Design of the KMTNet large format CCD Camera

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ABSTRACT

We present the design for the 340 Mpixel KMTNet CCD camera comprising four newly developed e2v CCD290-99 imaging sensors mounted to a common focal plane assembly. The high performance CCDs have 9k x 9k format, 10 micron pixels, and multiple outputs for rapid readout time. The camera Dewar is cooled using closed cycle coolers and vacuum is maintained with a cryosorption pump. The CCD controller electronics, the electronics cooling system, and the camera control software are also described.

Keywords: KMTNet, CCD, Wide-field imager, micro-lensing

1. INTRODUCTION

KMTNet, now under construction, is a system of wide-field telescopes and cameras which will discover and monitor thousands of gravitational micro-lensing events per year by observing dense star fields near the Galactic bulge.[1,2] Three identical observatory enclosures, telescopes and cameras will be constructed and deployed to three observing sites in southern hemisphere, at Cerro-Tololo (CTIO) in Chile, Sutherland (SAAO) in South Africa, and Siding Spring Observatory (SSO) in Australia.[3,4] These three astronomical sites are longitudinally well-separated so that KMTNet will be able to provide 24 hour monitoring of micro-lensing events, weather permitting. The telescopes will be equipped with CCD imagers that cover a 2.0 degree by 2.0 degree field of view with 0.40 arcsec/pixel sampling suitable for accurate photometry in crowded fields. Four fields in the Galactic bulge will be monitored with exposures of about 2 minutes and detector readout time of about 30 seconds giving a cadence per field of 10 minutes. Detailed simulations indicate that KMTNet will increase the micro-lensing planet detection rate by an order of magnitude, and measure the frequency of cool, earth-mass planets orbiting stars throughout the Galaxy. A huge amount of observing data for tens of millions of stars will also enable the discovery of numerous variable objects such as pulsating stars, eclipsing binaries and extra-solar transiting events.

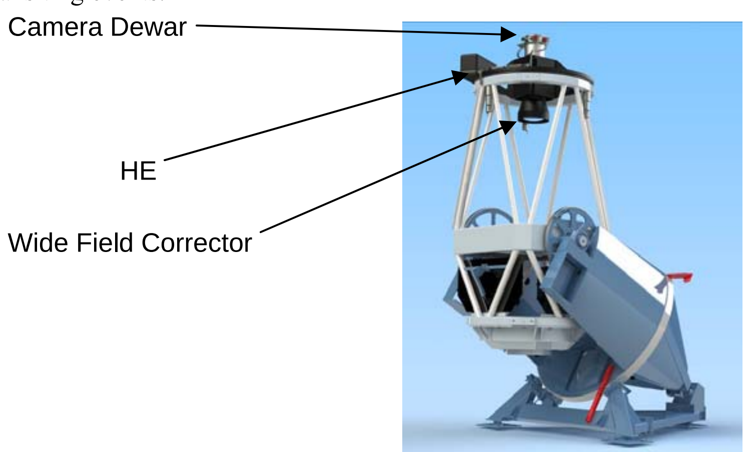

Figure 1. View of the telescope showing the location of the Camera and HE Box

2. INSTRUMENT OVERVIEW

The KMTNet camera is a wide field prime focus camera with a Focal Plane Array (FPA) comprising four e2v CCD290-99 science devices and four e2v CCD47-20 full frame transfer guide chips. The FPA is housed in a vacuum insulated Dewar which is cooled with PCC cryocold closed cycle coolers. The fused silica camera vacuum window is the fourth element of the wide field prime focus corrector. The camera is mounted to the top ring of the telescope. The top ring is positioned by three actuators to execute tip/tilt/focus adjustments of the camera relative to the primary mirror (Figure 10).

