KMTNet Camera to Telescope Interface Control Document (ICD)

THE OHIO STATE UNIVERSITY

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Following table shows revision history.

Version	Date	Comments
R3	11/30/2011	Submitted by OSU ISL for Camera CDR
R4	12/21/2011	Submitted by OSU ISL with responses to KASI Items from CDR
R5	01/10/2012	Submitted by OSU ISL with updated Optical Alignment, window condensation, and HE Box location
R6		
R7	08/03/2012	Corrected L4 Sag to 5.07 +/- 0.03mm
R8	08/08/2012	Updated HE Box mounting Drawing Added text describing benefits of SW HE Box location
R9	09/24/2012	Added Observatory Control Software Requirements
R10	02/20/13	Added details about 5" hole in M1 cover for projector
R11	03/21/13	Change glycol hoses to urethane

List of Acronyms

AR	Anti-Reflection
AS	Australia
CCD	Charge Coupled Device
CR	Computer Room
DDD	Data Disk Drives
DEC	Declination
DOF	Degree of Freedom
ER	Equipment Room

FOV	Field of View
FWHM	Full-Width at Half-Maximum
GE	Guide Electronics
GPS	Global Positioning System
GUI	Graphic User Interface
HE	Head Electronics (CCD Controller electronics)
HZ	Hertz
IC	Instrument Computers
ISL	Imaging Sciences Laboratory at the Ohio State University
KASI	Korea Astronomy & Space Science Institute
KMTNet	Korea Micro-lensing Telescope Network
KVM	Keyboard Video Mouse
OS	Observatory Software
OSU	The Ohio State University
OTA	Optical Tube Assembly
PCC	Polycold Compact Cooler (Brooks Automation, formerly Cryotiger)
PDU	Power Distribution Unit
PSF	Point Spread Function
QE	Quantum Efficiency
RA	Right Ascension
RMS	Root Mean Square
ROI	Region of Interest
SA	South Africa
TBR	TBR Construction & Engineering, Tucson, AZ (Telescope Prime Contractor)
TCS	Telescope Control System
TR	Top Ring
UPS	Uninterrupted Power Supply
US	United States
USD	United States Dollar
WB	Wall Bard

1 Overview of Camera to Telescope Interface

The control of interfaces between the telescope, CCD Camera, observatory systems, and software is critical to the success of the KMTNet project. The overall assignment of authority and responsibility for the systems engineering required to control the interface between the telescope and the camera must be carefully addressed by KASI. The ISL is prepared to cooperate fully with the systems engineering function for the KMTNet project.

2 Dewar to Telescope Interface

The interface of the Dewar to the telescope includes mechanical, optical, and electrical aspects which are addressed in the sections below.

2.1 Mechanical Interface of Dewar to telescope Upper Ring

The camera Dewar fits within a 580mm diameter cylinder as required by the telescope interface for no additional vignetting. The length of the Dewar from the outside vertex of L4 to the back plate is 470mm, which is shorter than the requirement of 500mm maximum length. This shorter Dewar will give additional clearance between the Camera and the telescope dome.

The Dewar has an estimated mass of 42 Kg including L4, the FPA, cooling system, copper straps, and cryocooler heads.

The Head Electronics Box mounted to the Upper Ring has an estimated mass of 56Kg including the HE box, cables, and glycol lines.

The total installed mass of the camera system is therefore ~98Kg, which easily meets the specified 250Kg maximum.

2.1.1 Dewar Specifications

2.1.1.1 Size

- 479mm Overall Length
- 470mm from L4 outside vertex to back plate
- 450mm Flange OD

2.1.1.2 Mass & Center of Gravity

- 42 kg. mass
- C.G is very near Dewar centerline and ~ 236mm behind the mounting face of the Dewar

