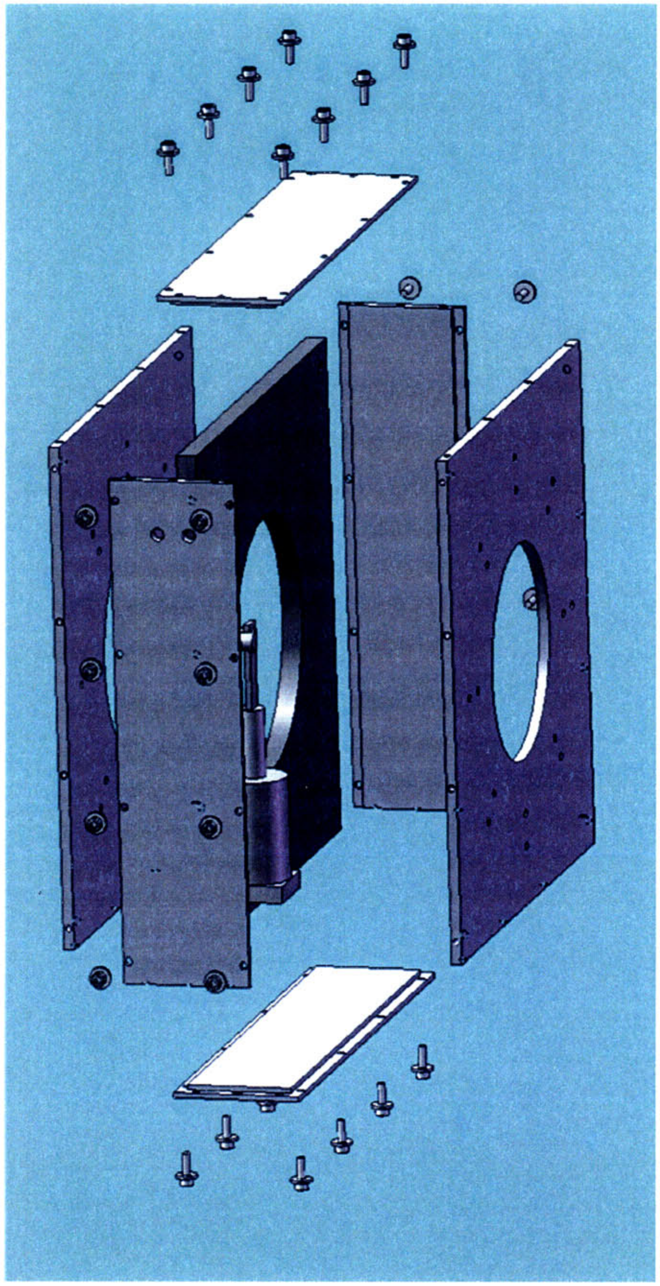
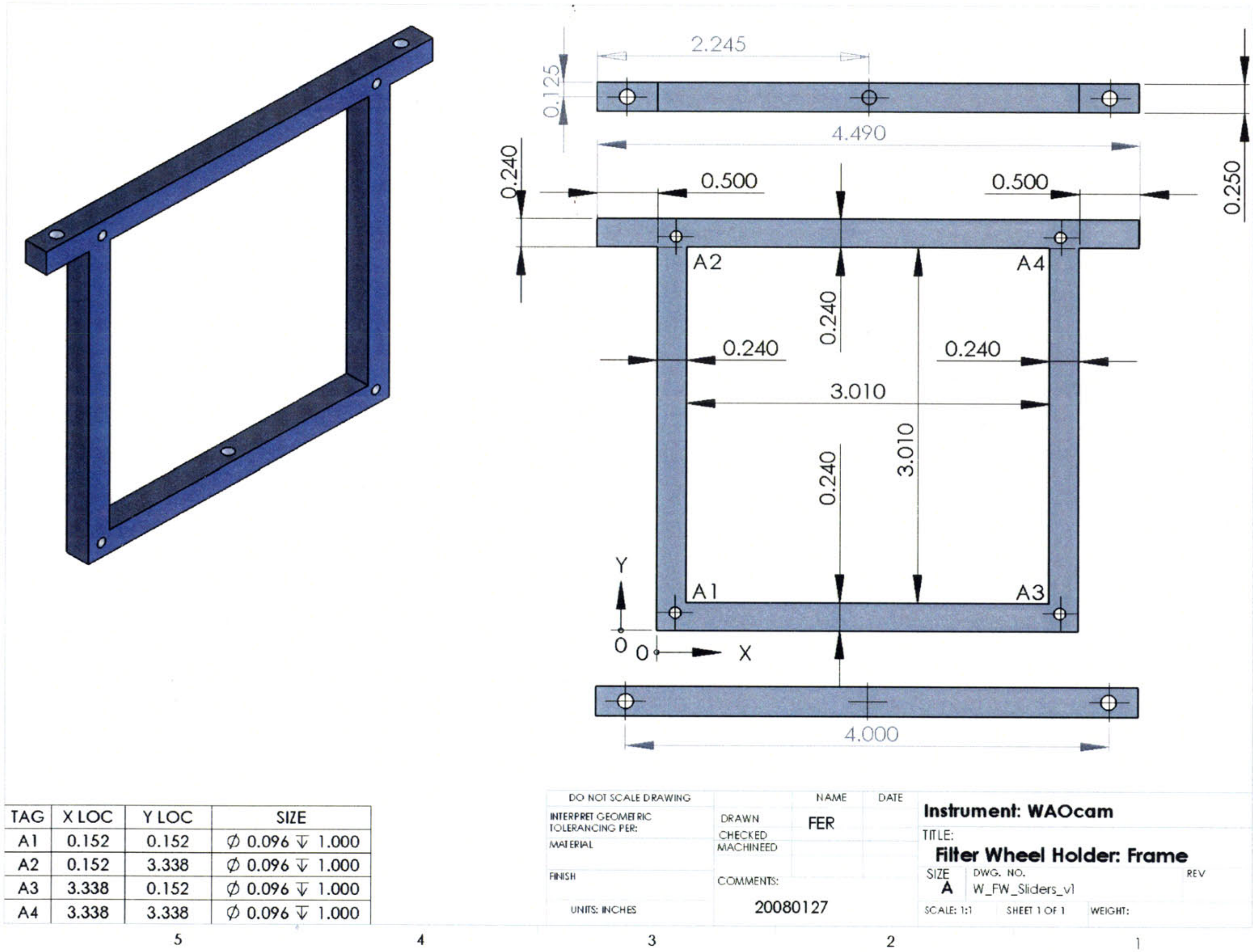
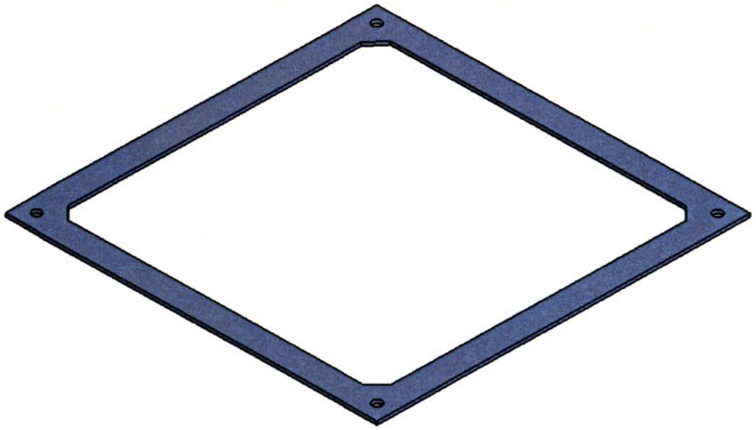


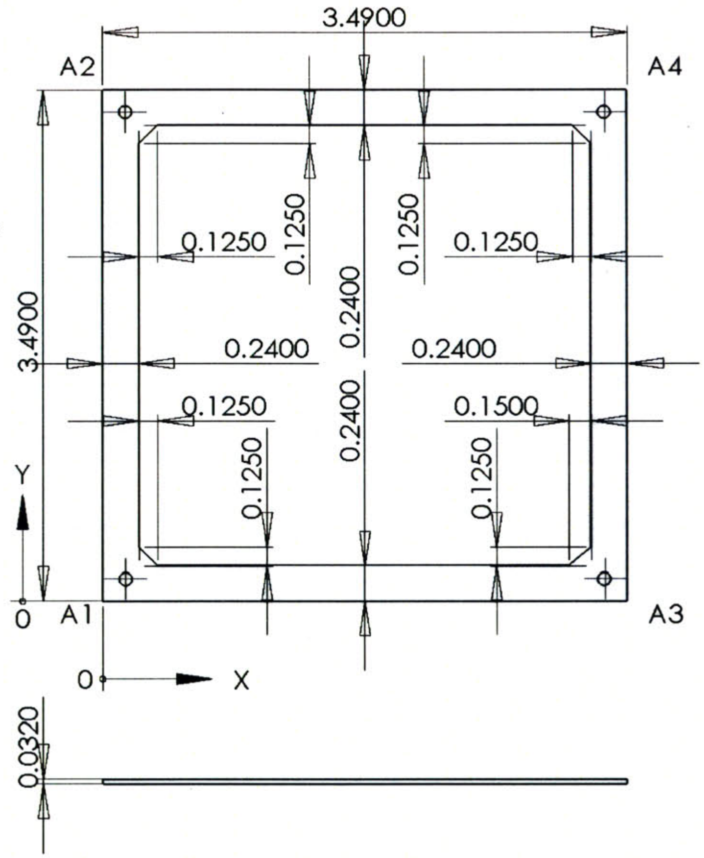
Figure 45 Shutter Assembly Layout

Appendix BB Filter Wheel: Holder (Drawing: W_Fw_Sliders_v1)



TAG	X LOC	Y LOC	SIZE
A1	0.152	0.152	∅ 0.096 ↧ 1.000
A2	0.152	3.338	∅ 0.096 ↧ 1.000
A3	3.338	0.152	∅ 0.096 ↧ 1.000
A4	3.338	3.338	∅ 0.096 ↧ 1.000