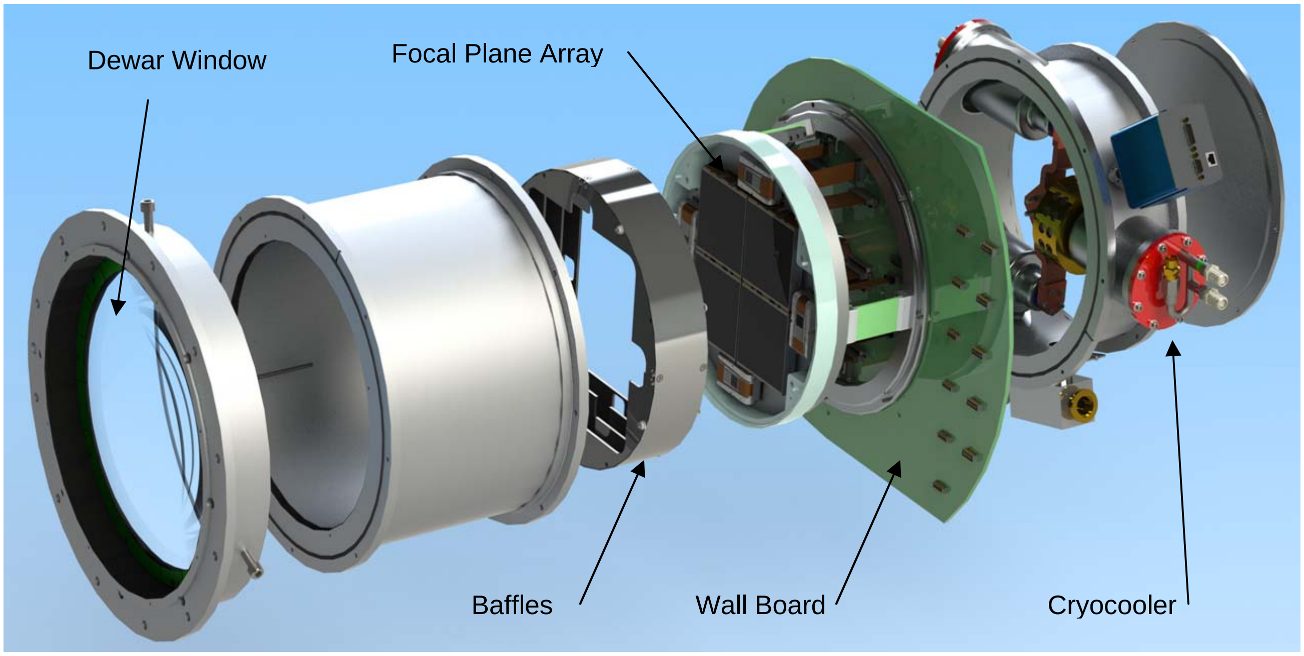

Figure 2. Exploded view of the KMTNet camera

2.1 KMTNet Camera Specifications

Telescope Aperture	1.6 m
Telescope Working f/Ratio (Prime Focus)	f/ 3.22
Telescope Focal Plane Scale	40arcsec/mm
Science Detector Pixel Size	10 microns
Detector Pixel Projection on Sky	0.04 arcsec/pixel
Number of Pixels in Mosaic	340,328,448
Mosaic Field of View on Sky	2.05 x 2.05 degrees
Mosaic Fill Factor	92.5%
Sky Coverage with Fill Factor	4.2 square degrees

3. CAMERA FOCAL PLANE ARRAY

The Focal Plane Assembly (FPA) comprises four 9k x 9k Science CCDs (e2v CCD290-99) mounted in a 2x2 array and four 1k x 1k guide CCDs (e2v CCD47-20) mounted it the cords of the field . Electrical connections to the Science and Guide CCDs are made with flex cables which exit to the rear of the FPA through slots in the Detector Mounting Plate (DMP) and mate with connectors on the front surface of the Wall Board where the CCD signals are routed outside the Dewar.

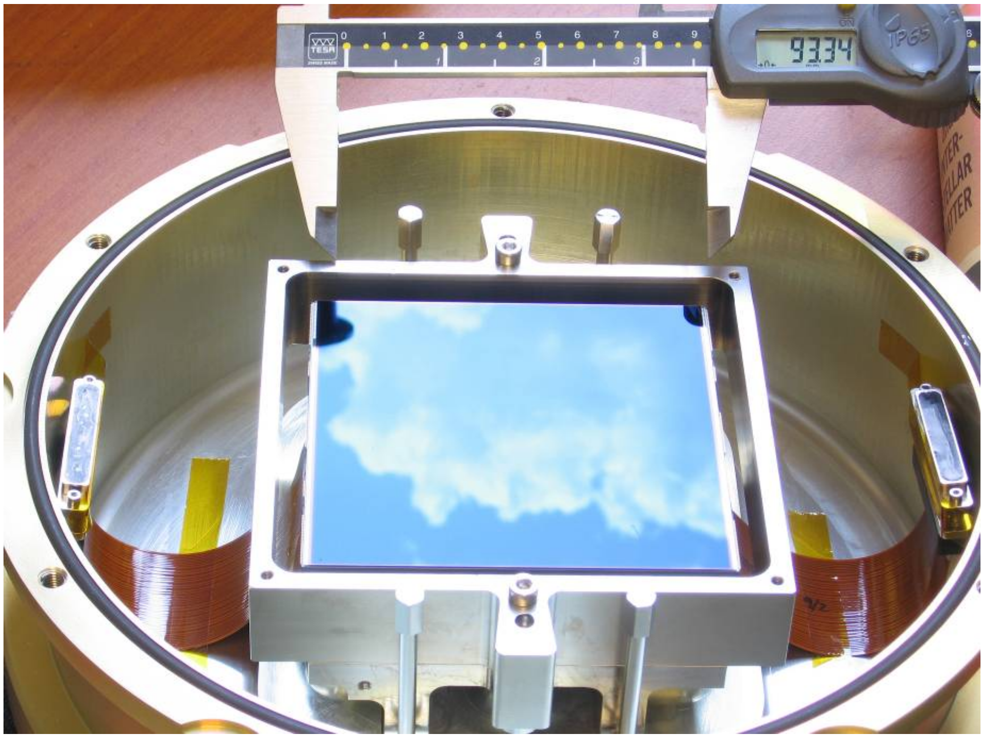

Figure 3. Image of a mechanical sample of the KMTNet science CCD. Flex cables are wrapped around in the shipping configuration with end connectors visible. The square box around the CCD is part of the shipping container.

The Science CCDs are in packages designed to be mounted very close to each other to minimize the dead area between the devices. The Four Guide CCDs will be used for auto-guiding and for measuring FPA Tip and Tilt for telescope collimation.

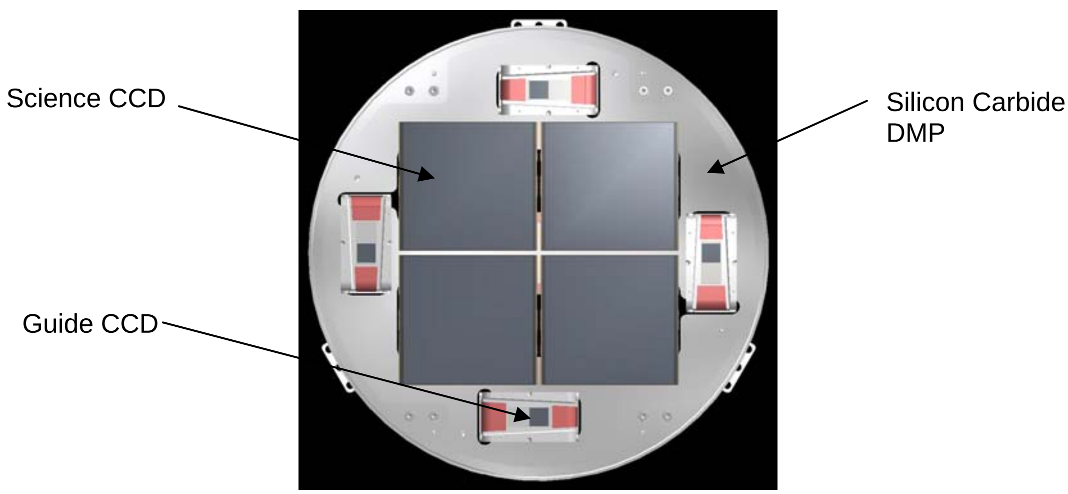

Figure 4. Face View of FPA Showing Science & Guide CCDs

3.1 Science Drivers for CCD Specifications

CCD performance requirements are derived from the science mission, 2 minute I-band exposures with the KMTNet 1.6m telescope. Assuming a dark time I-band sky brightness of 20 magnitude/arcsec2 we calculate ~625 detected sky photons per pixel resulting in a sky noise of ~25 electrons RMS. (The primary science fields, in the galactic bulge are so dense that the effective background will be even higher.) The limits on dark current and read-out noise, which add in quadrature to the sky noise, are selected so that the quadrature sum of all three noise terms (sky, dark current, read-out) will degrade the signal/noise ratio of the sky by no more than 4%. Specifically, dark current of (2electrons/2minute exposure) and a read-out noise of 7 electrons RMS gives a signal/noise on the sky of 25/26 = 96% relative to zero dark current and zero read-out noise.