2.1.1.3 Dewar Vacuum valve uses a KF 25 flange for pump line connection

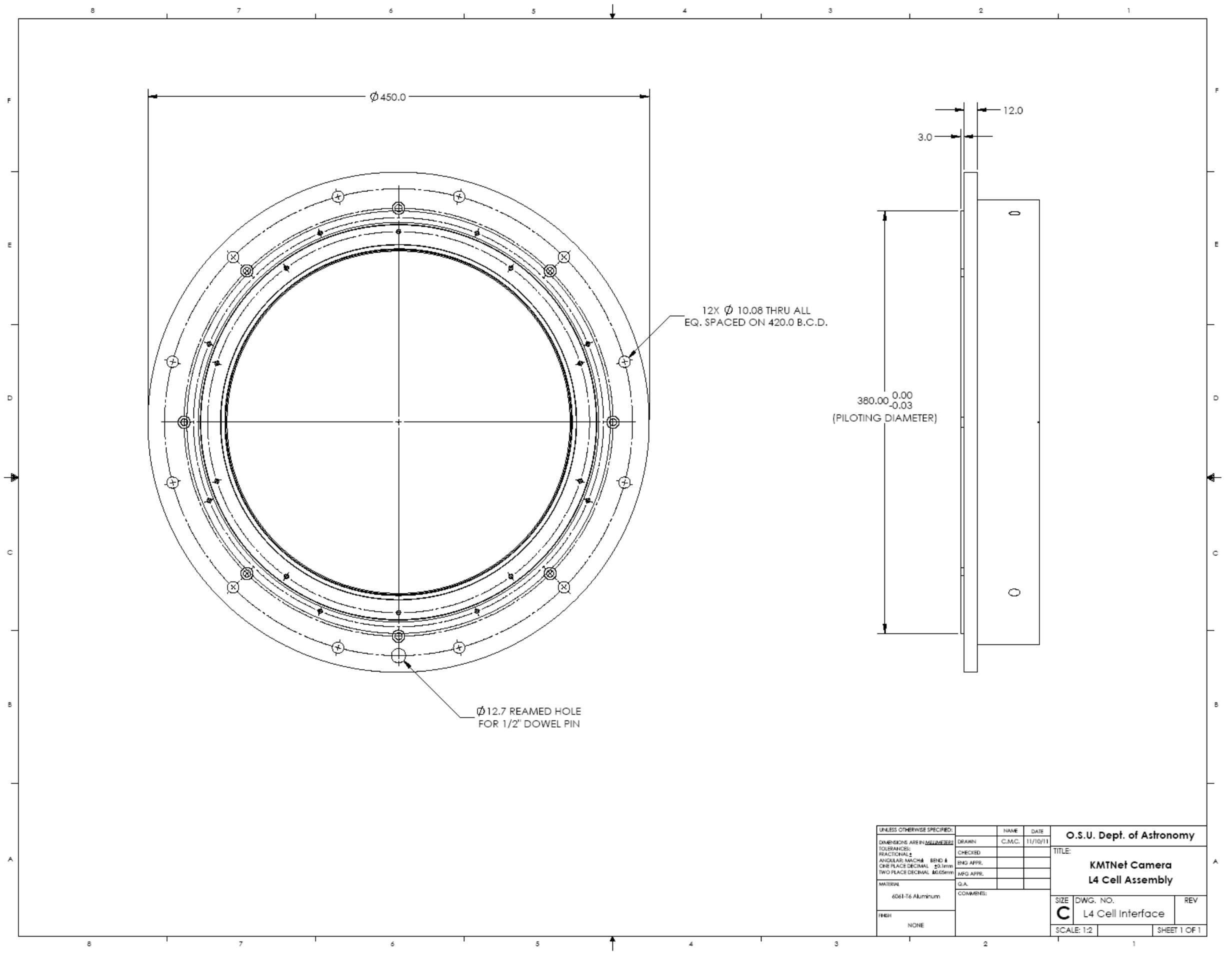
2.1.2 Mounting Bolt Pattern

The Camera Dewar is mounted to the Top Box of the telescope with a circular bolt pattern and guide dowel pins.

- **Number of Bolts:** 12, evenly spaced

- **Diameter of Bolt Circle Pattern:** 420mm
- **Bolt size:** 3/8-16 UNC - 2B, clearance holes in Dewar flange are 0.397” diameter
- **Outside Diameter of flange:** 445mm
- **Piloting Diamter of flange:** 380mm
- **Thickness of Dewar mounting Flange:** 12mm

Refer to L4 Cell drawing below:



2.1.2.1 Dowel Pins for Dewar Registration and Clocking

The Dewar precision registration in X & Y is controlled by the precision fit of the Dewar piloting flange into the bore in the Top Box. The mounting flange design and bolt circle with dowel pin for position registration and clocking have been developed in cooperation with the telescope vendor.

The azimuth orientation to the telescope Top Box is controlled by a dowel pin in the Top Box and a clearance hole for the pin in the Dewar Mounting Flange.

- Dowel Pin is ½” precision pin that extends ½” out of Top Box mounting surface
- Dowel Pin is on a 420mm Bolt Circle Diameter
- Dowel Pin is at 12 o’clock (facing L4 with wall board down)

- Dewar clocking on Top Box is show in Figure Below. Wall board extended side is on same side of Top Box as the filter stowed position.
- Refer to drawing of L4 cell and illustration showing clocking of Dewar on Top Ring

Refer to L4 Cell drawing above for the interface drawings.
Refer to rendering of Upper Ring below for clocking of Dewar and dowel pin location.

2.1.2.2 Camera Handling Cart

A handling cart will be provided to support the camera during assembly, test, and installation. A second Handling Cart will be used to support the HE box. These two carts can also be joined together in the correct relative position duplicate the on-telescope relative positions in the lab.

2.1.2.3 Camera Dewar Installation

The Dewar will be easily removable from the telescope with the telescope in the south service position.

The Dewar pilot flange insertion into the Top Box is only 3mm which simplifies the insertion and retraction of the Dewar during installation.

2.1.2.3.1 Dewar Installation Rigging

- Dewar Load Spreaders
- Dear Rigging Straps

2.1.2.3.2 Installation Guide Pins

Not required due to minimal retraction requirement.

2.2 Optical Interface & Alignment Tolerances

The Dewar entrance window is the fourth element (L4) in the telescope field corrector. OSU has the responsibility to control several optical alignment Degrees of Freedom (DOF). These include: axial spacing and tilts of L4 relative to the Detector plane, Centering and tilts of L4 relative to the Dewar mounting pilot feature. It is assumed by OSU that the pilot bore in the Top Box defines the optical axis of the other three lenses of the Corrector.

2.2.1 **Dewar Entrance Window (L4) Design Parameters**

- **L4 Surface 1 Radius:** 453.709mm +/- 0.25
- **L4 Surface 1 Clear aperture:** 316mm
- **L4 Center Thickness:** 44mm +/- 0.20
- **L4 Surface 2 Radius:** 2373.437mm +/- 1.5
- **L4 Surface 2 Clear aperture:** 308mm
- **L4 Mechanical Diameter:** 322mm
- **L4 Find Grind Flat Sag:** 5.07mm +/- 0.03
- **Surface1 of L4 to telescope flange:** 5.96mm

- **Focal Plane position relative to L4 S1 vertex:** 130.043mm

2.2.2 Dewar Window Clamp Functional Requirements

The Dewar window must perform the following functions:

- Retain the window when the Dewar is not evacuated
- Relieve over-pressure in the Dewar
- **Note that the Window Clamp has no function in the optical alignment of L4.** The window clamp simply holds the window gently against the O-ring allowing centering adjustments of L4.

