The LSST Instrument Concept

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ABSTRACT

The LSST Instrument is a wide-field optical (0.3 to 1um) imager designed to provide a three degree field-of-view with better than 0.2 arcsecond sampling. The image surface of the LSST is approximately 55cm in diameter with a curvature radius over 30 meters. The detector format is currently defined to be a circular mosaic of 568 2k x 2k devices faceted to synthesize this surface within the constraints of LSST's f/1.25 focal ratio. This camera will provide over 2.2 Gigapixels per image with a 2 second readout time. With an expected typical exposure time of as short as 10s, this will yield a nightly data set on order of 5 terapixels. The scale of the LSST Instrument is equivalent to a square mosaic of 47k x 47k. The LSST Instrument will also provide a filter mechanism, as well as optical shuttering capability. Imagers of this size pose interesting challenges in many design areas including detectors, interface electronics, data acquisition and processing pipelines, dewar construction, filter and shutter mechanisms. Furthermore, the LSST 3 mirror optical system places this instrument in a highly constrained volume where these challenges are compounded. Specific focus is being applied to meeting defined scientific performance requirements with an eye to total cost, system complexity, power consumption, reliability, and risk. This paper will describe the current efforts in the LSST Instrument Concept Design.

Keywords: CCD, Mosaic, Survey, Imager, LSST.

1. INTRODUCTION

The Large Synoptic Survey Telescope (LSST) is an 8-meter telescope with a 3 degree field of view that is being designed to: 1) characterize the small bodies in the solar system, including enabling the discovery of 90 percent of the near-Earth-asteroids over 250 m in diameter; 2) open up the time domain window and enable the study of optical bursters, supernovae, and variable stars; and 3) characterize the dark matter and dark energy in the universe by using the distortion of background galaxies produced by gravitational lensing to map foreground overdensities of mass. This 8-m class telescope will have a 3 degree field of view and will deliver images with 80 percent encircled energy within 0.2 arcsec across the entire field. The LSST will reach 24th magnitude in a 10 second exposure and will be operated as a survey telescope only. It will be able to scan 10,000 square degrees per night and will deliver upto 8 terabytes of data each night. Initial processing of the data will be carried out in real time and will be made publicly available immediately.

The LSST will be equipped with a single instrument—an optical imager. This instrument will be required to produce data of extremely high optical quality with minimal downtime and maintenance. This paper highlights the issues that must be addressed in designing such a camera. These issues will be addressed during the next two years as the LSST project team works to complete a fully costed proposal for the telescope, instrument, data management and distribution system, and operations.

Pictured in Figure 1 is the current telescope concept, the associated optical ray trace diagram, and a graphic depiction of the location of the instrument in relation to the 3 reflective elements in the telescope.

Further LSST project and related information can be found at:
www.noao.edu/lsst/ www.lsst.org/ www.noao.edu/ets/monsoon/ www.itl.arizona.edu/