3.2 CCD Chip Format, Fill-Factor, Flatness

- The Science CCD format of each chip is 9216(H) x 9232(V) 10 micron square pixels. The imaging area per CCD is therefore 8508 mm^2. The four packaged Science CCDs are mounted to the detector mounting plate in a 2 by 2 array. The dead space totals 2557 mm^2 giving a fill factor of 92.5%.

3.3 CCD Quantum Efficiency

The QE requirements set by KMTNet are shown in the table below. Maximizing the I-band quantum efficiency (QE) is desired.

Wavelength	440nm (B)	550nm (V)	650nm (R)	830nm (I)
Q.E.	60%	70%	85%	70%

Uniformity of thinning and coating over complete 150 mm diameter wafers has been demonstrated by the success of the MODS 8k x 3k devices (e2v CCD231-68) that are slightly larger (diagonal) than the KMTNet detectors.[5]

The figure below (solid green line) indicates the expected QE. KMTNet required QE at B V R I filter wavelengths are also shown as crosses. The QE figure also shows the "multi-4" coating. This is a newly developed coating designed for maximum QE across the 400-900nm range. It also has the advantage of reduced reflectivity. This has the benefit of reduced ghost images from surface reflections and perhaps more importantly reduced fringe amplitude in the 830nm wavelength range.

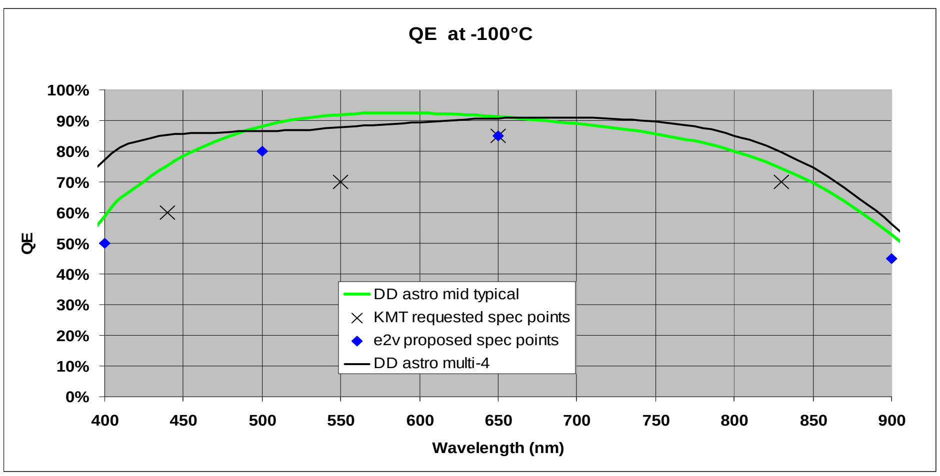

Figure 5. QE Curves of CCD290-99 Devices

3.4 CCD Specifications

CTE Charge Transfer Efficiency	0.99999 (5 nines)
CCD Linearity & well depth	linearity < 1% from 10% to 80% of full well
Full Well Depth	> 90,000 electrons (< 3% linearity)
Readout Noise	< 10 electrons (goal < 7 electrons)
Dark Current	< 1 electron/minute at 173K

3.5 Auto Guide Chips

The Guide CCDs will be e2v CCD47-20 devices. These devices are 1024 * 1024 format with 13 micron pixels and frame transfer architecture allowing integration during read-out. The four Guide CCDs are installed on the FPA outside the Science CCDs and inside the circle that circumscribes the square corners of the science field. The Guide CCDs are read out independently of the Science CCDs to provide auto-guiding signals to the telescope at a rate ~ 1Hz.

3.6 Detector Mounting Plate (DMP)

The DMP will provide the mechanical support for the detectors and the thermal connection to the detectors. The DMP will be fabricated from silicon carbide which provides a perfect CTE match to the CCD package and has very high stiffness to weight.

The DMP will be designed and procured by e2v and will:

- Mechanically support and position the Science CCDs to a flat reference plane
- Mechanically support and position the Guide CCDs to a flat reference plane
- Provide the thermal path from the back side of the DMP to the CCD packages
- Include thermal interface features on the DMP back side to connect to the copper cooling straps
- Include structural interface features to mount the FPA in the Dewar on G10 struts

3.7 FPA Interfaces

The electrical interface to the Science and Guide CCDs will use flex-cables extending from the back of the CCD packages. The flex-cables will be routed rearward through slots in the DMP and mated to connectors on a special printed circuit board called the Wall Board (WB). The flex-cables will provide the required thermal resistance between the cold detectors and the warm WB to minimize parasitic heat input to the detectors.

The WB carries the signals out of the Dewar serving the critical function of vacuum feed-through for all the signals to the focal plane. The WB is also used to bus signals that have redundant connections to the CCDs (pairs of connections to vertical clock phases for example) and provides ground planes for shielding the signals.

The FPA is semi-kinematically supported in the Dewar using three G10 fiberglass struts to rigidly mount the FPA while minimizing thermal conduction.

The DMP will be cooled at four points directly behind the CCD package centers. Temperature sensors will be mounted adjacent to the Science CCDs on the DMP to monitor and control the temperature of the DMP.

4. CCD CONTROLLER ELECTRONICS

The ISL CCD controller electronics provides a system with detector limited photometric accuracy, noise performance, and stability. The 16 bit ADC resolution allows good sampling of noise with linear operation to the full well depth limit of the detector. The system provides full control of detector readout speed and therefore provides access to the full range of readout speed vs. readout noise tradeoffs. Region of interest readout and binning are supported.