2.2.3 De-Center of L4 relative to Corrector Axis

The de-center of L4 relative to the optical axis (defined by the two piloting bores in the Top Box) must be < 0.10mm. L4 is mounted in a cell which pilots directly into the Top Box of the telescope with a precision clearance fit. The number of parts in the de-center tolerance stack-up for the camera is thus minimized. The bottom side of the Top Box connects to the cells which carry the remaining Corrector lenses.

L4 De-Center Item	**Tolerance Value (radial mm)**	**Responsible Company**
L4 Outer Edge of lens relative to optical axis defined by line through center of S1 and S2. This is done by optically centering the lens then grinding the final Outer edge.	0.081 mm Per email 12/14/11	JML
Location of Outer Edge of L4 lens relative to piloting diameter of L4 cell on camera. This is done with three radial adjusting screws pushing on L4 and a dial indicator measuring centering.	0.03 mm (0.06mm TIR)	OSU
Piloting of L4 lens cell (which is also the camera mounting interface to the telescope) into the hole in the Top Box Top Box Bore = 380.03 +0.03/-0.00 diameter tol. L4 Cell Pilot = 380.0 +0.00/-0.03 diameter tol.	0.045 mm max.	OSU & CPSI
Quadrature sum of L4/Top Box centering tolerance stackup	**0.097 mm**	

2.2.4 Axial Spacing of L4 relative to Focal Plane

The axial spacing from the vertex of S1 on L4 to the active plane of the CCD must be controlled to a tolerance of +/-0.25mm based on the sensitivity study in Appendix M, Case 2, Detector Plane axial Error.

The table below lists the items contributing to the tolerance stack-up for L4 axial spacing relative to the focal plane. The axial spacing error is dominated by the center thickness of L4. The length of the G10 struts will be adjusted to compensate for the as-built stack-up to improve axial spacing accuracy.

L4 Axial Spacing Item	Tolerance Value (axial mm)	Responsible Company
L4 S1 to S2 center thickness	+/- 0.2mm	JML
L4 O-ring surface to S2 vertex From L4 drawing tolerance	+/- 0.03mm	JML
L4 cell O-ring to Front Cylinder planes	+/- 0.05mm	OSU
Front Cylinder L4 Cell to Inner Ring Both machined in same setup	+/- 0.05mm	OSU
G10 Struts Length (Note: Length of G10 struts could be "tuned" to compensate for the as-built stack-up to improve axial spacing accuracy if required)	+/- 0.05mm	OSU
Thickness of DMP	+/- 0.05mm	e2v
Thickness of science package to CCD active plane Nominal 20mm distance	+/- 0.015mm	e2v
Quadrature sum of L4/Focal Plane axial spacing tolerance stackup	**0.226 mm**	

2.2.5 Tilt Angle of the Focal Plane relative to the Dewar axis

The tilt angle of the focal plane relative to the Dewar axis must be such that the axial focal plane displacement at the edge of the field of view (radius ~ 150mm) must be within +/- 30 microns based on the sensitivity study in Appendix M, Case 1 Depth of Focus.
This tilt will be controlled with standard precision machining. The table below lists the items contributing to the tilt angle of the focal plane relative to the Dewar axis. Fortunately, the image degradation caused by focal plane tilt increase with increasing field so the greatest effect is at the edge of the field. However, the images at the edge of the field are already degraded by design aberrations so the effect of tilt is mitigated.

Focal Plane Tilt Item	Tolerance Value (radians mm)	Responsible Company
Non-parallelism from front Dewar mounting surface to Front Cylinder surface on L4 Cell Machined in two set-ups	+/- 0.015mm	OSU
Front Cylinder L4 Cell to Inner Ring of Front Cylinder Both machined in same setup, tilt nearly zero	+/- 0.010mm	OSU
G10 Struts Length variation causing tilt (Note: Length of all three G10 struts will be final machined in a single set-up to match lengths)	+/- 0.010mm	OSU
Tilt between front and back of DMP	+/- 0.010mm	e2v

Thickness of science package to CCD active plane Nominal 20mm distance	+/- 0.015mm	e2v
Quadrature sum of Focal Plane tilt tolerance stackup	**0.027 mm**	

2.2.6 **L4 Radial Centering Adjustment Screws**

The radial centering of L4 is done using a set of three Delrin radial adjusting screws to push L4 to the concentric position. The very high CTE of the Delrin adjusting screws (5x aluminum) partially compensates for contraction of the aluminum cell at low ambient temperatures. At the lowest service temperature of -20C, each M10 Delrin adjuster screw will have a compressive force of about 300 Nt. on the tip of the screw. The compressive stress in the screws is >10x well below the Delrin material yield strength and well below the damage stress for fused silica.

This design allows precise adjustment, maintains centering at all temperatures, and does not overstress the adjuster screws or the L4 lens at the lowest service temperature.

2.2.7 **L4 Optical Alignment Procedure**

The L4 lens is mounted in its cell in a loose clearance bore. The S2 surface has a flat edge that seals against the Dewar O-ring and controls the tilt of L4 in the cell.
The radial centering of L4 is done using a set of three radial adjusting screws to push L4 to the concentric position.

The procedure for optical alignment of L4 is:

- Mount L4 in its cell with the L4 clamp. The L4 cell incorporates a piloting cylinder for registration to the telescope "Top Box" which carries the corrector tube. This approach minimizes the tolerance stack up.
- Install the 3 radial adjusting screws and tighten them against L4. L4 is in an arbitrary position at this point.
- Sequentially install each of the 3 digital indicators in the same 3/8" indicator hole and "ZERO" them. This sets the length of all 3 indicators to the same value.
- Install the 3 radial digital indicators into the three holes and tighten the setscrews that hold them in place. L4 is still in an arbitrary position at this point so the 3 indicators will all read different values.
- Use the three radial adjusting screws to move L4 relative to the L4 cell until all three indicators read the identical value. L4 is now centered.
- "ZERO" all three digital indicators
- Mount the L4 cell to the front Dewar. The L4 to Focal plane relationship has axial spacing and tip/tilt tolerances that can be met with precision machining and inspection of the parts and assemblies (see Tables above)
- Mount the Dewar to the telescope Top Box. The L4 cell has a high precision pilot into the Top Box to ensure excellent alignment during mounting/de-mounting of the Dewar to the telescope.