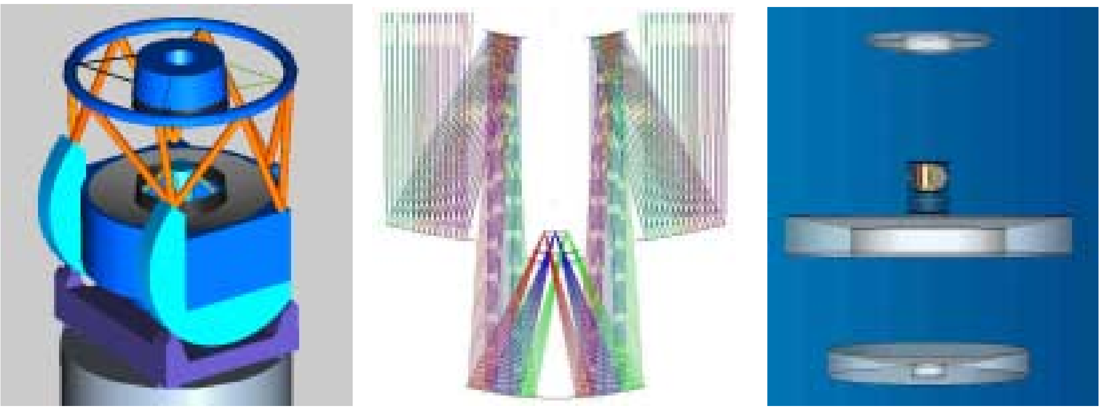

Figure 1. The LSST Telescope Concept, Optical Ray Trace, and Instrument Location. *Illustrates from left to right the current telescope design concept for LSST, the associated optical ray trace, and the position of the instrument containing the three refractive optical elements located in the center of the optical beam in the heart of the telescope structure.*

2. INSTRUMENT REQUIREMENTS

The LSST Instrument is required to provide exquisite wide-field visible imaging capability in multiple colors for the 0.3 to 1μm wavelength range over a 3 degree field with better than 0.2 arcsecond sampling. This translates with the current optical design to a 55cm focal surface with a 10μm pixel scale, and over 2.2 Gpixels per image. The instrument is planned to be used in survey mode with an extremely fast cadence of 10 to 20s exposure with a 2s read time. This corresponds to a peak data rate of over 1 Gpixel/s or over 2 Gbytes/s assuming 16-bit pixel dynamic range. Projections for nightly data rates for anticipated observing profiles are measured in the terabytes of data. The telescope will be dithered across a field to allow the filling of gaps in the focal surface and then repositioned to a new field on a frequent basis to allow full sky coverage at the anticipated rate of every 3 to 4 nights weather permitting. The enormous size of the focal plane represents almost an order of magnitude increase over any astronomical wide field imaging systems currently deployed or in commissioning [1]. In addition, the readout rate represents an order of magnitude decrease in readout time when compared to existing CCD mosaics. This instrument presents an exciting challenge to the design team on a number of technical fronts.

The field of view of this instrument will guarantee an abundance of bright objects in nearly every image frame. This raises significant concerns for the design of the optical system for baffling and scattered light reduction, as well as ghosting, blooming and residual image issues. The focal plane surface with device edges and optically reflective structures such as bond wires must be avoided completely or at least mitigated. Optical masks must be considered for addressing these issues. Device selection criteria must be tailored to this wide-field imaging mode of operation. Crosstalk issues are strong concerns whether considering optical crosstalk, detector crosstalk or system electronics crosstalk.

The physical location of the instrument, and the constraints imposed by that location, raise additional issues that must be considered from the time of the initial instrument concept. The instrument is located in the middle of the telescope optical beam in a highly constrained space (refer to Figure 1 above). This space is constrained in physical volume, and maximum allowable heat dissipation. These issues are critical as they will impact optical vignetting, and image quality due to thermal gradients in the optical beam. In addition, the total physical mass, and the requirement for precise registration of the focal surface during exposures. The instrument design is further constrained in ways relating to those faced by all projects without unlimited resources. We must be able to develop and deploy this instrument within a defined cost and schedule. This budgeting includes cost of development, as well as cost of operation over the maintainable lifetime. This instrument will be one of a kind and be required to provide almost uninterrupted service 365 days a year for a minimum 5 year lifetime. Any service issues need to be handled during the daytime hours so as not to affect science operations.

3. INSTRUMENT CONCEPT

Pictured below in Figure 2 is the instrument concept currently under development. Notice that the design shows a dewar within a dewar structure. The outer shell holds 2 of the 3 refractive elements needed for the wide field correction to the desired image quality. The third refractive element is the window of the inner dewar. The outer lens is over 1.6 meter in diameter and as such would be one of the largest refractive elements ever manufactured for astronomical applications. Notice that the instrument is down looking when the telescope is pointed at zenith. This means that the refractive elements are placed in tension rather than compression, which is not uncommon for many wide field correctors at prime focus. However the size of this lens is uncommon, and some means of support will be needed in order to maintain image quality over all telescope positions. To aid this lens support, the outer can is designed to be held at some controlled partial vacuum to provide active element correction and element support. The inner dewar holds the focal surface with all detectors and interface electronics. Included within this outer dewar is the filter mechanism which supports four 60 cm filters. This mechanism uses a novel approach to try to adapt to the extremely tight space constraints imposed on this instrument. The filter mechanism can be described as a "flower petal" arrangement. Classic filter "wheel" designs, or even filter "juke-box" approaches will not fit within the space constraints imposed by the optical design. A mechanism which supports compound translation of the filter as it is moved in and out of the beam is required. This "flower petal" filter mechanism is detailed later in this paper.