The controller electronics provide many utility features including:

- shutter timer for exposure control with 100 microsecond resolution and PPM accuracy
- RS232 and RS485 ports
- precision LED driver for detector calibration
- detector temperature control
- electronics temperature control and waste heat management
- system status monitoring and remote diagnostics
- The interface to the host computer uses the PCI interface protocol and hardware.

The KMTN telescopes will be controller with COMSOFT's "PC-TCS/CT" package. ISL camera systems have been successfully interfaced to many telescope control systems including COMSOFT's on the 2MASS telescope and the Yale 1m telescope on Cerro Tololo..

The ISL controller electronics system has operated a wide range of CCD and IR detectors at numerous observatories - including in Chile and South Africa - for over 25 years. The reliability of the ISL camera systems has been outstanding with only 2 known component failures in ~ 100 system years of field operation. These failures were promptly repaired and the systems were returned to service.

The electronics for the four Guide CCDs will be a copy of the Science CCD electronics with appropriate firmware and voltage settings. However, whereas each Science CCD has its own cable between the WB and the HE, all the Guide CCD signals will be carried on a single cable. The software required to centroid a guide star and to provide control signals to the telescope drives will run on the Guide computer.

4.1 Detector Connection Path (FPA through Dewar to HE)

The electrical interface to the Science and Guide CCDs will use flex-cables extending from the back of the CCD packages. The flex-cables will be routed rearward through slots in the DMP and mated to connectors on a printed circuit board called the Wall Board (WB). The flex-cables will provide the required thermal resistance between the cold detectors and the warm WB to minimize parasitic heat input to the detectors.

The WB carries the signals out of the Dewar and provides the critical function of vacuum feed-through for all the signals to the focal plane. The WB is also used to bus signals that have redundant connections to the CCDs (pairs of connections to vertical clock phases for example) and provides ground planes for shielding the signals.

Connectors outside the vacuum space on the WB will include the multiple co-ax connectors to the detectors as well as connectors for the temperature control of the focal plane assembly. The very compact 6QCD/QFS/QMS multiple co-ax cable and connector system from Samtec will connect the detector system to the head electronics box (HE) mounted on the upper ring of the telescope.

http://www.samtec.com/ProductInformation/TechnicalSpecifications/Overview.aspx?series=6QCD)

It is worth noting that the combination of the Wall Board with pre-fabricated cables from Samtec means that there are no individual wires, hand soldering or crimping required to connect the detectors to the electronics.

4.2 Head Electronics (HE)

The HE box houses the power supplies for the detector system, the Clock Bias Board (CBB), the signal chain daughter boards, the Rx communication board, and the temperature control electronics.

All connections to the Science CCDs come from the CBBs. The precision, low noise, power supplies for the CCD bias voltages and the clock levels are on the CBB as are the clock drivers. The low noise supplies have a voltage noise density of less than 15 nVolts/√Hz in the band pass of the CCD signal chain. The supplies have a stability of 5 PPM/C. The Clock drivers consist of 64 analog switches. The analog input to each switch can be selected from 32 adjustable clock levels. Each switch has an independent digital input. Programmable logic devices on the CBB control how the switches are combined to produce clock signals. Pairs of switches can be used to produce two level clocks. Three (or more) switches can be combined to produce multi-level clocks. The signal chains are contained on daughter boards which plug into the CBB. Each signal chain consists of a low noise gain stage, a dual slope integrator and a 16 bit ADC. Time constants for the dual-slope integrator (also called double-correlated-sample-and-hold) will be selected for a pixel rate for each signal chain of 500k pixles/second (2 µsec/pixel) for a total pixel rate from the 32 channels of 16 Mpixels/second. Serial data from the ADCs is converted to parallel form in a programmable logic device on the CBB. The digital electronics to receive clock patterns from the sequencer and to transmit data from the HE to the sequencer via a 120 MHz fiber link to the computer are on the Rx board. The CBB has a plug-in module that monitors all CBB voltages and can be read from the Instrument Computer.