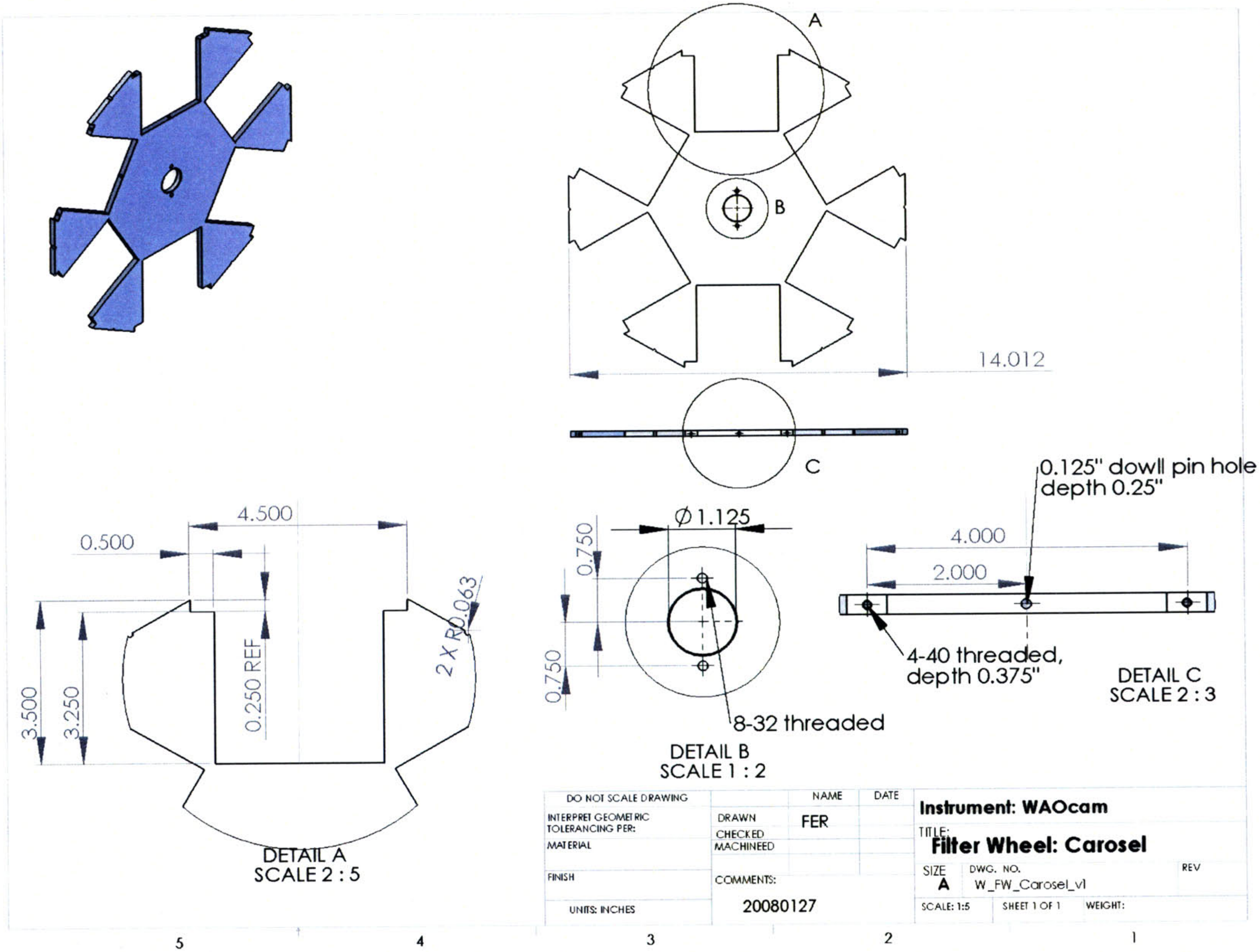
Two of these need to be produced for one holder. One needs to have 2-56 clearance holes and the other 2-56 threaded.

TAG	X LOC	Y LOC	SIZE
A1	0.152	0.152	∅ 0.0700 ↧ 0.2615 2-56 UNC ↧ 0.1720
A2	0.152	3.338	∅ 0.0700 ↧ 0.2615 2-56 UNC ↧ 0.1720
A3	3.338	0.152	∅ 0.0700 ↧ 0.2615 2-56 UNC ↧ 0.1720
A4	3.338	3.338	∅ 0.0700 ↧ 0.2615 2-56 UNC ↧ 0.1720

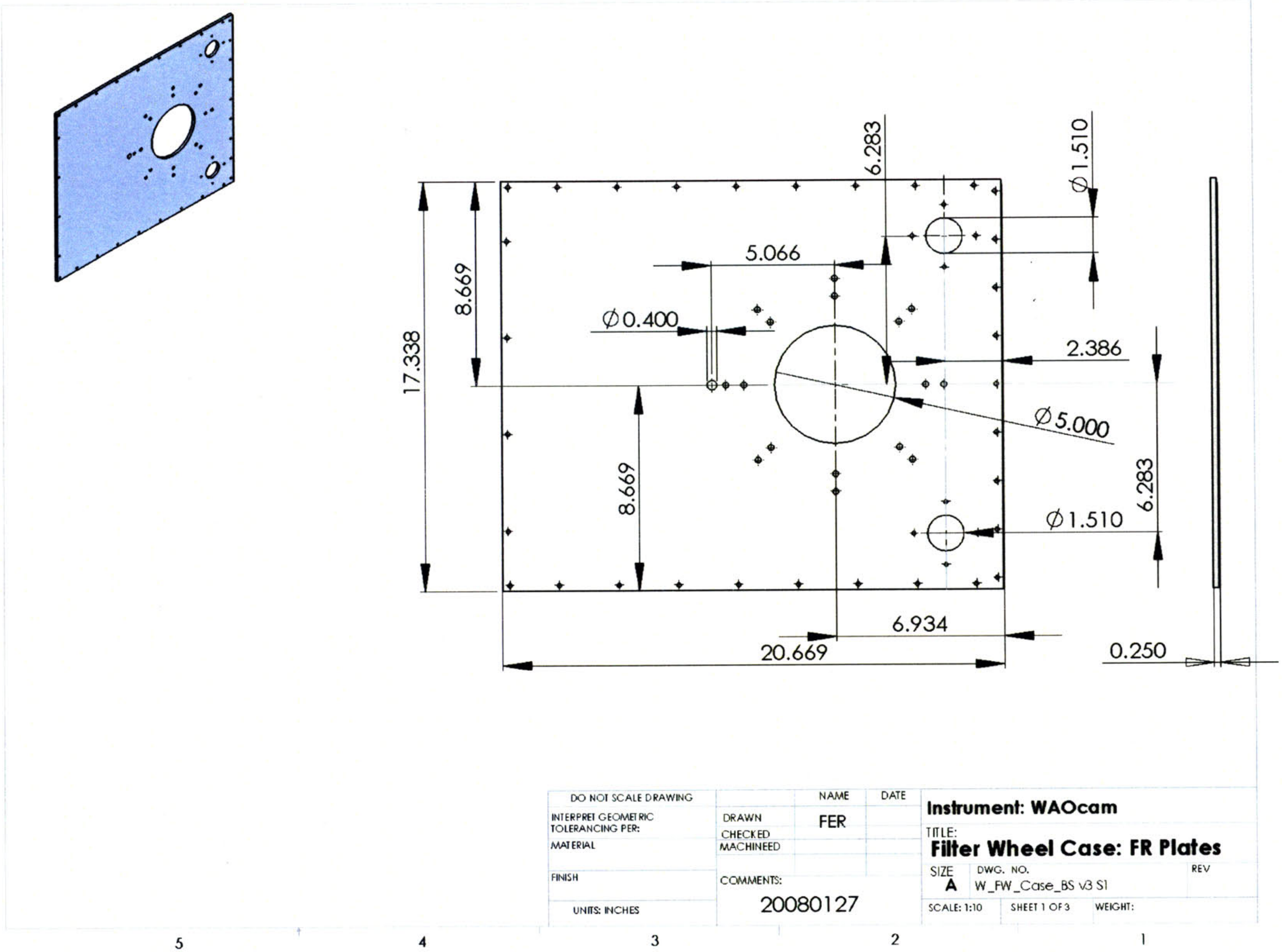
DO NOT SCALE DRAWING		NAME	DATE	**Instrument: WAOcam**
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER		TITLE: **Filter Wheel Holder: Covers I & II**
MATERIAL	CHECKED			
	MACHINEED			
FINISH	COMMENTS:			SIZE **A** · DWG. NO. W_FW_Slider_Cover_p1 v1 · REV
UNITS: INCHES	20080127			SCALE: 1:2 · SHEET 1 OF 1 · WEIGHT:

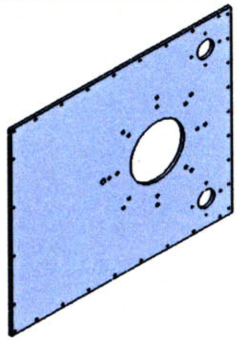
5 4 3 2 1

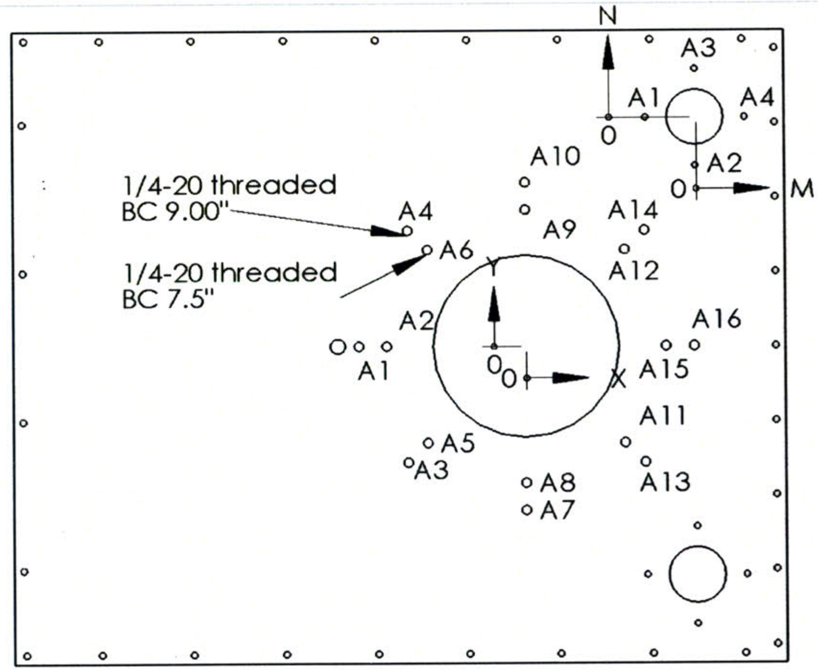
Appendix CC Filter Wheel: Carousel (Drawing: W_Fw_Carosel_v1)



Appendix DD Filter Wheel Case: Front & Back Plate (Drawing: W_Fw_Case_BS V3)







Main Bolt Circles

TAG	X LOC	Y LOC	SIZE
A1	-4.500	0.000	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A2	-3.750	0.000	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A3	-3.182	-3.182	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A4	-3.182	3.182	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A5	-2.652	-2.652	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A6	-2.652	2.652	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A7	0.000	-4.500	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A8	0.000	-3.750	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A9	0.000	3.750	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A10	0.000	4.500	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A11	2.652	-2.652	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A12	2.652	2.652	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A13	3.182	-3.182	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A14	3.182	3.182	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A15	3.750	0.000	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500
A16	4.500	0.000	∅ 0.201 ↧ 0.650 1/4-20 UNC ↧ 0.500

Automation Access Bolt Circles

TAG	M LOC	N LOC	SIZE
A1	-1.326	0.000	∅ 0.136 ↧ 0.422 8-32 UNC ↧ 0.328
A2	0.000	-1.326	∅ 0.136 ↧ 0.422 8-32 UNC ↧ 0.328
A3	0.000	1.326	∅ 0.136 ↧ 0.422 8-32 UNC ↧ 0.328
A4	1.326	0.000	∅ 0.136 ↧ 0.422 8-32 UNC ↧ 0.328

DO NOT SCALE DRAWING		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER	
MATERIAL	CHECKED		
	MACHINEED		
FINISH	COMMENTS:		
UNITS: INCHES	20080127		