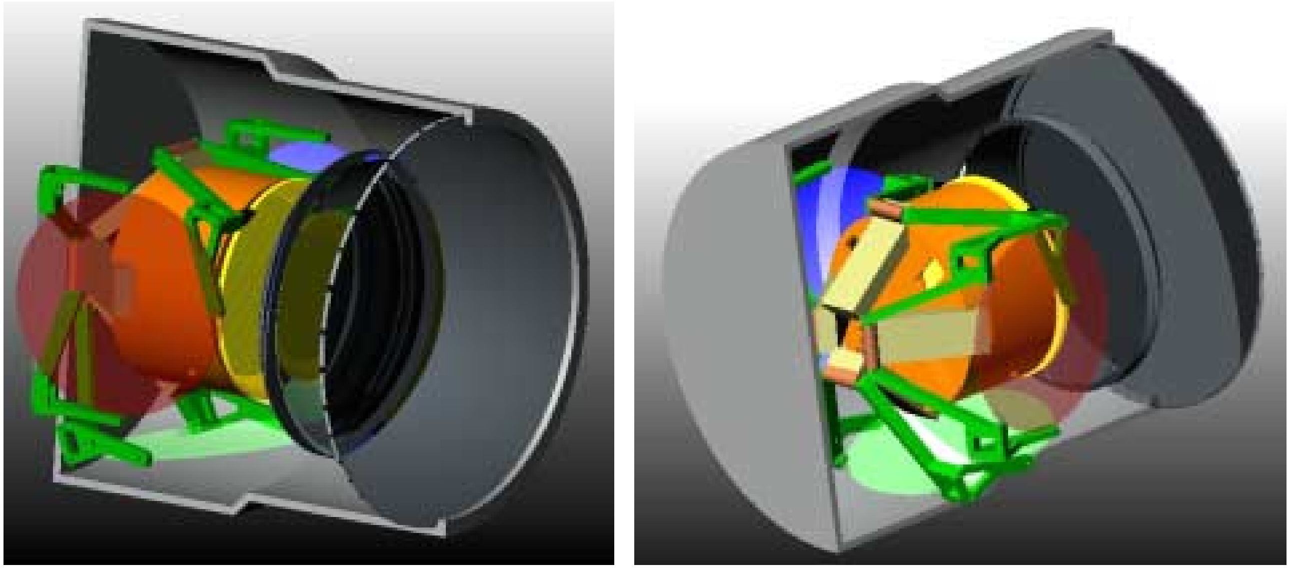

Figure 2. The LSST Instrument Concept.. *Illustrates the instrument concept of a dewar within a dewar. The outer dewar houses the refractive elements for the wide field correction as well as the filter mechanism. The inner dewar holds the focal surface with detectors and interface electronics.*

The interfaces to this instrument include the mechanical mount, which will provide an instrument rotation capability along with proper support and registration to the telescope, the electrical power interface which will come in the form of either AC or DC power which will then be translated to the necessary voltage forms required by the detector and interface electronics, the thermal control interface whether this is gas lines to a coldhead assembly or glycol cooling lines to a thermal enclosure, and fiberoptics and Ethernet for the instrument control and data interface.

The focal plane in the inner dewar will be held at a stabilized temperature of –20 to –40C in order to achieve the desired detector performance. The actual temperature will obviously depend on the devices chosen for the focal plane. The cooling technology needed to support controlled thermal operation is discussed later in this document. The inner dewar assembly is shown below in Figure 3. The focal plane assembly has analog interface circuitry in immediate proximity to the detector, flex-circuit wiring for interconnects and vacuum feed-throughs, and high-speed fiberoptic links to move data off the instrument and to the image acquisition computers. These issues are also detailed later in the paper.