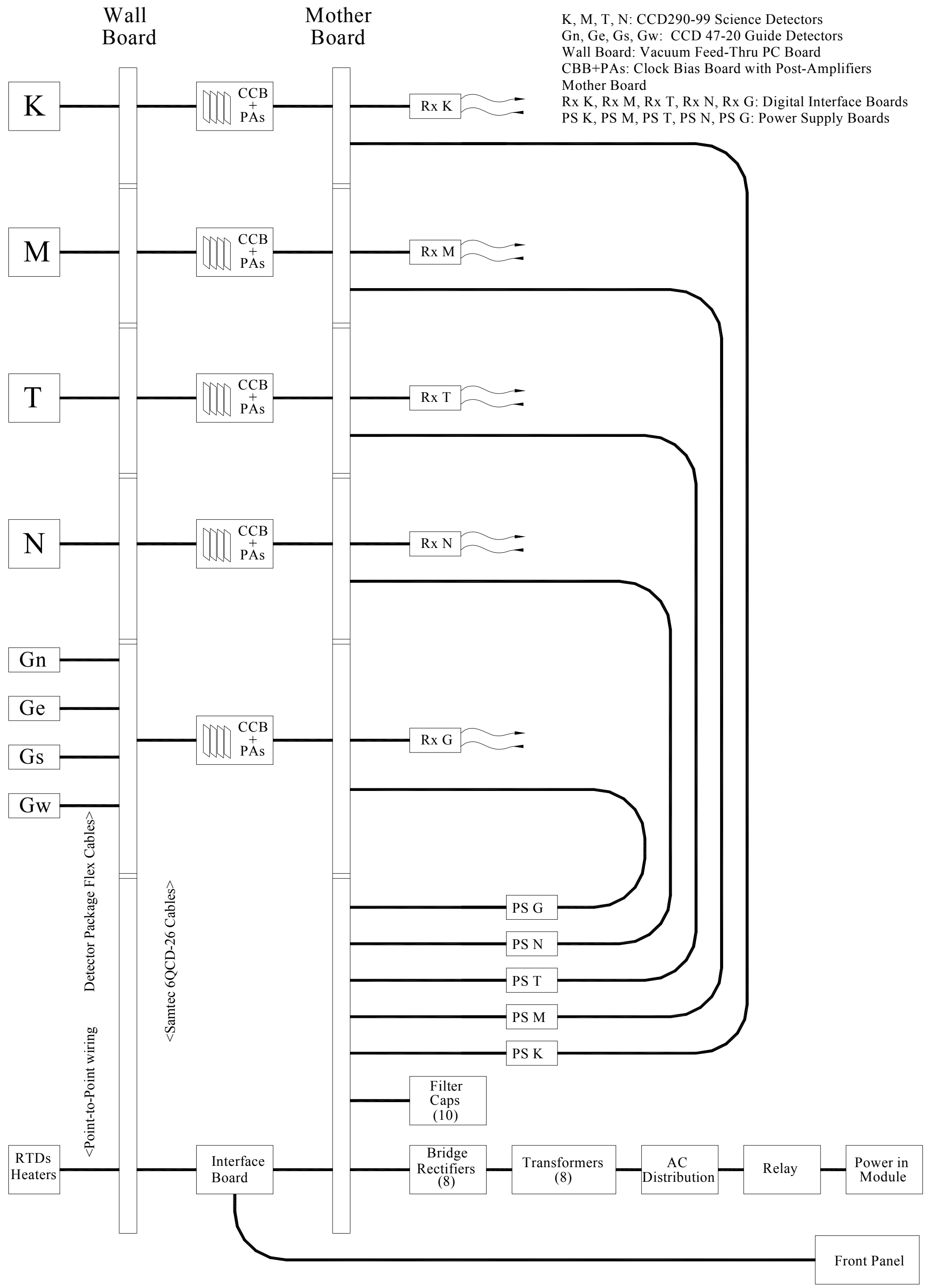

Figure 6. KMTNet HE System Diagram

4.3 Head Electronics Box

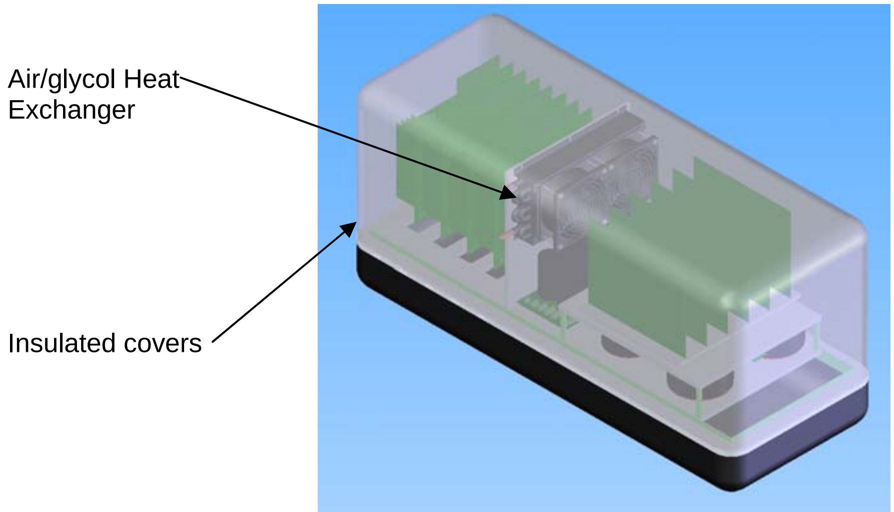

Figure 7. KMTNet HE Box Rendering

The controller electronics for all five of the detector systems are packaged in a single HE Box. Each of the five detector systems will have its own power supply regulators. Common transformers, bridge rectifiers and filter capacitors will be used to provide raw DC to all power supplies.

The single HE package provides the advantage of simplifying CCD timing synchronization. The full independence of the detector systems is retained with the exception of the raw DC supply. The design facilitates easy replacement of the power supply.

The HE has a very effective thermal management system that minimizes thermal leaks from the HE into the ambient air. The HE is housed in an aluminum box that measures 914mm x 350mm x 441mm and has a mass of >56kg. The covers of the HE are fully insulated to minimize the temperature difference between the HE outside surface and the ambient air. The HE surfaces will be maintained within 2 degree C of ambient temperature. Temperatures difference of < 2C are too small to induce convection. Total heat coupled into the air from the HE is <15 watts over an area of ~ 1.5m^2. This is a very small heat flux into the air and will produce negligible wavefront errors.

The heat from the HE is carried away with glycol that is supplied at a temperature ~1C above ambient in insulated transfer lines. The glycol is passed through a cold plate on the Power Supply and an air-to-glycol heat exchanger, both located inside the HE box. These heat exchangers transfer the heat from the HE electronics into the glycol.

5. CAMERA COMPUTERS AND CONTROL SOFTWARE

5.1 Instrument Computers (IC's)

The Instrument Computers (ICs) should be thought of as an embedded system, much like the computer system in a DVD player, an iPod or a GPS navigation system. (With the exception that the ISL will provides source code, compiler, and support.) The ICs are extremely hardware intensive by today's standards. All of the software that runs on an IC, and its compiler, will fit on a 3.5 inch floppy disk and takes about a minute to load. Compare that to a typical PC operating Windows or Linux. The hardware platform is the most widely available computer platform, a PC with a PCI slot. This platform is chosen specifically to avoid obsolescence and insure that spares are readily available. The function of the IC is to produce a FITS image and make that FITS image available to the Caliban Computer where the data is archived. The ICs, which are located in the computer rack, are equipped with a custom PCI card, the Sequencer. The Sequencer stores and generates the digital pattern which contains the CCD clocking pattern and the control for the analog processing of the CCD signal. These patterns are generated with precise timing and, once started by the IC, are independent of any software running on the IC. The Sequencer also receives data from the Head Electronics and transfers it to main memory of the IC through a DMA channel. The HE and the IC are coupled by a 120MHz optical fiber link which can be two hundred meters long. The HE is a slave to the Sequencer and runs no software. The software in the IC operates under

Microsoft DOS 6.21. Our existing software will be used but will require minor modifications in the form of new initialization files and sequencer maps to produce the correct clocking for the CCD290-99 detectors. The ICs are rack mount industrial quality computers. A spare is included in each camera system.