2.2.8 **Pressure Loading on Window**

The Dewar window is designed so that the stress induced by 1 atmosphere of pressure loading will be well within the safe operating stress limits for the window material. Fused Silica is being used for the window due to its high strength. The Dewar window has a stress margin of safety of more than 6:1. Dewar Pressure Relief using Window Clamp

The Dewar window clamp is engineered to yield if the internal pressure of the Dewar exceeds 2 psi. The yielding of the clamp will allow the window to lift off the window O-ring and vent the Dewar.

2.2.9 **Water Condensation on Window**

The radiation cooling of the center of the window will cause the central area of the window to be below the outdoor dew point temperature under some ambient conditions. The volume in front of the Dewar window is environmentally sealed and dry air with a dewpoint of ~ -100C will purge the volume in front of L4.

The radiation cooling of the center of the window will cause the central area of the window to be below the ambient dew point temperature under some conditions. The air volume in front of the Dewar window is environmentally sealed and dry air with a dewpoint of ~ -100C will continuously purge the volume in front of L4. The air drier and purge supply will be provided by OSU.

2.2.10 **Guide CCDs vignetting by filters**

The Guide CCDs will be vignetted by the 300mm square filters reducing the throughput to the guide CCDs by ~20%. The outer edges of all four Guide CCDs fall on a diameter of 252.54mm.

2.2.11 **Camera Baffles**

A baffle comprising a series of field stops will be placed between L4 and the FPA to help reject scattered light entering the camera.

3 HE Box to Telescope Upper Ring Interface

3.1 HE Box Specifications

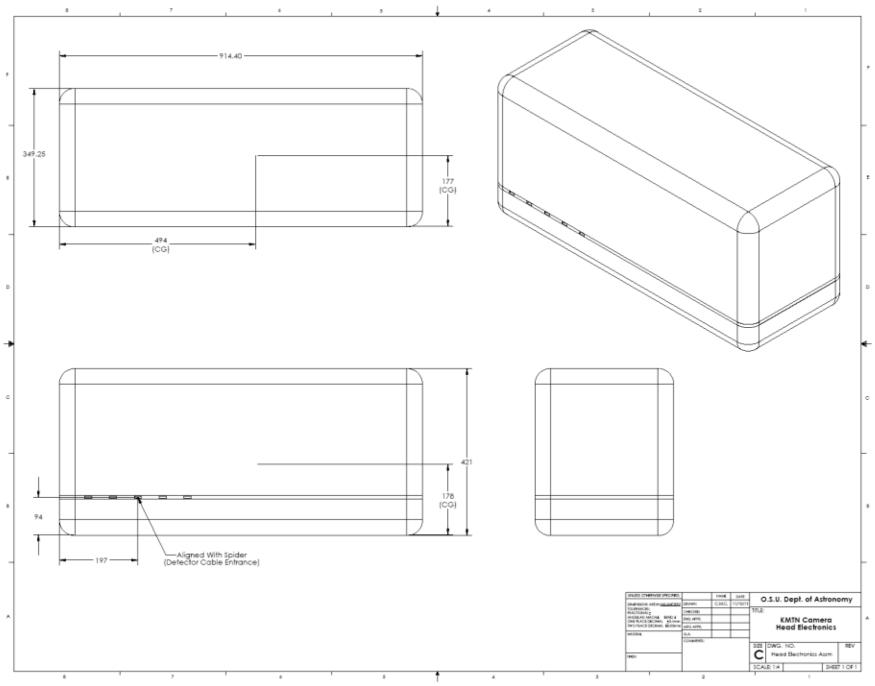
3.1.1 **Head Electronics Box Size**

A single rectangular Head Electronics box will control the 4 science and 4 Guide CCDs. The Head Electronics Box dimensions are:

Length = 36.00” (914mm)
Width = 13.75” (350mm)
Height = 17.37” (441mm)