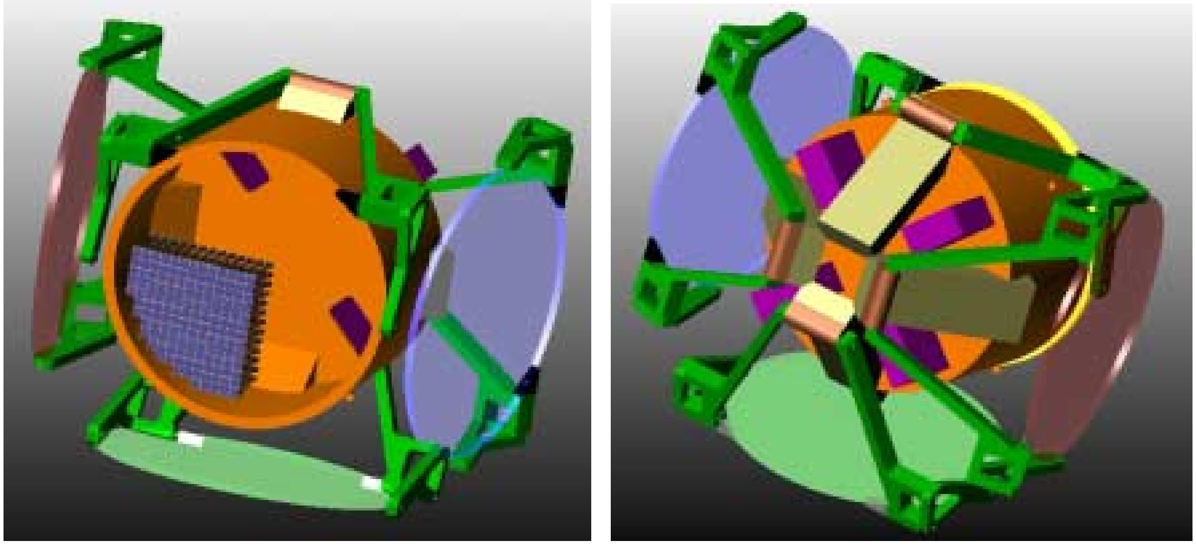

Figure 3. The LSST Instrument Concept Inner Dewar and Filter Mechanism. *The picture on the left shows a front-view of the inner dewar with ¼ of the focal plane assembly shown. The picture on the right shows the back view of the dewar and the filter mechanism supports and actuators.*

4. FOCAL PLANE ASSEMBLY

The LSST Instrument focal plane is more accurately described as a focal surface. However throughout this paper it will be referred to as a focal plane assembly as this is common terminology for this topic of discussion. The focal plane needs to be a fully filled 55cm diameter flat or slightly domed assembly. To achieve the desired image sampling the pixel size is 10μm square. The effective pixel size must not be expanded through defocus due to metrology issues, nor due to charge diffusion effects within the detector. In order to fill this focal surface at this pixel scale, 2.27 Gpixels are required. These devices will be close-butted on 4 sides in order to minimize optical gaps and maintain high optical fill-factor. Optical fill-factors of >90% are required in order to maintain system efficiency. This means that the “optically dead” area of the focal plane, whether inactive due to device characteristics within the central optically active area of the individual detectors, or due to gaps between mosaiced devices, must be less than a total area of .025 m^2 (the 55cm focal plane diameter translates to $0.25m^2$ focal plane area). Large format devices would be convenient for minimizing gaps and poorly behaved optical surfaces, easing electrical interface requirements, reducing device test and characterization efforts, and simplifying focal plane assembly. However large format devices pose problems when tiling a “curved” focal surface with flat devices, and also potentially raise issues with meeting the 2 second readout rate. The readout rate issue is obviously dependent on the devices used and the associated readout architectures.