5.2 KMTNet Camera Computer Architecture

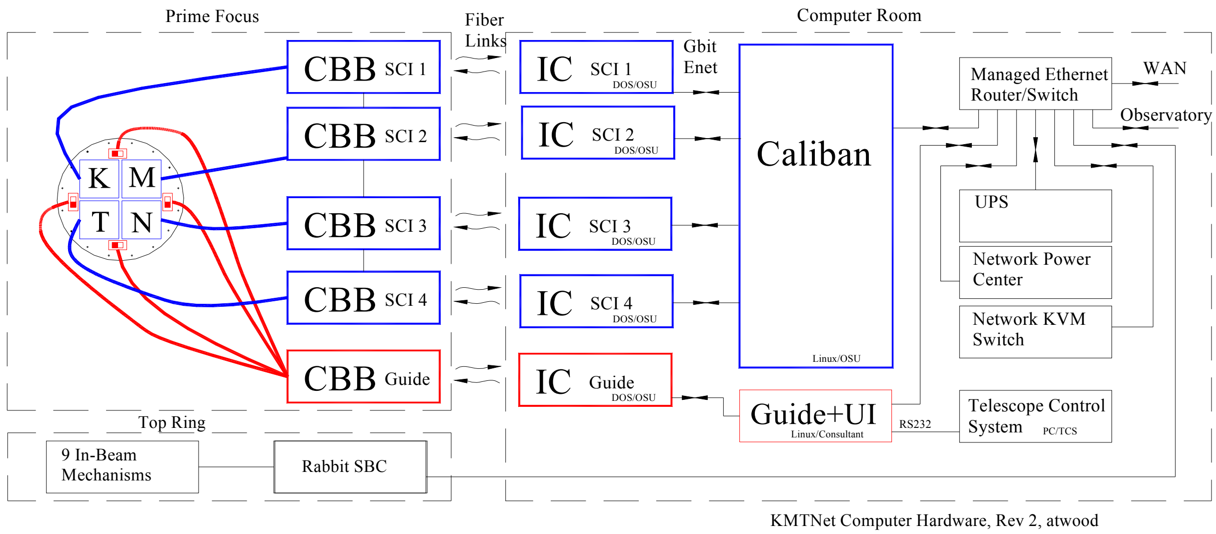

Figure 8. The camera system is designed around four Science CCDs (K, M, T, and N) and four Guide CCDs (in the chords of the DMP). Each of the four Science CCDs is serviced by a separate set of electronics. Clock and bias voltages are generated by the CBB. Analog signal processing and analog to digital conversion for the eight outputs of each Science CCD is done by four daughter boards on the CBB. Fiber-Optic links carry the data to separate ICs. Each image is unlaced and stored in main memory of the IC. Caliban receives the images over Gbit Ethernet links and writes the data as FITS images to removable hard disks. Data from the guide CCDs is handled in similar fashion but is written as a FITS image on the Guide Computer. The guide computer processes the guide images to produce correction signals for the TCS. The ICs, Caliban, the TCS, and the Guide Computer all have real-time image displays which may be selected by the network KVM switch.

5.3 KMTNet Camera Control Software

The IC will handle all low level tasks needed to read out the CCDs and move image data and header data to a FITS format file on disk.

The remaining high level software tasks including guide star identification, guide signal extraction, camera GUI, scripting, will be on the Guide Computer.

The camera will be operable using a command line interface with scripting capability to enable automatic operation. A GUI will also be provided to operate the camera. The camera software will support the following functions:

- exposure control including shutter interface
- binning, sub-region reading, multi-exposure,
- observing status reports; shutter open/closed, download, etc.
- CCD temperature control, cooling system control, etc.
- image display, zoom, stellar radial profile and contour display, column-row graph, contrast & brightness control, pseudo color table
- Observing information: target name, RA/DEC/Focus, airmass, time, filter
- interface with telescope and/or observation software via Ethernet

The scripting capability of the camera software will enable commanding sequences of exposures, telescope movements, filter changes, shutter exposures, and status query/reporting. All commands will be logged at the camera control computer.

Camera Control Software modules are required on three different type of machines, the ICs, Caliban, and the Guide computer. The four ICs that control the Science CCDs will run identical software while the fifth IC, for the Guide CCDs, will have different initialization files. The Caliban Code will be adapted by ISL programmers from an existing program. The Guide & User Interface Computer Code will be a major new package.

5.4 IC Code

The software for the five ICs will be an application of code that has been developed over many years. Since the ISL has previously applied the IC code more than a dozen detector system the process used to interface to a new detector system is well defined, quick and extremely low risk.

The ICs receive commands via the Gbit ethernet links from Caliban. The roughly 100 commands that the IC code responds to can be roughly divided into 3 types.

- Commands to set a parameter such as binning, region of interest, or exposure time.
- Commands requesting information such as status, which returns a string with a variety of parameters. The current value of any parameter can be read by issuing the command without a parameter.
- Action commands such as “go” to start and exposure or “oshut” to open the shutter.

All commands return an acknowledge upon receipt or wait until the command has finished and then returns a message indicating that the command is done and was successful or failed, in which case detailed error message is included. Commands can not be nested except that status commands can be issued during an exposure.

Any IC command can be entered on the IC keyboard or sent to an IC from any other computer in the Camera.

5.5 Caliban Code

Caliban receives commands from the GUI or command line interface running on the Guide computer. Most of these commands are passed on to all four Science ICs. Caliban receives image data from the IC and writes two copies of it, one for local archiving and one to be shipped to KASI, as FITS images on removable hard drives. Caliban specific commands include those required to define the path for storing data and commands relating to Caliban’s interaction with the ICs. The Linux based Caliban code has been used in a variety of environments and only minor modifications will be required for KMTNet. In addition to the Caliban Code any Linux application can be run on Caliban. The Caliban computer will be configured with IRAF, VISTA, and DS9 for image viewing and processing.

Any Caliban command can be sent to Caliban from the keyboard or from any other computer in the Camera.