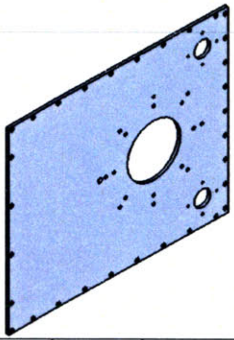
Instrument: WAOcam

TITLE:
Filter Wheel Case: FR Plates

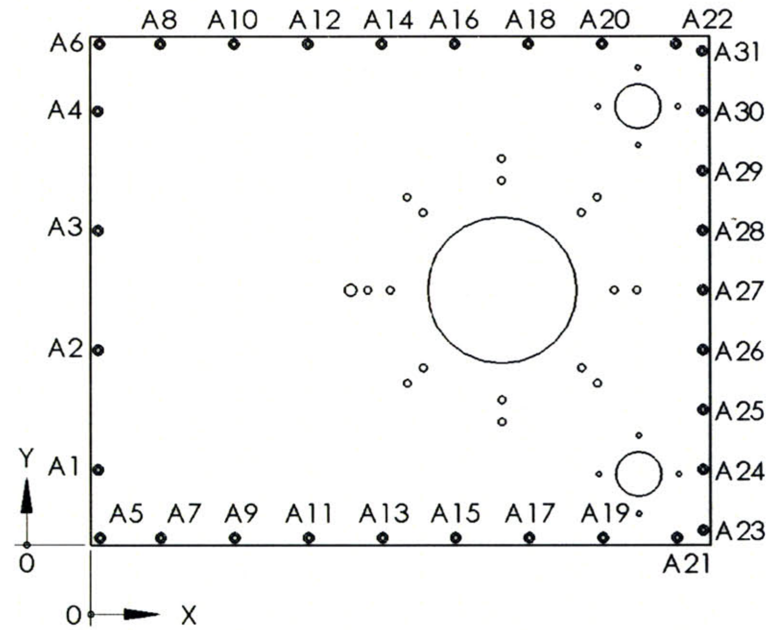
SIZE	DWG. NO.	REV
A	W_FW_Case_BS v3 S2	

SCALE: 1:10 SHEET 2 OF 3 WEIGHT:

5 4 3 2 1



TAG	X LOC	Y LOC	SIZE
A1	0.250	2.542	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A2	0.250	6.627	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A3	0.250	10.711	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A4	0.250	14.796	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A5	0.313	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A6	0.313	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A7	2.344	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A8	2.344	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A9	4.803	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A10	4.803	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A11	7.261	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A12	7.261	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A13	9.720	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A14	9.720	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A15	12.178	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A16	12.178	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A17	14.637	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A18	14.637	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A19	17.096	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A20	17.096	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A21	19.554	0.250	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A22	19.554	17.088	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A23	20.419	0.500	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A24	20.419	2.542	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A25	20.419	4.584	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A26	20.419	6.627	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A27	20.419	8.669	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A28	20.419	10.711	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A29	20.419	12.754	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A30	20.419	14.796	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°
A31	20.419	16.838	∅ 0.177 THRU ALL ⌵ ∅ 0.332 X 100°



DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		

COMMENTS: 20080127

Instrument: WAOcam

TITLE:

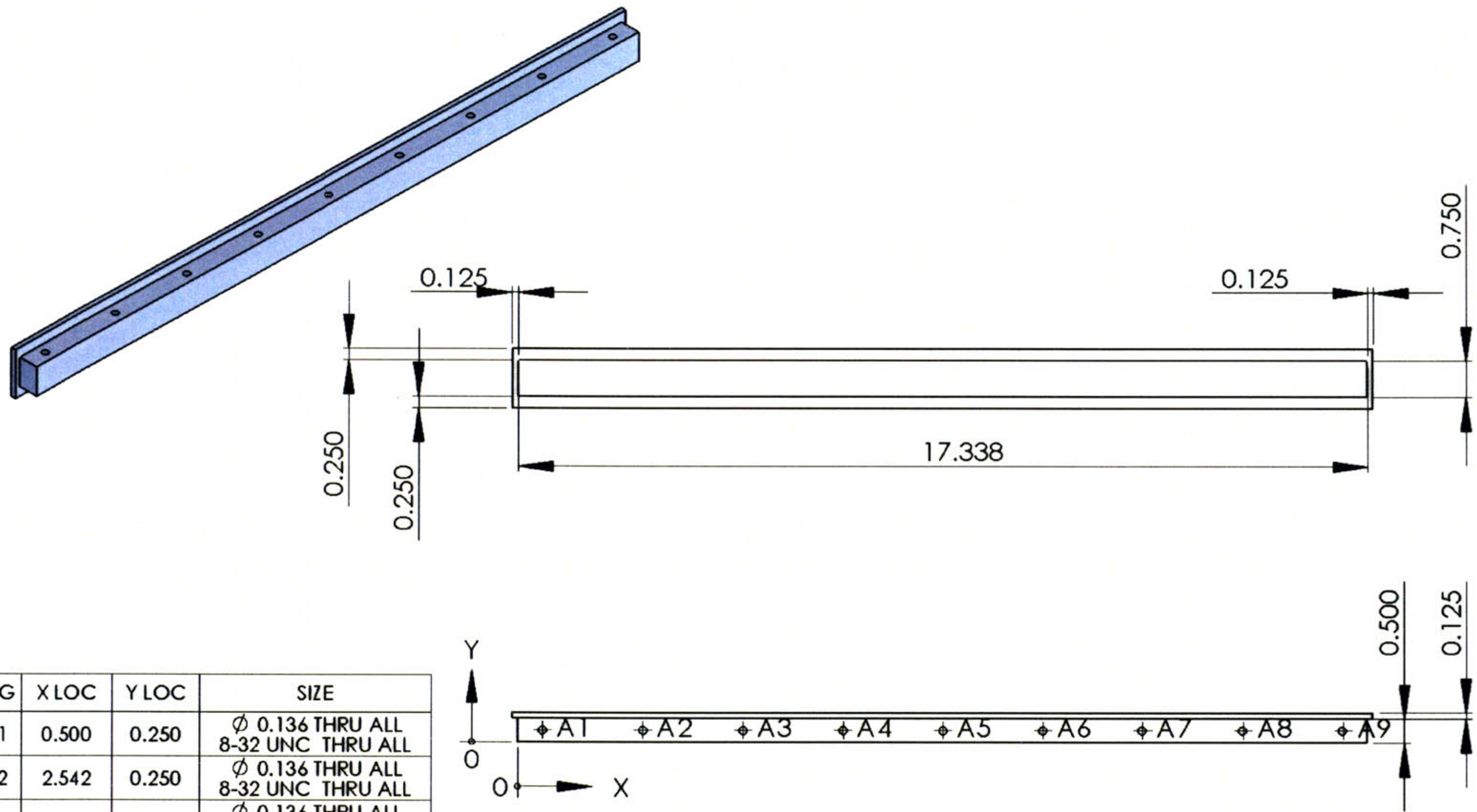
Filter Wheel Case: FR Plates

SIZE A | DWG. NO. W_FW_Case_BS v3 S3 | REV

SCALE: 1:10 | SHEET 3 OF 3 | WEIGHT:

5 4 3 2 1

Appendix EE Filter Wheel Case: Top Bar (Drawing: W_Fw_Case_H_Top v2)



TAG	X LOC	Y LOC	SIZE
A1	0.500	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A2	2.542	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A3	4.584	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A4	6.627	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A5	8.669	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A6	10.711	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A7	12.754	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A8	14.796	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A9	16.838	0.250	∅ 0.136 THRU ALL 8-32 UNC THRU ALL

DO NOT SCALE DRAWING

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

UNITS: INCHES

	NAME	DATE
DRAWN	FER	
CHECKED		
MACHINEED		

COMMENTS:

20080127

Instrument: WAOcam

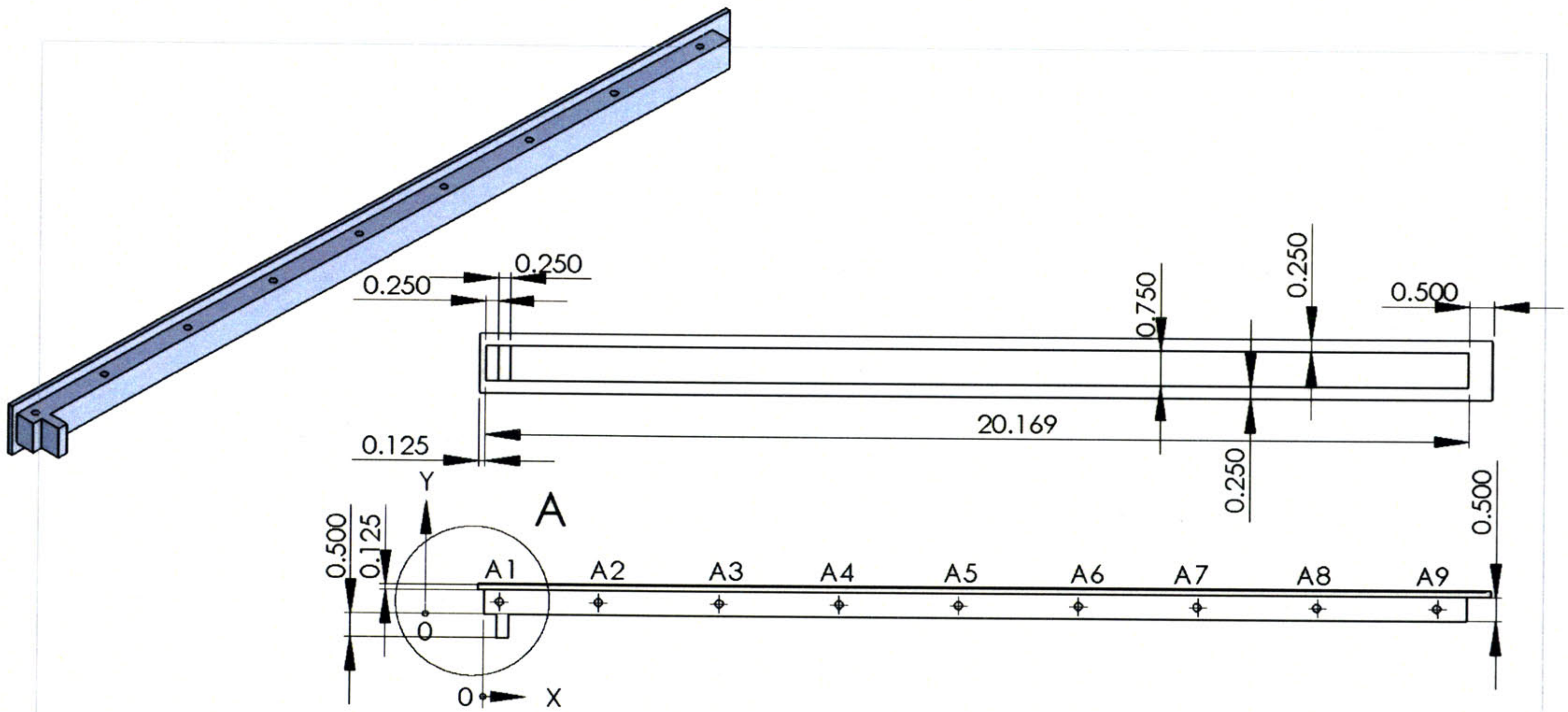
TITLE:
Filter Wheel Case: Top

SIZE A | DWG. NO. W_FW_Case_H_Top v2 | REV

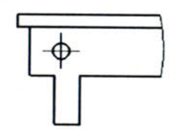
SCALE: 1:5 | SHEET 1 OF 1 | WEIGHT:

5 4 3 2 1

Appendix FF Filter Wheel Case: Right & Left Bar (Drawing: W_Fw_Case_H_R&L V2)



TAG	X LOC	Y LOC	SIZE
A1	0.31	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A2	2.34	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A3	4.80	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A4	7.26	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A5	9.72	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A6	12.18	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A7	14.64	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A8	17.10	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL
A9	19.55	0.25	∅ 0.136 THRU ALL 8-32 UNC THRU ALL

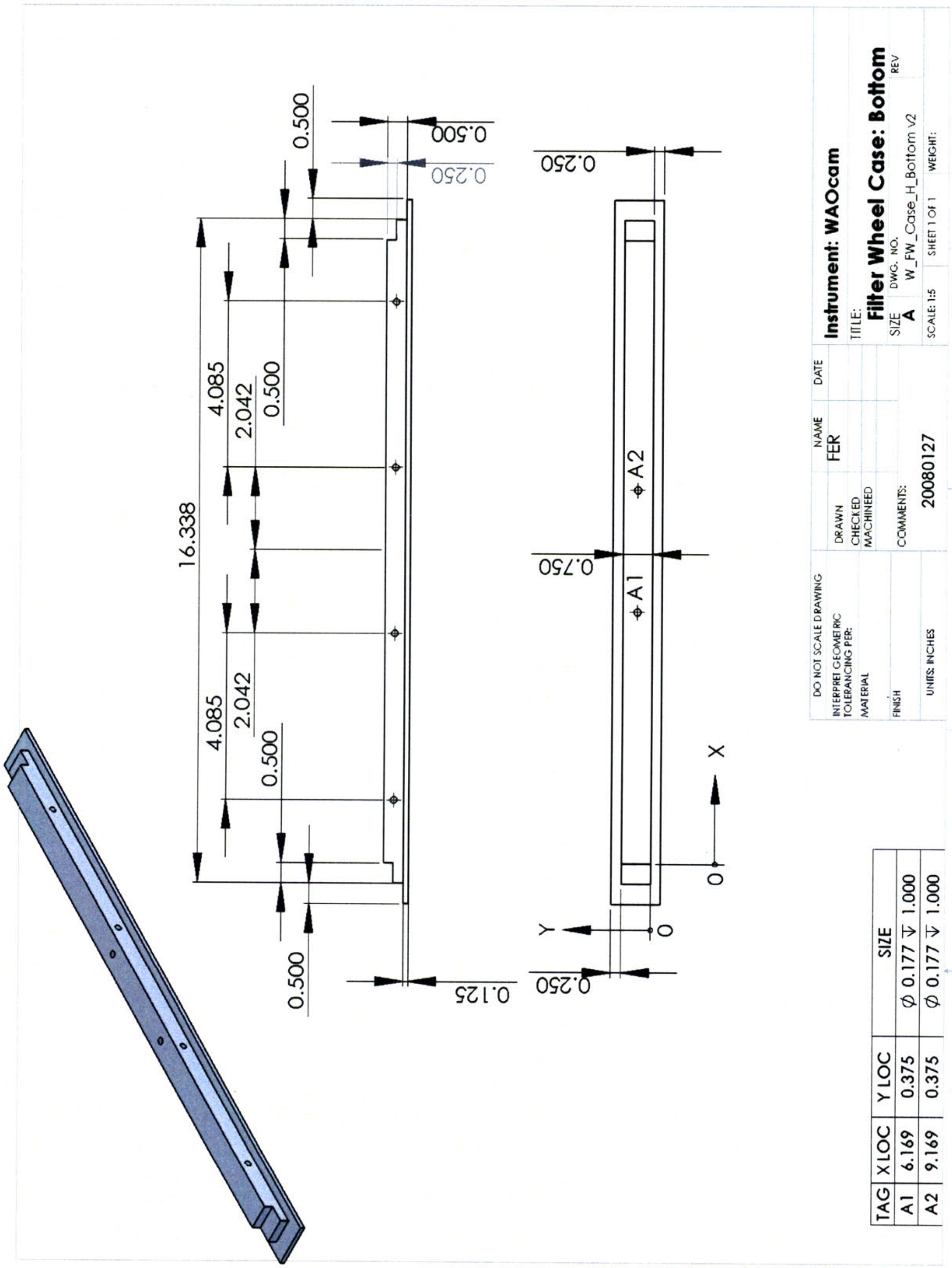


DETAIL A
SCALE 2 : 3

		NAME	DATE	
DO NOT SCALE DRAWING				**Instrument: WAOcam**
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER		TITLE:
MATERIAL	CHECKED			**Filter Wheel Case: Right & Left**
	MACHINEED			
FINISH	COMMENTS:			SIZE A — DWG. NO. W_FW_Case_H_RLB v2 — REV
UNITS: INCHES	20080127			SCALE: 1:5 — SHEET 1 OF 1 — WEIGHT:

5 4 3 2 1

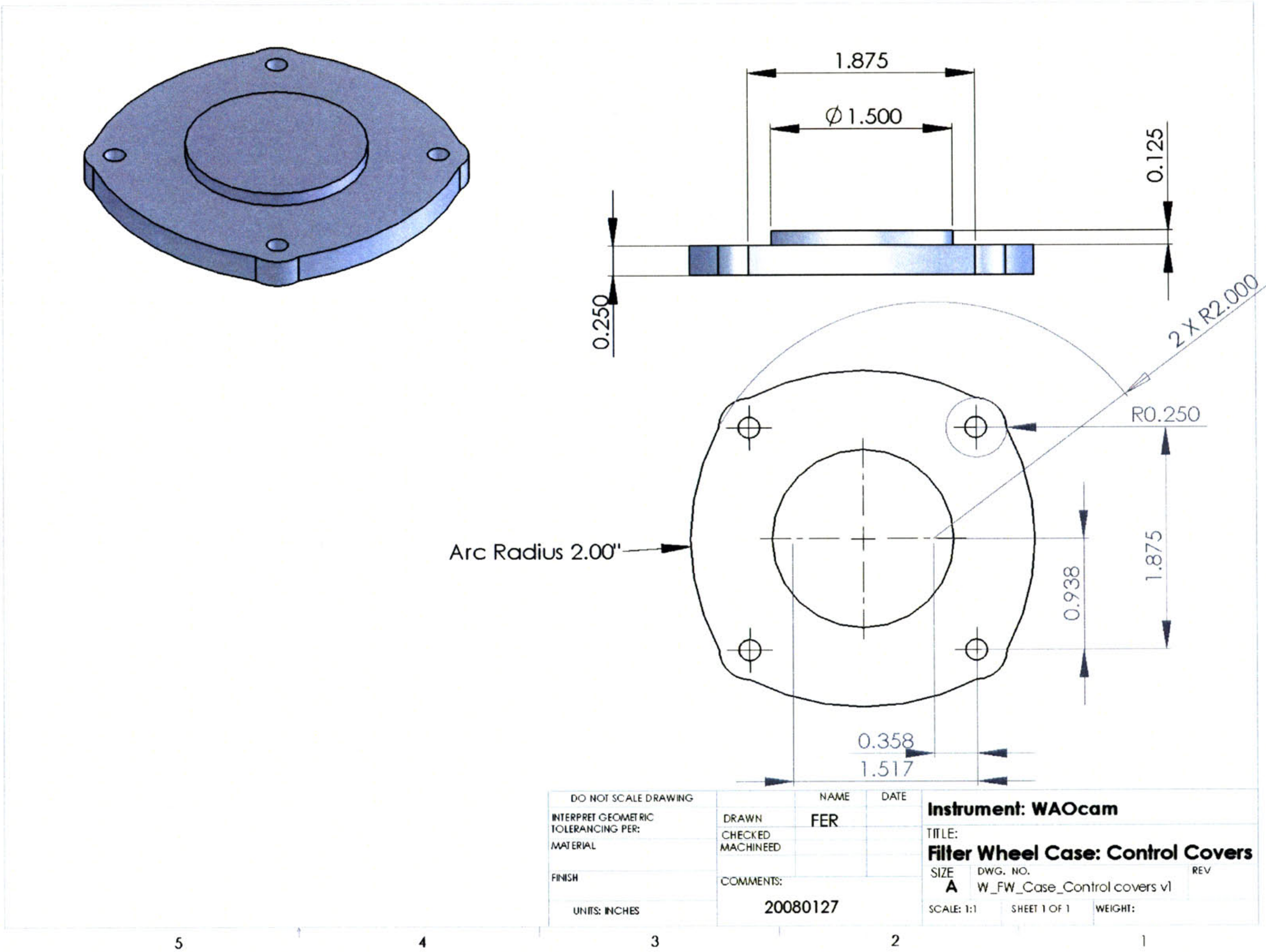
Appendix GG Filter Wheel Case: Bottom Bar (Drawing: W_Fw_Case_H_Bottom v2)



TAG	X LOC	Y LOC	SIZE
A1	6.169	0.375	∅ 0.177 ↧ 1.000
A2	9.169	0.375	∅ 0.177 ↧ 1.000

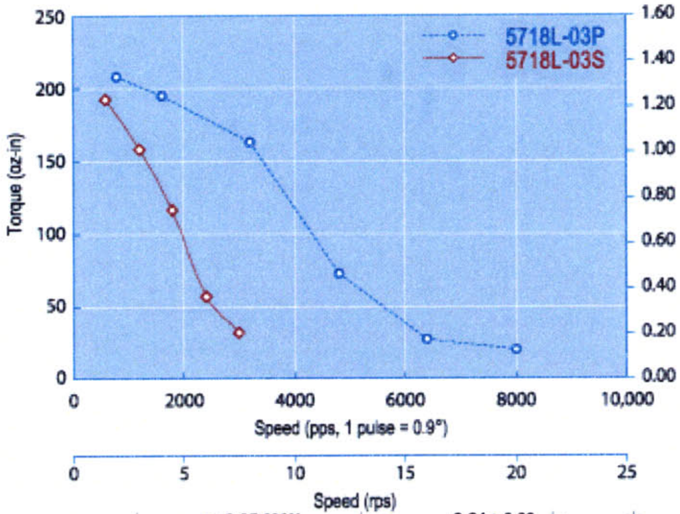
DO NOT SCALE DRAWING		NAME	DATE	Instrument: WAOcam
INTERPRET GEOMETRIC TOLERANCING PER:	DRAWN	FER		TITLE:
MATERIAL	CHECKED			**Filter Wheel Case: Bottom**
	MACHINEED			
FINISH	COMMENTS:			SIZE A DWG. NO. W_FW_Case_H_Bottom v2 REV
UNITS: INCHES	20080127			SCALE: 1:5 SHEET 1 OF 1 WEIGHT:

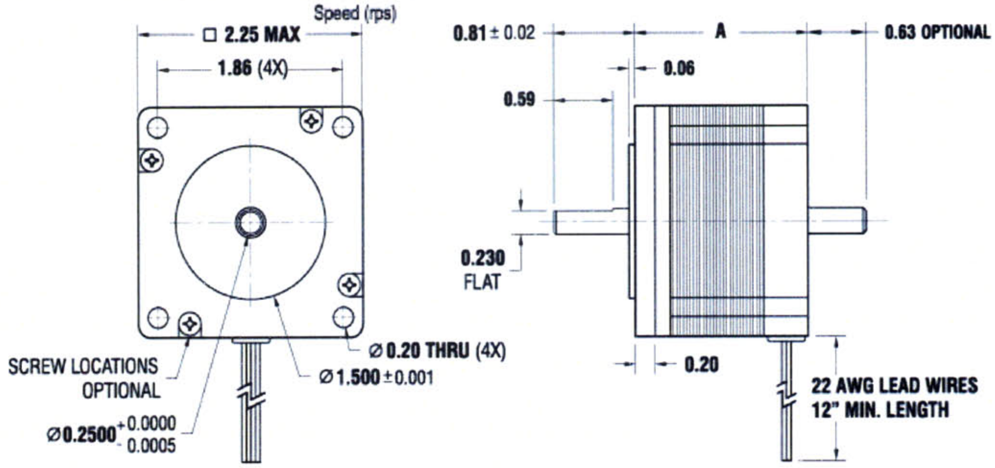
Appendix HH Filter Wheel Case: Covers (Drawing: W_Fw_Case_Control Covers v1)



Appendix II Filter Wheel Stepper Motor: 5728L-03S Lin Engineering

5718L-03S 24vDC, 2.1 Amps/Phase, Series Bipolar, 1/2 Stepping
5718L-03P 24vDC, 4.2 Amps/Phase, Bipolar Parallel, 1/2 Stepping

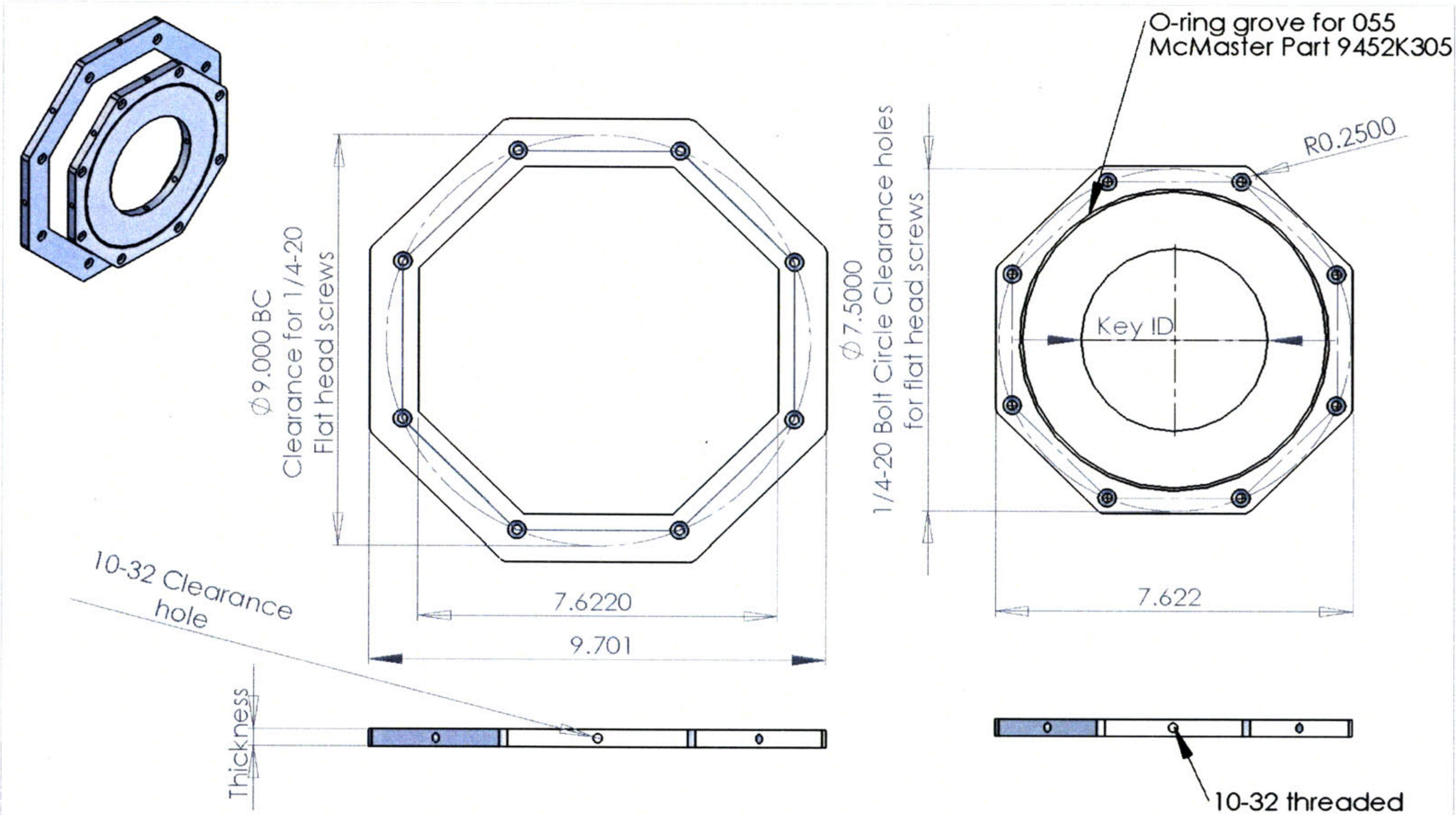




| BIPOLAR |

Dimension "A"	Model Number	Amp/ Phase	Holding Torque oz-in	Holding Torque N-m	Resistance Ohm/ Phase	Inductance mH/ Phase	Inertia oz-in²	Weight Lbs.	Number of Leads
1.74" 44.2 mm	5718X-01S	1.40	100.0	0.71	2.8	5.6	0.70	1.05	4
	5718X-01P	2.80	100.0	0.71	0.7	1.4	0.70	1.05	4
	5718X-05S	0.70	100.0	0.71	10.0	19.2	0.70	1.05	4
	5718X-05P	1.40	100.0	0.71	2.5	4.8	0.70	1.05	4
	5718X-15S	2.10	100.0	0.71	1.2	1.6	0.70	1.05	4
	5718X-15P	4.20	100.0	0.71	0.3	0.4	0.70	1.05	4
2.22" 56.4 mm	5718M-02S	2.10	173.0	1.22	1.8	5.2	1.50	1.50	4
	5718M-02P	4.20	173.0	1.22	0.5	1.4	1.50	1.50	4
	5718M-04S	0.70	173.0	1.22	14.0	42.3	1.50	1.50	4
	5718M-04P	1.40	173.0	1.22	3.5	10.6	1.50	1.50	4
	5718M-05S	1.40	173.0	1.22	3.6	10.0	1.50	1.50	4
	5718M-05P	2.80	173.0	1.22	0.9	2.5	1.50	1.50	4
3.1" 78.7 mm	5718L-01S	1.40	294.0	2.08	4.5	15.3	2.60	2.20	4
	5718L-01P	2.80	294.0	2.08	1.1	3.8	2.60	2.20	4
	5718L-03S	2.10	294.0	2.08	2.4	7.0	2.60	2.20	4
	5718L-03P	4.20	294.0	2.08	0.6	1.8	2.60	2.20	4
	5718L-04S	3.27	294.0	2.08	1.0	5.2	2.60	2.20	4
	5718L-04P	6.54	294.0	2.08	0.3	1.3	2.60	2.20	4

Appendix JJ Instrument Interfaces: Locks & Keys



Interface	Thickness	Key ID
3	0.375"	6.00"
4	0.375"	5.00"
5	0.375"	4.00"

DO NOT SCALE DRAWING | NAME | DATE

INTERPRET GEOMETRIC TOLERANCING PER:

DRAWN

CHECKED

MACHINEED

MATERIAL Al 6061

FINISH

COMMENTS:

UNITS: INCHES

Instrument: WAOcam

TITLE: Interfaces: Locks & Keys

SIZE A | DWG. NO. W_I_Standard All InterfacesV1 | REV

SCALE: 1:5 | SHEET 1 OF 1 | WEIGHT:

5 4 3 2 1

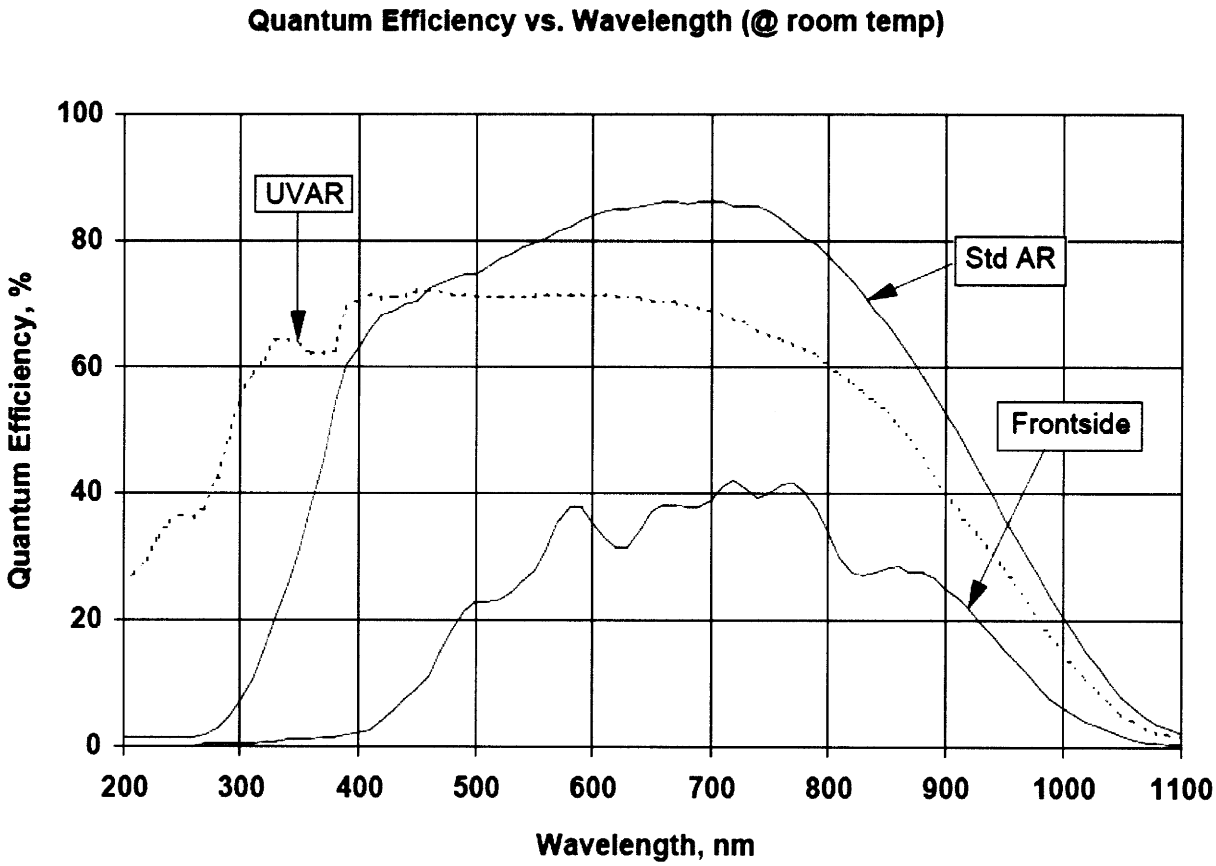
Appendix KK Apogee CCD: SiTe 1kx1k Details (Wu 2002)

Table 6.1: Apogee AP8P CCD Specifications

CCD Chip	SiTe SI-003AB
Array (pixels)	1024 x 1024
Pixel size (microns)	24
Area (mm)	24.6 x 24.6
Well Depth (e^-) Binned 1:1	> 300,000
Anti-blooming	None
Charge Transfer Efficiency	0.99999
Read Noise (e^-) (Typical)	15
Dark Count (pA/cm^2)	50 @ 20°C
Dynamic Range	>86 dB
Digital Resolution	16-bit 35kHz
System Gain	4-5 e-/ADU (16-bit)
Pixel Binning	1 x 1 to 8 x 63 on chip binning.
Exposure Time	0.02 seconds to 10,400 seconds in 0.01 second increments.
Cooling	Two Stage Thermoelectric cooler with forced air. 50-55°C below ambient.
Temperature Stability	± 0.1°C
Shutter	Melles Griot 42mm iris

Table of Apogee AP8P CCD specifications reproduced from the Apogee Instruments web page at http://www.ccd.com/apseries.html.