The fast optical design and high image quality requirements of the project place tight constraints on the metrology of the focal surface. The issue of tiling flat devices on a curved focal surface with a stringent depth of focus requirement poses an interesting design challenge as a “focal surface” assembly. The current flowdown from the system error budget allows defocus due to the static focal plane metrology to be on the order of 5μm and certainly no more than +/- 10 μm from the ideal optical surface. It is clear that this instrument “raises the bar” in focal plane metrology requirements over the previous generation astronomical CCD mosaics, both in “flatness”, that is in terms of meeting the required tolerances in matching the focal surface to the detector array, and in scale. We need to look toward optical assembly fabrication techniques as well as other precision machining methods in order to meet these requirements. To achieve this tight tolerance, attention to detail will be essential for each element in the assembly. In addition, the prospect of an extended assembly, measure, disassembly, remachine, reassemble, remeasure process is disastrous for such an enormous focal plane. The impact of this “rework” approach in terms of time, labor costs, and risk to a delicate assembly are clearly unacceptable. The preferred approach is to improve manufacturing tolerance and quality control of the subassemblies to allow the focal plane to be assembled to print, without adjustments. First the focal surface assembly mounting “plate” will have to be manufactured to optical tolerances. Plate is a poor term for what will in reality be a domed precision reference surface with numerous cutouts for device mounting and electrical feed-throughs. A number of potential fabrication technologies are currently under investigation, as well as materials. Classic focal plane mounting plate materials such as molybdenum, Invar, and Kovar are being evaluated as well as other alternate materials such as composites that may have attractive qualities.

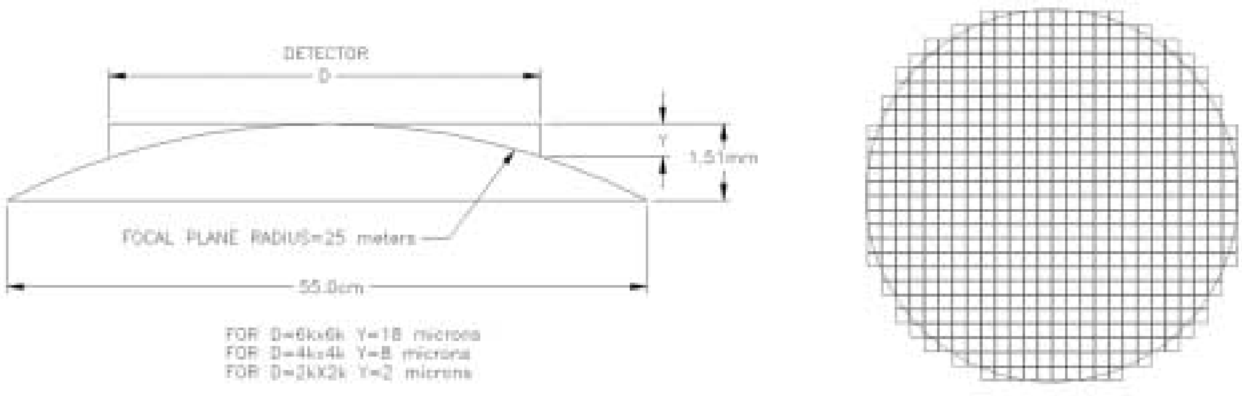

Figure 4. The LSST Focal Plane Assembly Metrology The LSST Focal Surface Curvature. *Graphic on the left illustrates the issue of fabricating a curved focal surface with flat devices. Assuming a device with a 10um pixel, deviations for various devices sizes are shown and reflect the deviation along a side, not the diagonal of the device. The numbers shown above should be multiplied by 1.414 to show deviation on the line of the device diagonal. Graphic on the right illustrates the 55cm focal surface fully-filled with 568 closed packed 2k x 2k 10um pixel devices.*

The current concept is to manufacture the individual device packages to a very tight flatness specification (~3μm) then use a centered three point mount to the focal plane plate. By having the three mounting points centered relative to the detector, it is assured that the detector will always remain tangent to the reference surface to with the tolerance of manufacture. The plate is manufactured with the desired curvature as an “optical element” to an extremely high level of precision, then the individual device focal surface will be tangent to that surface at it’s center point. There will be deviation from ideal as illustrated in Figure 4. This approach has another advantage in that no detector/package is unique, thus reducing over all costs of manufacture, assembly and maintenance. Moreover there is now an optical design with a flat focal plane.