5.6 Guide & User Interface Code

The Guide computer will generate the guide corrections to be sent to the TCS and will act as the central location for control of the entire observatory. The Guiding function has three main components, Guide Star Selection, Error Calculation, and Communication with the TCS. Guide Star Selection will be with the Magellan Observatory’s GMAP program (the Magellan director has kindly offered us access to GMAP). GMAP will also be used to access star catalogs. Once a guide star has been selected the stream of FITS images, arriving from the Guide IC, will be windowed on the guide star and the centroid calculated. The change in the centroid position will be used to produce an error signal that will be sent to the TCS via ethernet. Although the pixels of the Guide CCDs are slightly larger than the Science CCDs it will be possible to centroid the high-signal-to-noise guide star images to a small fraction of a Science CCD pixel since the error in centroiding is approximately the FWHM/Signal-to-Noise. The Guide Computer will perform the operations necessary to make the Tip-Tilt-Focus corrections to the telescope top end. A series of guide images will be taken from all four guide chips at focus settings spanning best focus. The best focus value will be calculated in each chip and the best tilt and focus setting calculated. The Guide computer will then request that the TCS move the TTF mechanisms to the correct positions. The camera will be operable using a command line interface with scripting capability to enable automatic operation. A GUI will also be provided to operate the camera and communicate with the TCS. GUI organization will include user level screens for normal observing and engineering level screens for maintenance. The GUI and command line interface will each allow control of all camera functions including:

- Exposure control including selecting filter, exposure time, sequencing multiple exposures binning, sub-region reading, multi-exposure
- Observing status reports such as shutter open/closed, time remaining in an exposure, data written to disk
- Housekeeping functions such as CCD temperature control and FPA cooling system control, HE Box cooling system control
- Observing information such as target name, RA/DEC/Focus, airmass, time, and filter

IRAF, VISTA, and DS9 will be loaded on the Guide Computer for image display, zoom, stellar radial profile and contour display, column or row plots, contrast and brightness control, pseudo color display and all the image analysis functions in these packages. The scripting capability of the Guide Computer will be able to command sequences of exposures, telescope movements, filter changes, shutter exposures, and status query/reporting. All commands will be logged by the Guide computer.

6. CAMERA DEWAR AND COOLING SYSTEM

The detectors will be maintained at operating temperature in an O-ring sealed vacuum insulated Dewar. The detectors will be cooled with PCC mechanical refrigerators. Vacuum will be maintained with cold activated charcoal cryosorption pumping. A layout of the Dewar with PCC refrigerator heads, copper cooling straps, and electronic flex cables is shown in Figure 9.

6.1 Dewar Window

The Dewar vacuum window is also the fourth lens of the wide field corrector and is designed so that the stress induced by 1 atmosphere of pressure loading will be well within the safe operating stress limits for the fused silica window material. The Dewar window retaining clamp is engineered to lift off the O-ring to relieve pressure if the internal pressure of the Dewar exceeds 2 psia.

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 dew point of ~ -100C will purge the volume in front of L4 to prevent condensation.

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 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. 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.

6.2 Detector Cooling System

The Dewar cooling system will use 3 PCC commercial mechanical refrigerators available from Brooks Automation (formerly called CryoTigers). This equipment has no moving parts in the cold heads providing very low vibration performance. The three PCC compressors are located off the telescope in a separate equipment room to prevent heat from disturbing observations. The PCC mechanical refrigerators have a very good history of reliable performance in astronomical applications.

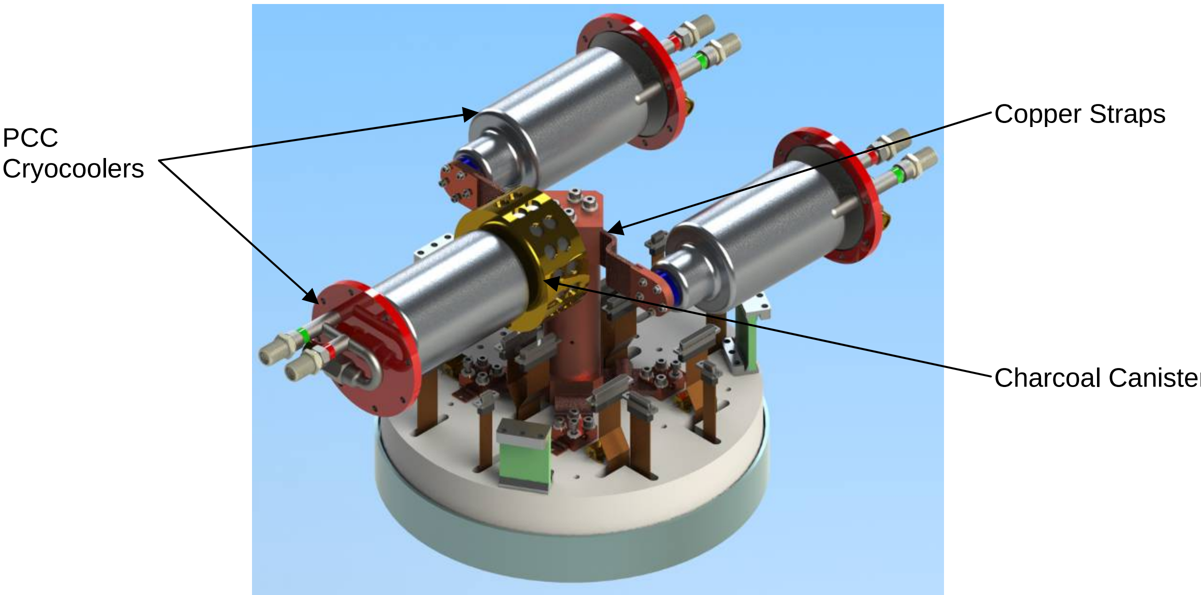

Figure 9. Detector Cooling system and cryosorption pump charcoal canister

Two PT30 high performance cold heads are thermally connected to the back of the Detector Mounting Plate (DMP) with heavy laminated copper straps. The first strap bridges between the two cold fingers with a copper bar at the midpoint which connects to the DMP thermal bus block. The DMP bus block has four identical copper straps fanning out to the DMP. Each strap is bolted to the DMP directly behind the center of a CCD. The symmetry of this arrangement ensures CCD temperature uniformity. The copper straps have a design temperature rise of 40K from cold finger to CCD providing a CCD temperature of ~163K, which is 10K colder than the required detector temperature established by e2v to meet the dark current specification.