Appendix LL SiTe 2kx2k: Quantum Efficiency (%) vs. Wavelength (nm) (SiTe 2kx2k 1994)



Appendix MM SiTe 2kx2k: Temperature (K) vs. Dark Current (Electrons/Pixel/sec)

(SiTe 2kx2k 1994)

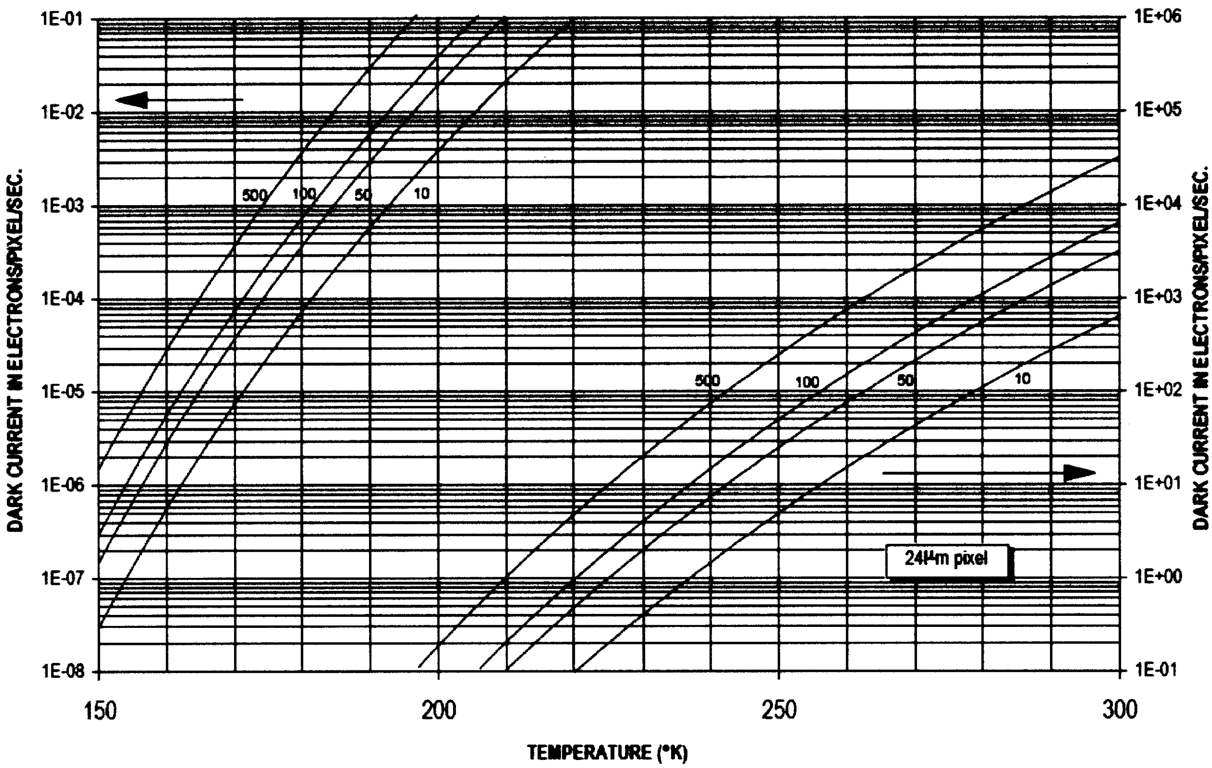


FIGURE 9 *Effect of temperature on dark current. Parameter is pAmp/cm² at 293K*

Appendix NN SiTe 2kx2k: SI424A Pin Definition (SiTe 2kx2k 1994)

SI424A PIN DEFINITION							
PIN # (BACK)	FUNCTION	REGISTERS	SYMBOL	PIN # (BACK)	FUNCTION	REGISTERS	SYMBOL
1	Substrate and Package Ground		SUB	41	Substrate and Package Ground		PKG
2	Output transistor source, c output	c register	OUTc	42	Output transistor source, b output	b register	OUTb
3	Reserved	*	Res	43	Reserved	*	Res
4	Reset Drain Supply, c output	c register	RDc	44	Reset transistor drain, b output	b register	RDb
5	Reset Gate, c output	c register	RGc	45	Reset transistor gate, b output	b register	RGb
6	Last gate, c output	c register	LGc	46	Last gate, b output	b register	LGb
7(8)	Serial phase 3, c register	c register	S3c	47(48)	Serial phase 3, b register	b register	S3b
8(7)	Serial phase 1, c register	c register	S1c	48(47)	Serial phase 1, b register	b register	S1b
9	Serial phase 2, common cd register	cd register	S2cd	49	Serial phase 2, common ab register	ab register	S2ab
10	Serial phase 2, common cd register	cd register	S2cd	50	Serial phase 2, common ab register	ab register	S2ab
11(12)	Serial phase 1, d register	d register	S1d	51(52)	Serial phase 1, a register	a register	S1a
12(11)	Serial phase 3, d register	cd register	S3d	52(51)	Serial phase 3, a register	a register	S3a
13	Last gate, d output	d register	LGd	53	Last gate, a output	a register	LGa
14	Reset transistor gate, d output	d register	RGd	54	Reset transistor gate, a output	a register	RGa
15	Reset transistor drain, d output	d register	RDd	55	Reset transistor drain, a output	a register	RDa
16	Reserved	*	Res	56	Substrate and Package Ground		PKG
17	Output transistor source, d output	d register	OUTd	57	Output transistor source, a output	a register	OUTa
18	Substrate and Package Ground		PKG	58	Diode Protection substrate		DPS
19	Output transistor drain, d output	d register	VDDd	59	Output transistor drain, a output	a register	VDDa
20	Output Ground Reference	d register	GNDd	60	Output Ground Reference	a register	GNDa
21	Summing well, d output	d register	SWd	61	Summing well, a output	a register	SWa
22	Transfer gate, lower serial register	cd register	TGd	62	Transfer gate, upper serial register	ab register	TGa
23	Parallel phase 3	lower quadrants	P3d	63	Parallel phase 3	upper quadrants	P3a
24	Parallel phase 1	lower quadrants	P1d	64	Parallel phase 1	upper quadrants	P1a
25	Reserved	*	Res	65	Reserved	*	Res
26	Reserved	*	Res	66	Reserved	*	Res
27	Parallel phase 2	lower quadrants	P2d	67	Parallel phase 2	upper quadrants	P2a
28	Reserved	*	Res	68	Reserved	*	Res
29	Temp. Sense Diode and Resistor		TD1/TR1	69	Temp. Sense Resistor		TR3
30	Temp. Sense Resistor		TR3	70	Temp. Sense Diode and Resistor		TD2/TR4
31	Reserved	*	Res	71	Reserved		Res
32	Parallel phase 2	upper quadrants	P2b	72	Parallel phase 2	lower quadrants	P2c
33	Reserved	*	Res	73	Reserved	*	Res
34	Reserved	*	Res	74	Reserved	*	Res
35	Parallel phase 1	upper quadrants	P1b	75	Parallel phase 1	lower quadrants	P1c
36	Parallel phase 3	upper quadrants	P3b	76	Parallel phase 3	lower quadrants	P3c
37	Transfer gate, upper serial register	ab register	TGb	77	Transfer gate, lower serial register	cd register	TGc
38	Summing well, b output	b register	SWb	78	Summing well, c output	c register	SWc
39	Output Ground Reference	b register	GNDb	79	Output Ground Reference	c register	GNDc
40	Output transistor drain, b output	b register	VDDb	80	Output transistor drain, c output	c register	VDDc

NOTES: The signals applied to pins 7, 8, 11, 12, 47, 48, 51, and 52 are different for front and back-illuminated parts. The amplifier ground references (GNDx) are local substrate connections, intended for signal chain reference. They should not be biased differently than the other substrate or package connections.

* This is a package connection on the current version; future versions may omit this connection.

TABLE 3 SI424A *pin definitions*

Appendix OO SiTe Wiring Diagram From CCD to Electronic Control Box

From sek 7/17/07
Verified Mack wiring scheme

CCD-A	Signal	driver	driver	video-0	video-1
1	NA				
2	vdd A				1
3	pkg + gnd A			16 – 25	
4	out A			DMA top	
5	rd A			3	
6	rg A	1	clk 0		
7	lg A			9	
8	s3 A	13	clk 12		
9	s1 A	14	clk 13		
10	s2 AB	11	clk 10		
11	s1 B	18	clk 17		
12	s3 B	17	clk 16		
13	lg B			9	
14	rg B	1	clk 0		
15	rd B			3	
16	out B			DMA bottom	
17	DPS			17	
18	vdd B			1	
19	NA				
20	NA				
21	NA				
22	GND			DMA top shield	
23	GND			DMA bottom shield	
24	sw A	35	clk 21		
25	tg A	10	clk 9		
26	p3 A	9	clk 8		
27	p1 A	5	clk 4		
28	p2 A	7	clk 6		
29	p2 B	7	clk 6		
30	p1 B	5	clk 4		
31	p3 B	9	clk 8		
32	tg B	10	clk 9		
33	sw B	34	clk 20		
34	NA				
35	NA				
36	NA				
37	NA				

CCD-B	Signal	driver	driver	video-0	video-1
1	NA				
2	vdd D				2
3	gnd D				16
4	out D				DMA top
5	rd D			4	
6	rg D	3	clk 2		
7	lg D			10	
8	s3 D	15	clk 14		
9	s1 D	16	clk 15		
10	s2 CD	12	clk 11		
11	s1 C	33	clk 19		
12	s3 C	19	clk 18		
13	lg C			10	
14	rg C	3	clk 2		
15	rd C			4	
16	out C				DMA bottom
17	sub + gnd C				16
18	vdd C			2	
19	NA				
20	NA				
21	NA				
22	GND				DMA top shield
23	GND				DMA bottom shield
24	sw D	37	clk 23		
25	tg D	10	clk 9		
26	p3 D	9	clk 8		
27	p1 D	6	clk 5		
28	p2 D	8	clk 7		
29	p2 C	8	clk 7		
30	p1 C	6	clk 5		
31	p3 C	9	clk 8		
32	tg C	10	clk 9		
33	sw C	36	clk 22		
34	NA				
35	NA				
36	NA				
37	NA				

Appendix PP Shutter Electronics Controls

Written By Steve Kissel

The shutter control signal comes from U25 pin 15; this is an ABT574A tri-state output octal flip-flop (pin 15 is bit 4 counting from 0).