3.1.2 **HE Box Mass and Center of Gravity**

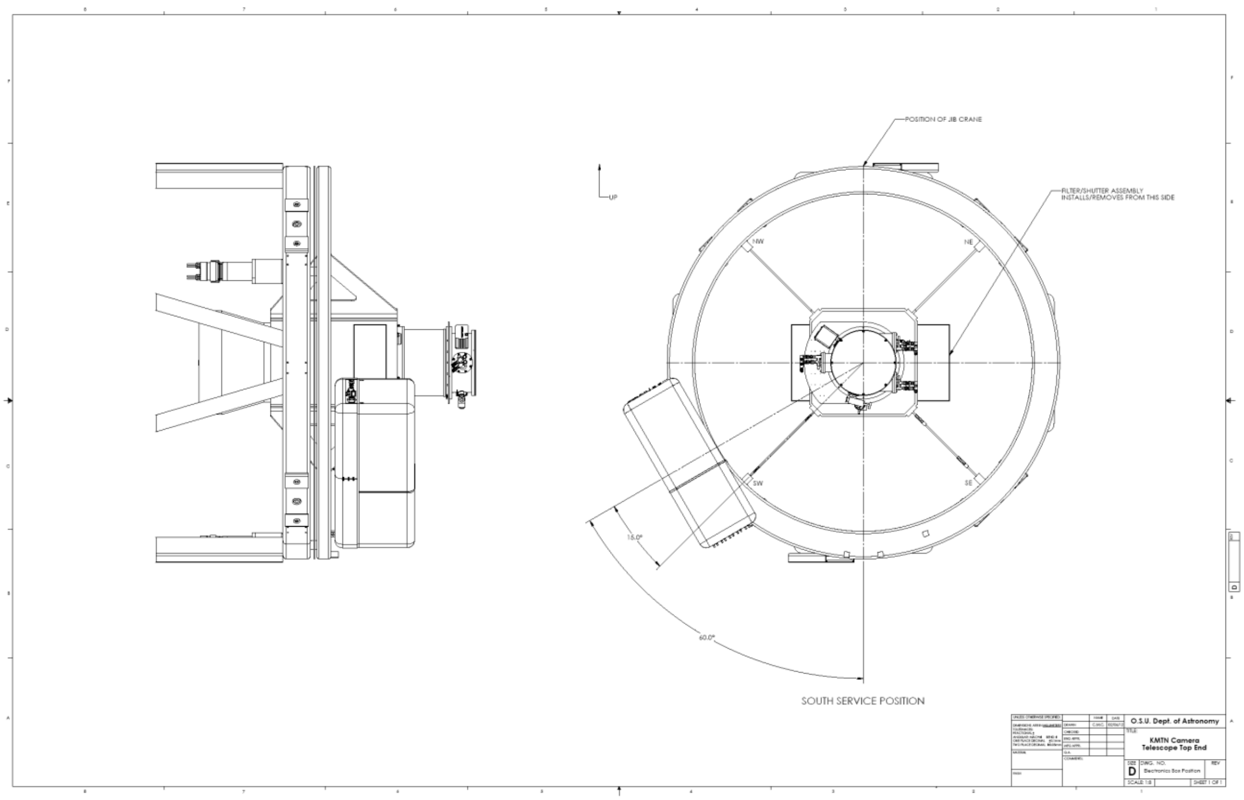
- Mass of HE Box will not to exceed 56 kg.
- The HE Box C.G. is very near the center of the HE Box volume.



3.1.3 **HE Box Mounting Location**

Refer to the drawing of Telescope Top End on the next page. The Filter/Shutter installs/removes from the East. Previously this had been shown removing to the West. The new HE Box location allows the removal of the shutter/filter assembly without removing the camera HE box.

- OSU will now use the SouthWest (SW) location for the HE Box without obstructing the filter/shutter servicing.
- The Wall Board (facing West) fits in the shadow of the updated filter/shutter enclosure as shown.
- The SouthWest (SW) HE Box location gives the shortest possible detector cable length with the Wall Board facing west.
- The SouthWest (SW) HE Box location gives much more clearance to the jib crane which was a previous KASI concern.
- The SouthWest (SW) HE Box location allows it to be installed/removed with the telescope at the South service position.
- OSU will mount the HE Box at its original SouthWest location.



3.1.3.1 HE Box Mounting Brackets

The HE box will be mounted to the fixed portion of the telescope Upper Ring using tapped holes in flat pads on the outer cylindrical surface of the Upper Ring. The Bolt Pattern on Upper Ring for HE Box mounting is shown in drawing ????? provided by CPSI.

3.1.3.2 HE Box location for Service Access

The HE Box azimuth location allows good service access to HE Box from the scissor lift when the telescope is in the service position. The top cover of the HE Box is removable for service at this position.

3.1.3.3 HE Box location for Detector Connectors

Azimuth location of the HE Box has the clock/bias section of the HE centered on a spider vane to minimize detector cable length

3.1.3.4 HE Box Utility Connectors

Glycol lines will use Swagelok quick connect fittings with zero leakage mating. This will simplify installation and removal of the HE Box by preventing any glycol leakage.

3.1.3.5 HE Box Power

The HE Box will require 600 watts of power

3.1.4 **HE Box Installation Procedure**

The HE box is large and heavy and must be mounted to the telescope with the assistance of the scissor lift. Rigging hardware will be provided by OSU to aid in the HE Box installation from the scissor lift.

3.1.4.1 HE Box Rigging & Straps

Rigging and procedures to install & remove the HE Box will be designed and provided by OSU.

4 Hoses, Cables, Optical Fibers

4.1 Dewar Cables and Hoses Routing across Spider Vanes

4.1.1 **PCC Cryocooler supply and return hoses**

The detector Dewar uses three PCC commercial mechanical refrigerators (model #T2111-01-13 cold heads, model PCC W/PT13 compressor). The compressors are located off the telescope. Routing is therefore required for three hose sets (**six 13mm diameter hoses in total**).

The cryocooler hoses are gathered together and stacked in a plane parallel to the telescope axis. This routing and stacking takes place in the shadow of the filter changer. The hoses are then routed along a cable handling vane directly above one of the telescope Upper Ring vanes. The hoses will not add any additional obscuration area.

The cryocooler hose minimum centerline static bend radius is 4” (~100mm).

4.1.2 **Dewar Detector Cables**

Five Samtec Science CCD and Guide CCD to HE box cables will be routed from the camera Dewar to the HE box along a spider vane. These flat cables can be stacked.

4.1.3 **Dewar Utility Cable to HE Box**

A Dewar utility cable (~10 mm dia) will route from the Dewar to the HE Box.

4.2 Cables & Hoses from Upper Ring Through Telescope to Equipment Room

4.2.1.1 PCC Cryocooler supply and return hoses

The six cryocooler hoses must be routed down one side of the OTA, through the DECLINATION axis, through the RA axis, and through the cable trough into the Equipment Room. Several coils of the flexible hose will be placed near the compressors to store excess line.