The cool-down time analysis predicts that the CCDs can be cooled from room temperature to their 163K operating temperature in about 6 hours.

6.3 Dewar Cryosorption Pump and Vacuum Performance

The Dewar will be pumped to rough vacuum with a mechanical roughing pump with a cold trap. During rough pumping a canister of Zeolite molecular sieve will be connected to the roughing plumbing near the Dewar. The Zeolite is a very effective desiccant and will remove water from the Dewar interior.

The Dewar will use a cryosorption pump to maintain high vacuum. An activated charcoal canister is attached directly to the PCC cryocooler PT13 cold finger (optimized for cold finger temperatures from ~75 - 90K, capacity ~ 3 watts @ 77K). The temperature of the charcoal will be kept between 75- 80K. At this temperature the charcoal has enormous cryosorption capacity for maintaining low pressures. The 100 gram of activated charcoal in the canister will be sufficient to maintain the Dewar pressure below 5e-5 Torr for a period of >1 year without re-evacuating the Dewar.

A very important feature of using a separate cooler for the charcoal canister is that it allows remote starting of the cool down cycle without the need to re-evacuate the Dewar. For example, if the Dewar is permitted to warm up (e.g. due to a power failure) after many months of service, the pressure in the Dewar at room temperature will be on order 10Torr. The PT13 has enough excess capacity to cool the charcoal to 77K even with initially high gas conduction loads. The Dewar would thus be cryopumped to low pressures prior to cooling the FPA with the other two PT30 coolers. This remote restart without re-pumping is an important operational advantage.

The Dewar instrumentation will be connected to the HE. The telemetry data will be routed through the HE and available at the GUI. The Dewar pressure will be monitored with a Granville Phillips "Micro-Ion Plus" vacuum gauge. This unit combines a convectron gauge for rough vacuum measurements and an ionization gauge for high vacuum measurements with an accuracy of ~ 1e-07 Torr. This is the same gauge used on the MODS detector Dewar.[6] Up to eight Dewar and detector temperatures can be monitored by the HE:

- Science detector package temperature
- Detector Mounting Plate temperature
- PCC cold finger temperatures

7. CAMERA INTEGRATION WITH TELESCOPE

The first telescope and enclosure will be fully assembled and tested in Tucson, AZ prior to its shipment to Chile. All critical camera interfaces with the telescope and enclosure will be demonstrated in Tucson. These include:

- Camera handling and installation on the telescope
- Camera mechanical interface to telescope including piloting and clocking
- Camera optical interface to the telescope
- Routing and handling of camera cryocooler lines, HE Box cooling hoses, power line, and optical fibers including routing through the Elevation and Azimuth cable wraps
- HE Box handling and installation on telescope

A Test Camera will be used to verify the delivered image quality of the telescope. This camera comprises seven commercial small format CCD cameras placed at strategic locations in the KMTNet image plane. The cameras will image bright stars with very short exposures (~0.020 seconds) with the intention of capturing the rare moments when good seeing occurs. "Lucky Imaging" software will sort the images based on image quality, select the best images, and align and co-add them. This technique will demonstrate the performance of the telescope optics over the entire 2 degree x 2 degree field in the expected poor seeing in Tucson.

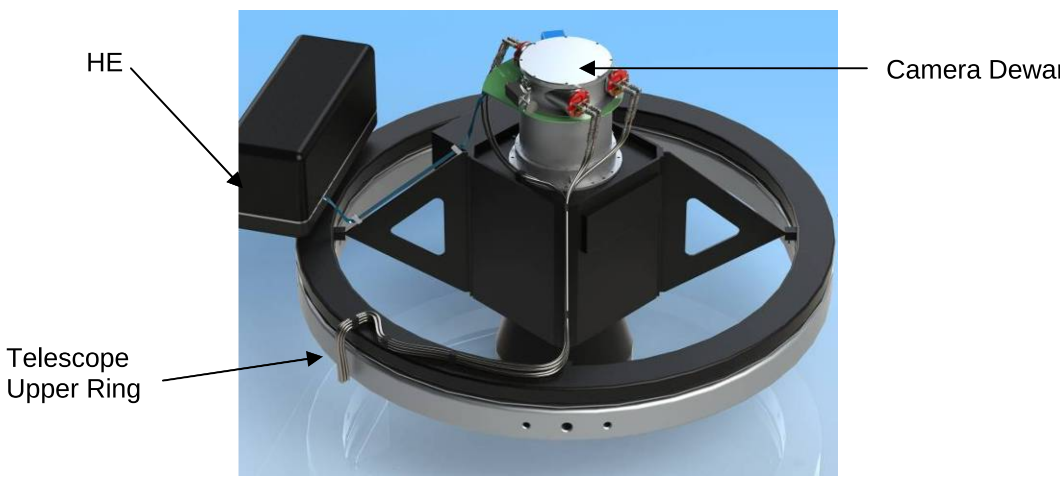

Figure 10. Isometric view of the telescope Upper Ring showing location of the Dewar and HE Box and cabling paths

8. CONCLUSIONS

The KMTNet camera covers a 2 degree square field with 340Mpixels using a high fill factor 2x2 mosaic of four newly developed e2v CCD290-99 imaging sensors mounted to a common focal plane assembly. The high performance CCDs have 9k x 9k format, 10 micron pixels, and multiple outputs for rapid readout time. The four science CCDs and four auto-guide full frame transfer CCDs are mounted to a monolithic silicon carbide plate for excellent CTE match, flatness, stiffness, and thermal conductivity. The fully integrated Focal Plane Array is provided to OSU by e2v. This approach minimizes detector handling and reduces program risk to the instrument builder.

The camera Dewar is cooled using PCC closed cycle coolers and vacuum is maintained with a cryosorption pump which is cooled by a separate PC cryocooler.

The Dewar window is the fourth element of the wide field optical corrector requiring that opto-mechanical interface control be carefully managed to achieve the required delivered image quality.

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