5. DETECTOR TECHNOLOGY OPTIONS

Multiple detector technologies have been examined and will continue to be examined at an increasingly detailed level for suitability for the LSST instrument. These include the range of optical detectors currently known to exist: classic back-side illuminated CCDs (specifically high resistivity devices) [2,3], CMOS APS sensor [4], hybrid CMOS focal plane assemblies [5,6] with PIN photodiode arrays, and orthogonal transfer CCD technology [7]. All device technologies have merit, as well as strengths and weaknesses relative to each other, when all issues are considered. At this time the most promising technologies are back-illuminated scientific CCDs and hybrid CMOS FPAs. For the purposes of this instrument design it is not necessary to make a choice at this time as the first order issues for instrument design can be applied to all detector technologies. These issues are examined in more detail in another paper in this proceedings by Lesser and Tyson [8]. Whenever there is a choice for analysis in the instrument design a worst-case technology will be evaluated in order to bound the problem.

Scientific CCDs represent the current pinnacle of optical detector performance for QE, linearity over a broad range, low-noise and high dynamic range. They do however suffer from some undesirable characteristics for a wide-field applications like LSST such as requiring optical beam shuttering for full format 100% fill-factor devices, a relatively high sensitivity to blooming effects with bright stars, and relatively high power dissipation and interface complexity. Hybrid silicon PIN photodiodes on CMOS readouts are attractive due to a number of reasons: extended QE, electronic shuttering, high-speed readout, low-power operation and simplified interface electronics. Silicon PIN diodes on silicon CMOS devices significantly simplify the hybridization issues found with IR FPAs using HgCdTe or InSb on silicon as the differential contraction of materials is not present.

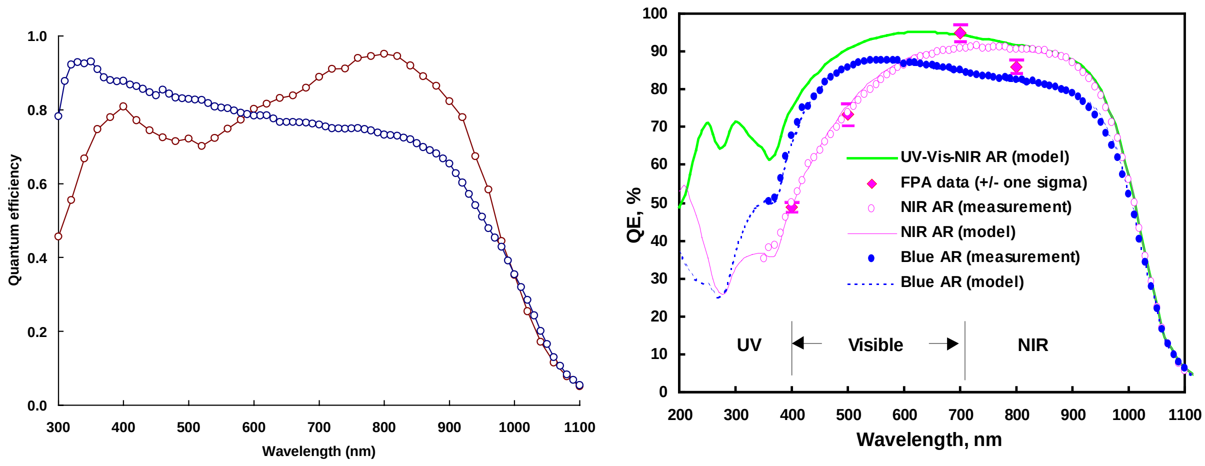

Figure 5. QE Plots for CCDs and PIN Photodiode FPAs. *Illustrates QE plot for LL-MIT CCDs [3] on the left, and Rockwell HyVis photodiodes[5] on the right.*