The cryocooler hose minimum dynamic centerline bend radius for continuous flexing is 6 inches (150mm). The dynamic bending in the cable wrap for the DEC and RA axes must be in a single plane to prevent torsion on the hoses. Two plane bending induces very high torsional stress in the hoses leading to premature failure.

4.2.1.2 Power Cord

120 or 240 Volt power cable, 10 Amps, 10 AWG/3 conductor with ground, type SO equivalent or as required by local codes

4.2.1.3 Optical Fibers

5 optical fiber pairs, each is a 15 x 5 mm rectangle.

4.2.1.4 Glycol supply & return hoses for HE Cooling

- McMaster Carr #5439K23
- 1/2” (12.7mm) I.D. by 3/4” (19mm) OD
- 195psi working pressure
- Tygothane clear urethane reinforced hose
- 2” minimum allowable bend radius

5 Equipment Room Requirements

5.1 Equipment Room Dimensions

- A 5’10” by 9’10” (inside dimensions) building on a concrete pad (referred to as the “Equipment Room”) is being designed by TBR to house camera support equipment.
- The Equipment Room must be able to accommodate a standard 36” wide door for personnel entry
- Good personnel access for maintenance and service in a covered environment is required. This requires a full height (~8 feet) building.

5.2 Equipment

4 PCC cryocooler compressors on an equipment rack spare parts
Water Cooler Nu-Tec R2000 for HE Box cooling
CDA12-220520 Twin Tower Engineering, Air Dryer for L4
MAXI-COOL RC 100BL000 recirculating cooler for M1 Mirror Cooling

5.3 Cryocooler Compressors

Four (3 in service and 1 spare) PCC cryocooler compressors will be placed in the Equipment Room on an equipment rack.

5.3.1 Compressor Dimensions

17.88”(454mm) wide * 14.75”(375mm) high * 11.06” (281mm) deep

5.3.2 Compressor Weight

74 lbf (33.6kg) each

5.3.3 Compressor Operating Temperature Range

+ 10C to + 35C (+50F to + 95F)

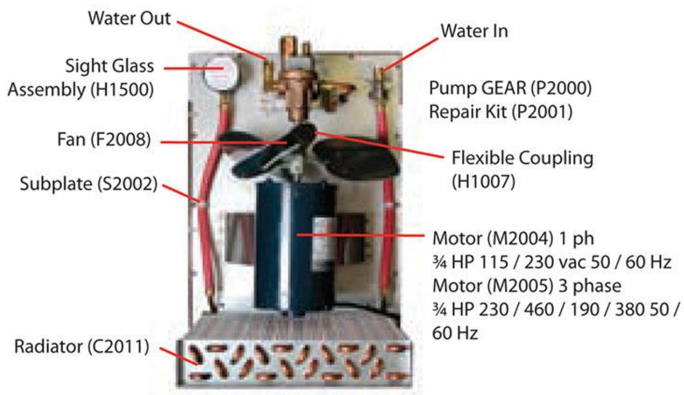
5.3.4 **Compressor Electrical Service & Power Dissipation**

600 watts during cooldown, 500 watts nominal steady state for each compressor
50 hz operation is acceptable with reduced cooling performance
Voltage externally selectable (100, 120,220, or 240 VAC)

5.4 HE Cooler

A single forced air glycol cooler will be placed in the Equipment Room to cool the glycol circulating to the HE boxes. This cooler must have direct access to outside air for inlet

and exhaust.



5.4.1 **Cooler Model**

R2000 Dynaflux. Available from Welding Direct.

5.4.2 **Cooler Dimensions**

23"(584mm) deep * 16"(406mm) wide * 19.5" (495mm) high

5.4.3 **Cooler Weight**

68 lbf (30.9kg)

Cooler Operating Temperature Range
+ 10C to + 35C   (+50F to + 95F)

5.4.4 **Cooler Airflow**

- The airflow of the HE cooler is ~ 900 cfm.
- An air inlet duct - direct to outside ambient air - must be provided to allow outside air to be drawn across the cooler heat exchanger.
- An exhaust duct must be provided to allow the cooler exhaust air to directly exit the Equipment Room.

5.4.5 **Cooler Glycol flow**

Glycol pump capacity is 3.5 gpm at 50 psi

5.4.6 **Cooler Electrical Service Requirement**

60 or 50 hz operation is acceptable
Power   120 VAC at 13.4 amps
Power   230 VAC at 6.7 amps
Voltage externally selectable (115 or 230 single phase VAC)

5.5 Air Dryer for L4, Shutter/Filter Volume

An air dryer will be provide to supply very dry air to the volume in front of the L4 lens which also encloses the Shutter and Filter Changer assemblies. This volume will be environmentally sealed so that some exhaust air will beed out of the volume as fresh dry air is supplied from the dryer.

5.5.1 **Dry Air Performance**

- Delivered Dewpoint — -40C @ +38C saturated input
- Delivered Flowrate — 6 Standard liters per minute
- Delivered Pressure — 0-75 psi user adjustable

5.5.2 **Dryer Model**

Twin Tower Engineering Model CDA12-220520

5.5.3 **Dryer Dimensions**

16.25"(412mm) deep * 24"(610mm) wide * 15" (380mm) high

5.5.4 **Dryer Weight**

72 lbf (32.7kg)

5.5.5 **Dryer Operating Temperature Range**

+ 1C to + 45C   (+34F to + 113F)

5.5.6 **Dryer Electrical Service Requirement**

60 or 50 hz operation is acceptable

230 VAC, single phase, at 1.6 amps

5.6 M1 Mirror Chiller

5.6.1 Cooler Model

RC100BL000 from FTS Systems, SP Scientific

5.6.2 Cooler Dimensions

24”(610mm) deep * 18”(457mm) wide * 34” (864mm) high

5.6.3 Cooler Weight

275 lbf (125kg)

5.6.4 Cooler Operating Temperature Range

+ 12C to + 27C (+55F to + 80F)

5.6.5 Cooler Airflow

This cooler has an air cooled condenser. The airflow of the cooler is inside the equipment room. The heat rejected by the cooler condenser must be exhausted from the equipment room by the ventilation fans

5.6.6 Cooler Glycol flow

Glycol pump capacity is 4.0 gpm at 10 psi, centrifugal pump. (Note that high pressure pumps are available.