Output high level ➔ shutter closed (-2.6 mA max)
Output low level ➔ shutter open (24mA max)

The two shutter signal wires are pin 15 and +5 pin 15 goes to A30 on edge connector and is taken out of the electronics by gray wire on edge connector 0 to g pin D-sub. =5 is taken on black wire from A32 to g pin d-sub. To test:

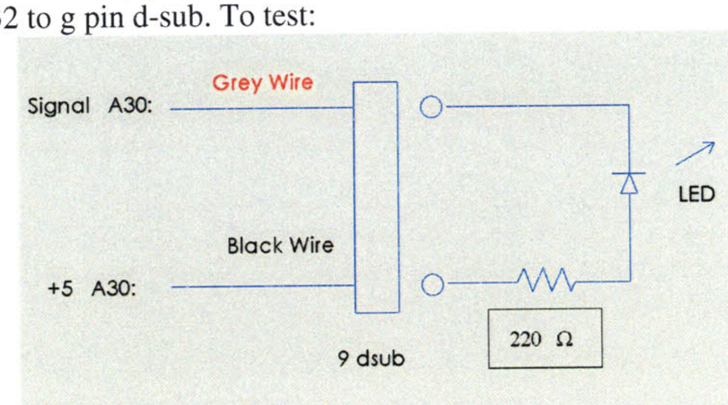


Figure 46 Shutter Signal Testing

Shows how the signal comes through A30 on the grey wire and a +5 on the black wire both going to the 9dsub. This is used for testing the electronics.

When shutter "Open" A30 goes low and draws ~ 18mA LED is on you need to have a load to do this! Using a voltmeter on A30 won't show much because A30 will be ~+5 unless current flows.

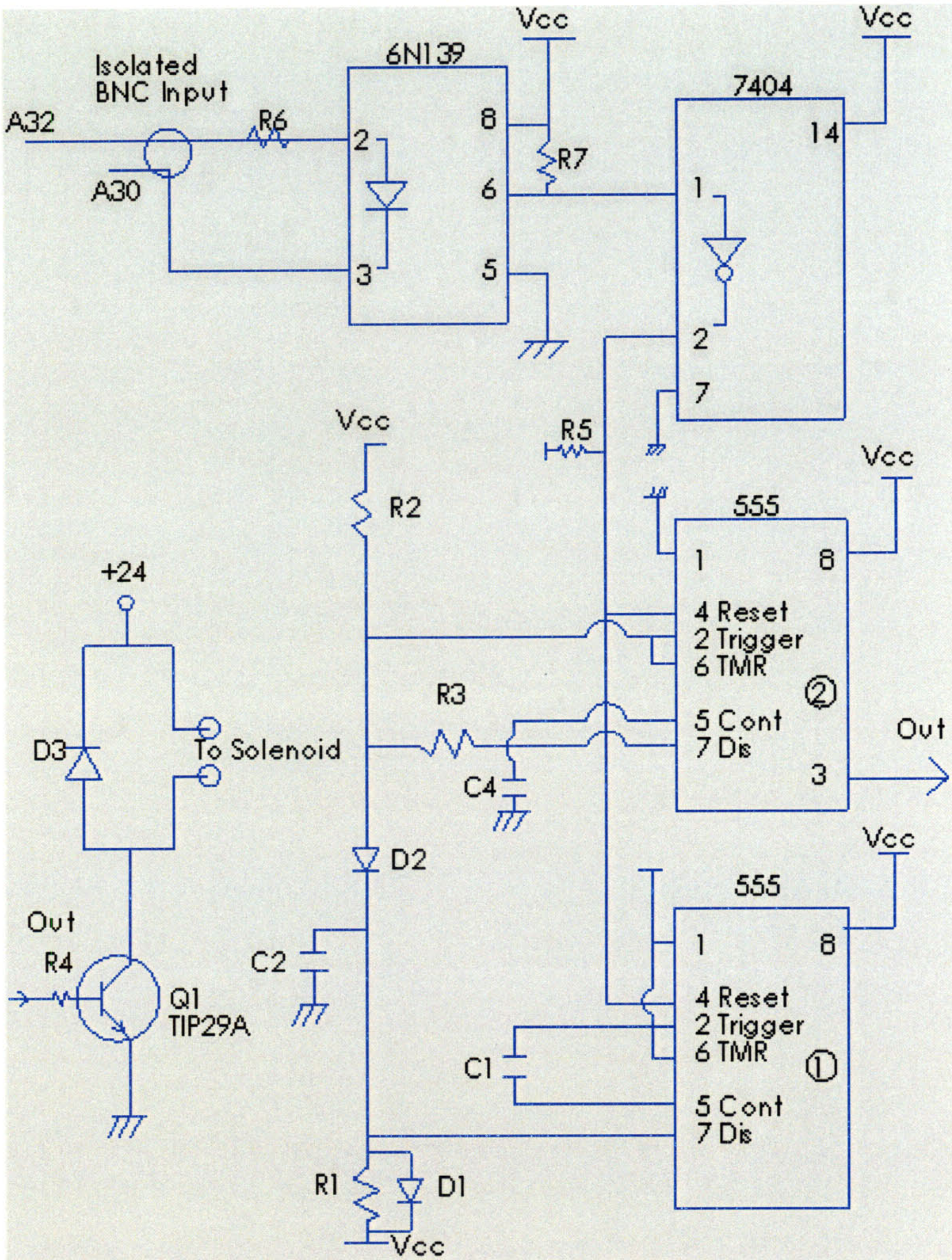


Figure 47 Shutter Wiring Diagram

Shows where the signal enters and leaves the timing board.

The wave form at "out" should look like:

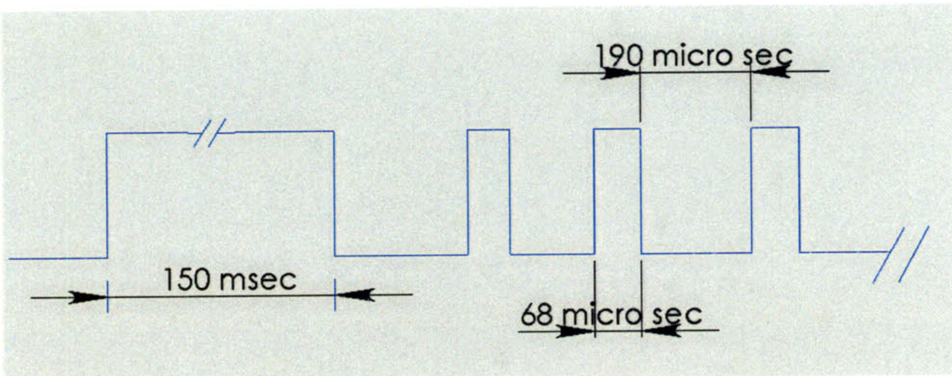


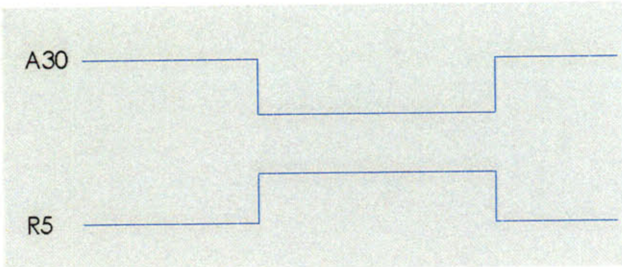
Figure 48 Shutter Signal Wave Form

The ~150msec period is to open the shutter (max voltage) the rest is just to hold the shutter open.

- Controls hold ration
  - R2 = 47 k
  - R3 = potentiometer
- Controls Opening time
  - C2= ~ 4 µF
- Decoupling
  - C1, C4 = .01 µF
- Initial pulse length
  - R1 = 100 k
- Limits base current
  - R4 = 270 Ω
- Pull down on Inverter
  - R5 = 100 k
- Limit
  - R6, R7 = 200 Ω
- Rectifier
  - D3 = IN4001
- Removes C2 from 2nd Timer after charged
  - D1, D2 = IN4148
  - C3 = .001 µF

How it works

GN139 is an inverting opto coupler, when A30 goes low (shutter open) the diode conducts through current limiter RG. This causes the output to go low drawing current through R7. The low level is inverted in 7404 held low by R5.
At this point:



When R5 goes high, both 555 start a stable operation. The first timer charges C2 in time:

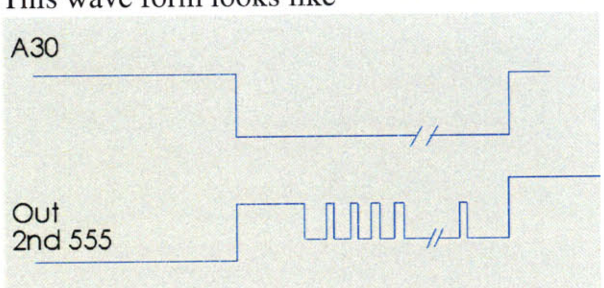
$$C2 \sim .69x\frac{R1 \cdot R2}{R1+R2} \cdot (2 \sim 100m\sec)$$

Once C2 gets charged it gets moved from the 2nd 555 which then has Ton ~ .69 R2*R3 2nd Toff

$$T_{on} \sim .69 * R2 \cdot R3$$

$$T_{off} \sim \frac{R_2 R_2}{(R_2+R_3)} C_2 \cdot Ln\left(\frac{R_2 - 2R_3}{2R_2 - R_3}\right)$$

This wave form looks like



The output of the second timer controls the current through Q1 which drives the solenoid. The specs say ~150 msec @ 24V to open and ~12V to hold, but experiment shows a lower holding current can be used.

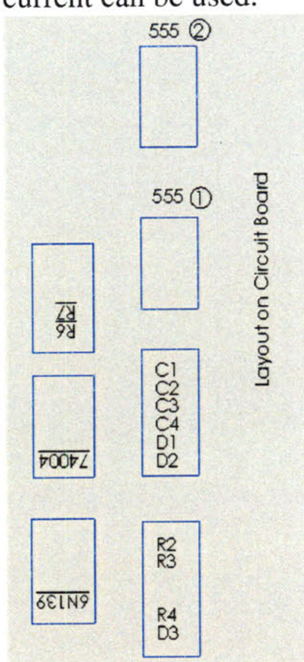


Figure 49 Shutter Electronics: Circuit Board Layout

Appendix QQ Optical Diagram *LensLab*: Wallace Camera.V19.nb

Located on Astron

Optical Path for Wallace Camera 2006/2007

```
Needs["LensLab`LensLab`"]
```

LensLab version 1.5 is now loaded.