The packaging designs and electromechanical interfaces to all the described devices are extremely similar. This probably should come as no surprise as a relatively small group of individuals are involved in a number of these device packaging efforts [9]. The designs focus around 4-edge buttable packages using similar materials such as AlN, molybdenum, Invar, polyamide flex circuit interconnects and high-density micro d connectors. Representative packages are shown below in Figure 6 along with a possible patterning of 2k x 2k 10 *u*m devices on an 8” wafer. This figure shows that 50 to 60 devices could be patterned on an 8” wafer. Device costs are influenced heavily by yield. Small devices will have a higher yield than large devices. By providing a large number of devices per wafer, and using large-scale wafers, the costs of device fabrication can be reduced. For a focal plane with 568 devices, adding 10% in spares takes us to 625 devices. Assuming 50 devices per wafer, and a 50% yield, this would require 625/25 = 25 wafers or approximately 1 lot run to produce the required devices. If yields fell to 25% this would require 2 lot runs. Obviously if 6” versus 8” wafers are used these numbers would scale accordingly.

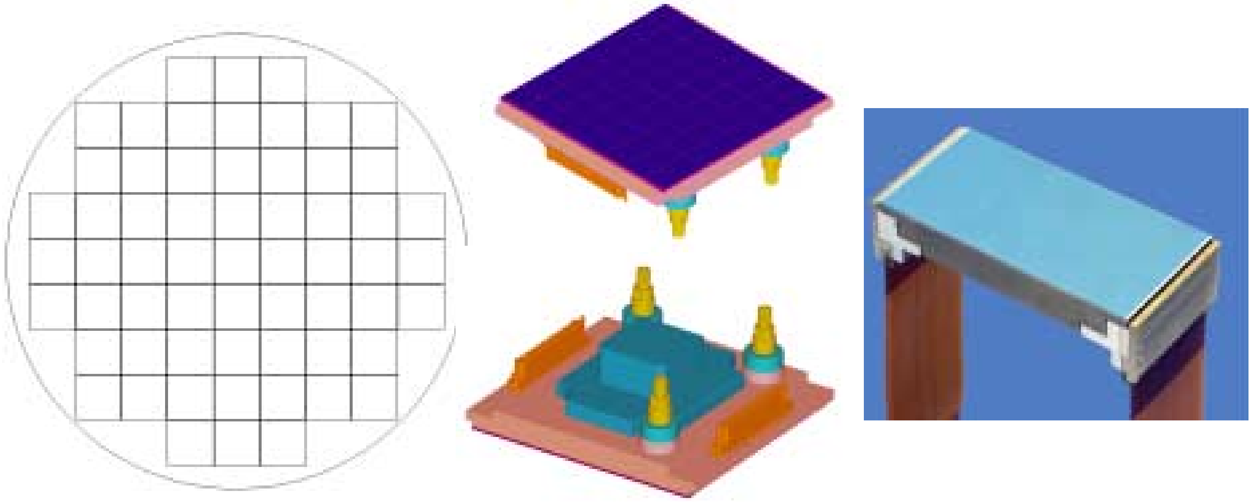

Figure 6. 2k x2k 10um Devices on an 8” Wafer. *Graphic on left, illustrates a possible patterning of devices on an 8” silicon wafer. Pictures on right show device packaging options currently under development for CCDs and other devices (package concepts courtesy of G.L. Scientific).*

6. FOCAL PLANE INTERFACE

The focal plane data interface is a critical issue for an instrument of this massive scale. The process of providing the required electrical interface for a focal plane of this size with over 500 hundred devices is a signifcant challenge not only for signal integrity issues but also thermal conduction issues. Previous methods using high-power printed circuit boards based interface electronics mounted external to the dewar and connected by massive cable assemblies is not a viable methodology for construction of focal planes of this size and scale. Previous generation astronomical instruments [10,11] have made inroads in new technology approaches that optimize the detector electronics interface by using flex circuit interconnections. These methods can now be extended further to address this issue in an optimal way.