5.6.7 Cooler Electrical Service Requirement

60 or 50 Hz operation must be ordered from factory
Power 230 VAC at 15 amps
2800W capacity, COP = 3. 930W work to compressor = 1200 W electrical compressor
300W for fan. 150W misc. Total = 1200W + 300W + 150W = 1650W
1650W/230V ~ 7.2 amps typical

5.7 Equipment Room Electrical Service Summary

A 6” rigid conduit will be routed directly from the Equipment Room wall nearest the telescope chamber through the chamber wall and terminate above the RA axle of the telescope. This will carry 6 cryocooler hoses, 2 glycol hoses, a dry air line, and a few small hoses.
The power will be controlled with two APC AP8653 ethernet controlled outlet strips located in the equipment room.

Equipment Description	Connection Description	Volt	Current (amps)	Power (watts)
3 PCC Cryocooler compressors	3 plug outlets	240	8	1800
HE Box Cooler		230	6.7	1500
Air Dryer		230	1.6	375

M1 Cooler		230	15max	3450
Baseboard heater		230	6.5	1500
1000 cfm ventilation Fan		230	1.0	230

5.8 Equipment Room Temperature Regulation

The temperature inside the Equipment Room must be limited to range from +10C to +35C to meet the PCC compressor operational limits.
The observatory ambient temperature range is specified to be -20C to + 35C
A thermostatically controlled exhaust fan (~ 1000cfm) with barometric inlet and outlet dampers will be used to limit the high temperature
A 1500 watt wall mounted unit heater will provide additional heat to limit the room low temperature.
The wall insulation is expected to be approximately R12 (fiberglass in 4" metal studs)

6 Computer Room Requirements

6.1 Computer Rack Size & Access

6.2 Electrical Power Requirement

A single 30 amp circuit is required for the OSU camera computer rack. Estimated power is 4 kw.
A single 30 amp circuit is required for the KSAI data server computer rack. Estimated power is 4 kw.

6.3 Air Conditioning Requirement

4 kwatt of AC is required for the 19" Camera computer rack.

7 Camera Software Interface

7.1 Shutter Control

Shutter control will be by a single bit from the HE to the Rabbit Cage (see below). A high signal on this line means: start moving the leading blade of the shutter. A low signal on this line means: delay by the time required for the leading blade to travel a distance equivalent to any overlap of the shutter blades and then start moving. As long as the leading and following blade move at the same rate this algorithm works for both long and short exposures.

7.2 Observatory Control Functions

7.2.1 Introduction

The hardware for which OSU is responsible is located in three places, the Equipment Room (ER) the Computer Room (CR) and on the top ring of the telescope (TR). Facility power in the CR is connected to a UPS (Tripp-lite 6kVA Model SU6000RT4UHVPM with SUPDMB6K NEMA PDU (power distribution unit) and SNMPWEBCARD (AC7960) network interface card) located in the bottom of the computer rack. The output of the UPS is connected to an APC AP8641 “Metered by outlet power distribution unit”. The AP8641 has 24 IEC outlets. All loads in the computer rack are supplied by the AP8641. The CR AP8641 has an AP9335TH temperature/humidity sensor and a network interface. An isolation transformer, located in the computer rack supplies power to the TR. OSU has suggested that the Korea supplied data reduction computers also be powered from the AP8641.

Power for equipment located in the ER will be supplied from two AP8641s connected to grid power (no UPS). One of AP8641s will have an AP9335TH temperature/humidity sensor. Both AP8641s will be on the network

The OS will not be used in any control loops. For example, while the heater in the ER can be monitored and disabled by the PDUs, temperature control is by a local wall mounted thermostat.

7.2.2 Power Types

Each of the three KMTN sites has its own type of power. Power on Cerro Tololo is 60 Hz and nominally US standard. We anticipate that it will be 240 Volts wired as an Edison circuit, that is Phase A, Phase B, and Neutral with 240 volts phase to phase and 120 volts phase to neutral.
Both SA and AS will be 50 Hz wires as single phase and neutral. The nominal voltage in SA is 230 Volts while it is 240 Volts in AS . Power to the TR, supplied by the isolation transformer, will be 240 Volt Edison circuit in all cases, 60 Hz in Chile and 50 Hz elsewhere.
(Shielded cable will be used to the TR. The Edison circuit is used to eliminate first order current in the shield.)

7.2.3 Equipment Lists

7.2.3.1 Equipment Room

- 4 Brooks Automation Cryocooler Compressors
- Wall heater, 1500 W to maintain 50 F minimum temperature in the ER as required by the Brooks Compressors
- Motorized wall lover, air outlet
- Motorized wall lover, air inlet
- Exhaust fan. The lovers and the exhaust fan remove excess heat from the ER
- HE Box Cooler, supplies room temperature glycol to the HE
- Air Dryer, supplies dry air to the Camera Assembly on the TR
- Chiller, Supplies chilled glycol to the primary mirror cooling system. This is not OSU’s responsibility but could be controlled through the PDU?
- PDU 1, with temperature/humidity monitor. Controls the four compressors, the heater, and the inlet lover.

- PDU 2 Outlet strip 2, controls the outlet lover, the cooler and perhaps the chiller. Exactly which of PDUs outlets will power which load is TBD. Note that the PDUs allow each outlet to be individually switched. The load on each outlet, and the line voltage is measured by the PDU and reported on request. The PDUs store a startup states sequence, and limits on power consumption. Interface to the PDUs is via the network.