Password: 59416063968825

Units are in Cm and Inches. 1 Inch = 2.54 cm
The Site 2kX2k CCD Chip is represented by a 2.8284 Inch equivalent to 7.2 cm plate in order to not viniet the chip.

Telescope Components

Information

Taken From Janet's Thesis pg 49: The 24-inch Primary Mirror: Focal Length 213 cm, Clear Aperture 59.7 cm diameter. Thickness was assumend.

Secondary Mirror is hyperbolic and needs a "CustomMirror" command.

Secondary Mirror

```
Clear[ConicMirror];
ConicMirror[eccentricity_, curvature_, aperture_,holeaperture_,opts___] :=
Block[{options},
options = Flatten[{opts,Options[CustomMirror]}];
Hole[Resonate[CustomMirror[Function[(curvature( #1^2 +
  #2^2))/(1+Sqrt[1-(1-(eccentricity^2)) *(curvature^2)*( #1^2 + #2^2)])], aperture,
"ConicMirror", SurfaceRayIntersections->Solve, SurfaceLabel -> OtherShape,
FunctionCenter -> 0., options],
"ConicMirror"] ,holeaperture, options]];

SecMirror := ConicMirror [-1.5451,.0071,20.3,0.];

DrawSystem[SecMirror,PlotType->Full3D];
```

Cassagrain Telescope

```
(*units are in cm*)
(*PrimaryMirror:= ParabolicMirrorWithHole[213 focal length, 59.7
large diameter, 20.3 hole diameter, thickness]*)

PrimaryMirror :=ParabolicMirrorWithHole[213.129, 59.7, 20.3, 2];
BackofTelescope :=BaffleWithHole[70, 22.2, 2] ;
SecondaryMirror := SecMirror;
TelescopeEntrance := PinHole[100,60];
SiteCCDChip:= PinHole[7.2,0]; (*Equivalent diameter of the 2"x2"
CCD*)

DrawSystem[PrimaryMirror,PlotType->Full3D];
DrawSystem[BackofTelescope,PlotType->Full3D];
DrawSystem[TelescopeEntrance,PlotType->Full3D];
DrawSystem[SiteCCDChip,PlotType->Full3D];
```

Shutter Case

```
in = 2.54;

ShutCase[{xmin_,ymin_,zmin_},{xmax_,ymax_,zmax_},
    holeaperture_,options___]:=
    Hole[BoxGraphic[{xmin,ymin,zmin},{xmax,ymax,zmax},options],
    holeaperture,options];

ShutterCase:= ShutCase[{-3 in,-6 in,-6 in},{0 in, 6 in, 6 in}, 5
in];

(*Shutter case as of 1/7/07 is not 3.5" it is 3.386"  This part
should be remachine in order
to make it 3.5" thick and to make it stronger to hold dewar
weight without distorting.
The machined shutter case is 3.0" thick.*)

DrawSystem[ShutterCase,PlotType->Full3D];
```

Filter Wheel

```
FilWheel[{xmin_,ymin_,zmin_},{xmax_,ymax_,zmax_},
    holeaperture_,options___]:=
    Hole[BoxGraphic[{xmin,ymin,zmin},{xmax,ymax,zmax},options],
    holeaperture,options];

FilterWheel:= FilWheel[{-1.25 in,-8 in, -8 in},{0,8 in,8 in},5
in];

(* Filter Wheel is 1.246 inches thick, but the other dimensions
are incorrect.  The Y, and Z directions
must be symmetrical in order to have the aperture in the center.*)
(* Three Inch square filters.  Will translate into a 4.2426 inch
diamter hole.  Leave hole size to be 3 inches.
The diameter of the hole is 5.0" as machined*)

DrawSystem[FilterWheel,PlotType->Full3D];
```

Field Rotator

```
(* FieldRotator := BaffleWithHole['large
aperture','holeaperture',thickness];*)

FieldRotator:= BaffleWithHole[12 in,4.75 in,3 in];

(* The thickness of the field rotator is an estimate.  The
largest of the counter field rotator
is found at www.rcopticalsystems.com/pirlf.html, this has a hole
aperture of 4.75 inches.*)

DrawSystem[FieldRotator,PlotType->Full3D];
```

Four Port Instrument Rotator

```
FourPortInstrumentRotator[{xmin_,ymin_,zmin_},{xmax_,ymax_,zmax_},
    holeaperture_,options___]:=
    Hole[BoxGraphic[{xmin,ymin,zmin},{xmax,ymax,zmax},options],
    holeaperture,options];

InstrumentRotator:= FourPortInstrumentRotator[{-10 in,-10 in,-10
in},{0 in, 10 in, 10 in}, 8 in];

DrawSystem[InstrumentRotator,PlotType->Full3D];
```

Interfaces 1-5

```
Interfaceone:=BaffleWithHole[24 in, 8 in, .5 in];
Interfacetwo:=BaffleWithHole[12 in, 7 in, .5 in];
Interfacethr:=BaffleWithHole[12 in, 6 in, .375 in];
Interfacefou:=BaffleWithHole[12 in, 5 in, .375 in];
Interfacefiv:=BaffleWithHole[10 in, 4 in, .375 in];
```

```
(*DrawSystem[Interfaceone,PlotType->Full3D];*)
```

Diagrams

Information

```
(* For angle: Plate Scale 20.74 arcsec/mm and the chip is 2"X2"
therefore a 50.8 mm length.  The actual change of the chip is
.170 degrees*)
(20.74*50.8)/3600
(.170*3600)/50.8
```

```
0.292664
```

```
12.0472
```

Complete Telescope Components in Top View

```
WallaceTelescopeFTV = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[BackofTelescope,.000],
    Move[Interfaceone,-.5 in],
    Move[InstrumentRotator,-.5 in],
    Move[Interfacetwo,-11 in],
    Move[FieldRotator,-14 in],
    Move[Interfacethr,-14.375 in],
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->TopView]
    (* The Baffles use the backside as the origin so the
movements change by the thickness of the baffle*)
```

Complete Telescope Components in Full3D View

```
WallaceTelescopeFTIvt = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->5,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[BackofTelescope,.000],
    Move[Interfaceone,-.5 in],
    Move[InstrumentRotator,-.5 in],
    Move[Interfacetwo,-11 in],
    Move[FieldRotator,-14 in],
    Move[Interfacethr,-14.375 in],
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D]
```

Testing Four Port Instrument Rotator Entrance

```
WallaceTelescopeA = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[InstrumentRotator,-.5 in],
    Move[Interfacetwo,-11 in],
    Move[FieldRotator,-14 in],
    Move[Interfacethr,-14.375 in],
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D];

    (* Deleted Lines
        Move[BackofTelescope,.000],
        Move[Interfaceone,-.5 in],
    *)
```

Testing Field Rotator Entrance

```
WallaceTelescopeB = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[FieldRotator,-14 in],
    Move[Interfacethr,-14.375 in],
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D];

(* Deleted Lines:
    Move[InstrumentRotator,-.5 in],
    Move[Interfacetwo,-11 in],
*)
```

Testing FilterWheel Entrance

```
WallaceTelescopeC = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D];

(* Deleted Items:
    Move[FieldRotator,-14 in],
    Move[Interfacethr,-14.375 in],
*)
```

Testing Shutter Entrance

```
WallaceTelescopeD = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D];

    (* Deleted Lines:
    Move[FilterWheel,-14.375 in],
    Move[Interfacefou, -16 in],
    *)
```

Testing Site CCD

```
WallaceTelescopeE = DrawSystem [ {
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{1,0,0}],250,180-.17],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,1,0}],250,180],
    Move[CircleOfRays[58,
NumberOfRays->15,RayLineRGB->{0,0,1}],250,180+.17],
    Move[PrimaryMirror,26.77,180],
    Move[PinHole[50,49],26.77,0],
    Move[SecondaryMirror,185.7,0],
    Move[SiteCCDChip,-20.0338 in]},
    PlotType->Full3D];

    (* Deleted lines:
    Move[ShutterCase,-16 in],
    Move[Interfacefiv,-19.375 in],
    *)
```

Intensity Diagrams

```
Intensity1 = FindIntensity[{WallaceTelescopeA}, Plot2D -> False]
Intensity2 = FindIntensity[{WallaceTelescopeB}, Plot2D -> False]
Intensity3 = FindIntensity[{WallaceTelescopeC}, Plot2D -> False]
Intensity4 = FindIntensity[{WallaceTelescopeD}, Plot2D -> False]
Intensity5 = FindIntensity[{WallaceTelescopeE}, Plot2D -> False]

ShowSystem[WallaceTelescopeA,PlotType->Surface];
ShowSystem[WallaceTelescopeB,PlotType->Surface];
ShowSystem[WallaceTelescopeC,PlotType->Surface];
ShowSystem[WallaceTelescopeD,PlotType->Surface];
ShowSystem[WallaceTelescopeE,PlotType->Surface];
```

Appendix RR Excerpts from PT30 Datasheet

Complete datasheet located as a PDF file on Astron

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY

Product Name:	Liquefied Gas, flammable, n.o.s (Propane, Ethane) (Flammable HC POLYCOLD® Refrigerant: PT-13, PT-14, PT-16 and PT-30)
Chemical Classification:	Hydrocarbon and Inert Gas Mixture
Product Use:	Refrigerant Gas for PCC, CRYOTIGER® and AquaTrap® Cooling Systems
Chemical Names:	Mixture of: Argon, Ethane, Methane, Neon, Nitrogen, Propane (Ar, C_2H_6, CH_4, Ne, N_2 and C_3H_8)
Company Identification	Brooks Automation, Inc.
Address:	3800 Lakeville Highway, Petaluma, CA 94954
Business Phone:	(707) 769-7000
Emergency Phone: Chemtrec North America:	1-800-424-9300 or 1-703-527-3887
Preparation Date:	April 3, 2003
Revision Date:	October 9, 2006

2. COMPOSITION AND INFORMATION/ INGREDIENTS

Component	Weight by %	CAS Number	EINECS Number	Symbols	R Phrases
Argon	0 - 25	7440-37-1	231-147-0		
Ethane	5 - 25	74-84-0	200-814-8	F+	R12
Methane	1 - 15	74-82-8	200-812-7	F+	R12
Neon	0 - 10	7440-01-9	231-110-9		
Nitrogen	0 - 30	7727-37-9	231-783-9		
Propane	25 - 70	74-98-6	200-827-9	F+	R12

For occupational exposure limits, please refer to Section 8: *Exposure Controls-Personal Protection*.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State:	Gas at room temperature
Vapor Density (range of individual components at standard temperature and pressure):	Greater than 1.0 (Heavier than air)
Specific Gravity:	Not applicable
Evaporation Rate:	Not available
Vapor Pressure:	Not available
Odor Threshold:	The product is odorless
Appearance and Color:	Colorless gas in nomal conditions.
How to Detect This Substance (Warning Properties):	The gas has no odor and is not visible; however, rapidly released gasses may cause the formation of a vapor cloud.
pH:	Not applicable
Freezing Point :	Less than -200°C
Boiling Point:	Less than -100 °C
Flash Point:	Less than 0 °C
Flammability:	Highly Flammable
Auto Flammability:	Not Applicable
Explosive Properties:	Can form explosive mixture with air
Oxidizing Properties:	None