7.2.3.2 Computer Room

- UPS
- PDU 3 with temperature/humidity monitor
- 9 PC computers (5 ICs, Spare IC, Caliban, Guide computer, TCS)
- Rack mounted network and KVM hardware
- Isolation transformer for power to TR. Exactly which of PDUs outlets will power which load is TBD. Note that the PDUs allow each outlet to be individually switched. The load on each outlet, and the line voltage is measured by the PDU and reported on request. The PDUs store a startup states sequence, and limits on power consumption. Interface to the PDUs is via the network.

7.2.3.3 Top Ring

- Head Electronics
- Camera Assembly

7.2.4 **Observatory Software Requirements**

7.2.4.1 Setup and Verify Function

The OS should store the configuration for each outlet, including what is connected, limits on power consumption for that device (both high and low), position in startup sequence, position in shutdown sequence, delay after starting before starting next device, delay after shutdown before shutting down next device.
Control
The OS should be able to turn on or off any outlet of the PDUs via either local or remote command.

7.2.4.2 Readback

The OS should be able to readback the power to any outlet, the power to banks of outlets, the line voltage, when equipped the optional sensors, temperature or humidity.

7.2.4.3 Shutdown

The OS should be able to execute a shut down sequence.

7.2.4.4 Other sequences

tbd

7.2.4.5 Monitoring and Logging

The OS should log the power consumption of each outlet, the temperature and humidity in the CR, the temperature and humidity in the ER, several temperatures and the Dewar pressure returned from the HE through the master IC, Dome temperature (source unknown), and parameters returned from the TCS including telescope position, Dome position, Slit status, Primary Mirror temperature. Parameters should be monitored one to a few times a minute and logged a few times an hour.

7.2.4.6 Warning and Status Messages

High and low limits should be stored for each parameter. A method to define the limits for a parameter as not applicable (minus infinity to plus infinity?) should be included. Two emails should be sent to the addresses on a “warning list”. The first should be short, suitable for receipt on a dumb cell phone, under ~100 characters, listing the out of range parameter and the valued measured. If more than one parameter is out of range the email should include information on the first detected limit violation and the number of detected violations. The second email, which goes to a separate list, should include the present values and the most recent previous log entries for all parameters. Once a warning is sent it should not be repeated unless a different parameter is newly detected out of range.

8 On-Telescope Projector Design Requirements

An optical projector to illuminate the KMTNet Camera for test and calibration is required. The projector enables daytime and nighttime local and remote Camera testing. The projector will relay an image of a slide in the projector through the 4 lenses of the KMTNet telescope corrector and produce a magnified image of the slide on the Camera Science and Guide CCDs. The magnified image will fully illuminate the camera.

8.1 Slide Size

A film “slide” will be used as the source image. Grain size of film will be ~ 10 microns or less. This will be magnified onto the CCDs limiting spatial resolution. The Science and Guide CCDs fit in a square about 255mm on a side.

8.2 Projector Optical Design

Projector Telescope	Stellarvue SVR80ED
Focal Length	560mm
Magnification	8:1
Slide Size	32mm square
Image quality	~ 65 micron FWHM @ Camera CCDs

8.3 Slide Illumination

The slide will be back-illuminated using Vishay TSHG8200 LEDs with a center wavelength of ~820nm and a wavelength FWHM ~ 40nm. This wavelength is in the middle of the Johnson I band. The illumination intensity can vary smoothly by a factor of several over the extent of the slide.

8.4 Packaging on Telescope

- The on-axis optical projector telescope tube will project through the mirror covers.
- A round 125mm (5”) diameter hole will be required on the optical axis through the mirror covers
- The projector will have an adjustable collar that will be located a few millimeters below the covers to provide a rough seal between the projector and the covers. A flexible rubber V-seal could also be provided if required.
- The projector (with slide & LED illuminator) will be pre-assembled on the bench to the M1 Central Disk. The M1 Central Disk will then be installed to the 6 standoffs using six ¼ -20 Button Head Cap Screws on a 224mm Bolt Circle. OSU will supply the M1 Central Disk that carries the projector.
    - CP systems projector interface responsibility ends at the ends of the 6 standoffs.

- The three ¼ -20 bolts that mount the projector flange to the standoffs for the Center Disk will use heavy Belleville springs to allow tip/tilt adjustment of the projector for steering the image to the CCDs
- O.D. of Central Disk is ???mm. The O.D. will have a knife edge
- The new Central Disk will have a center hole for the projector
- The Central Disk with projector will be installed from the front (reflective side) of M1 so that the M1 cooling system will not need to be removed for projector installation.
- A small 2 wire low voltage electrical cable will need to be routed from the projector, through the M1 Cell, to the CCD Head Electronics Box on the Upper Ring. This cable remains on the OTA so it doesn’t pass through any cable wraps.
- The projector focuser knob will be behind the mirror covers so that the hole in the mirror covers can be minimized in size.
- The projector can be used completely independently of the telescope. No TCS commands will be required to operate the projector.
- The projector can be operated with the mirror covers closed or open. Closed is preferred to protect mirror and reduce background light.

9 Lab Projector Design Requirements

A lab projector will be required to project a magnified image of a test target slide through the L4 lens (Dewar window) onto the Camera science CCDs. This projector should be as similar as possible to the on-telescope projector.

- Must have feature(s) to allow set up from the floor (tripod mount)
- Centerline height same as height of Dewar on its handling cart

10 Camera/Telescope Open Issues

- Equipment Room detailed design
- Computer room size, layout, racks, A/C, power,
- Computer room window has been deleted from design.

- DEC & RA cable wrap design
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