There are two potentially viable approaches to this solution. The first is an application specific integrated circuit (ASIC) and the second is an approach using existing standard mixed signals components. In either case the goal is to simplify and optimize the device interface, turning the detector effectively into a digitzing focal plane and providing a digital interface. The use of flex-circuit interconnect or hybrid bump bonding techniques to focal plane segments simplifies device interface. All required detector interface circuitry is contained within the inner dewar. The digitized data will be passed through the vacuum feedthrough using flex circuit vacuum feedthrough. The data will be high-speed low voltage differential signal in order to minimize the number of electrical conductors passing from the cold internals of the inner dewar to the warm outer dewar. Low voltage differential signalling on controlled impedance flex circuits allows high-speed data transfer with minimized EMI considerations and low-power. This is illustrated in Figure 7.

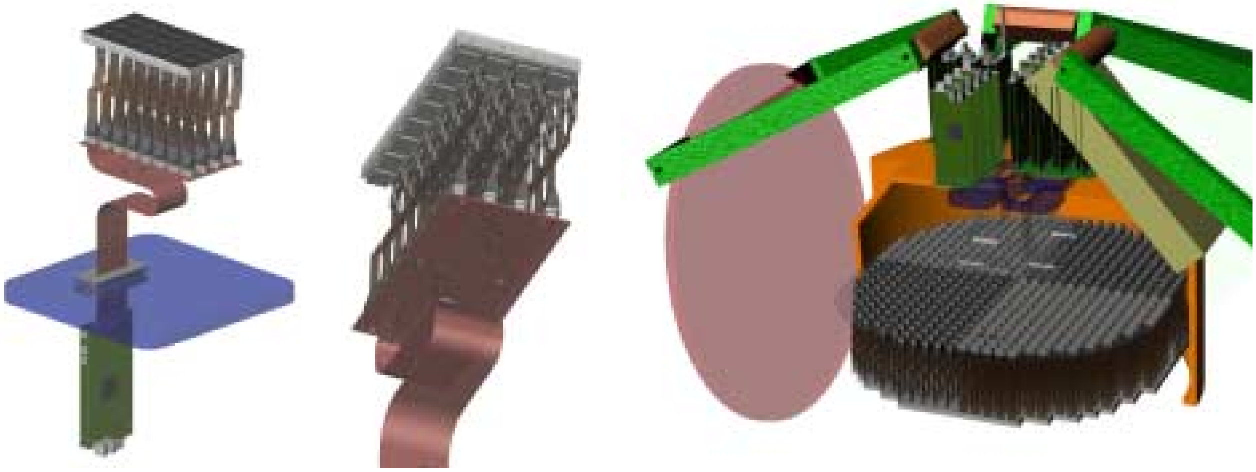

Figure 7. Rigid-flex Interconnect and Vacuum Feedthrough. *Pictures on the left and center illustrate the flex circuit interface to a segment of the focal plane along with the vacuum feedthrough and the fiberoptic interface pcb. The fiberoptic interface is outside the internal dewar and inside the external dewar. Picture on the right shows the inner dewar assembly in cutaway.*

There are ASIC based development efforts currently underway for the NGST and other projects [5] and these solutions may yield attractive results for LSST. One such concept is shown below in the left side of Figure 8. An ASIC based approach would likely provide an optimal solution for performance and power and as such is being pursued. The good news is that the desired performance and functionality can be achieved using currently available standard mixed signal components from commercial suppliers that can implement this functionality on rigid-flex printed circuit technology. These components show outstanding package densities, low-power operation, and provide an established low-risk, low NRE cost profile when compared to ASIC based technologies. If ASIC efforts fall short we have a very nice existing solution in hand already. This alternative approach for a 2k x 2k CCD with 4 outputs is also shown in the right-side of Figure 8. It shows a single stage preamp, CDS, PGA, ADC device on one side, and clock and bias circuitry on the other. This exact circuitry shown above is currently under test and evaluation for a single board CCD controller prototype that is part of the NOAO MONSOON development effort[12].

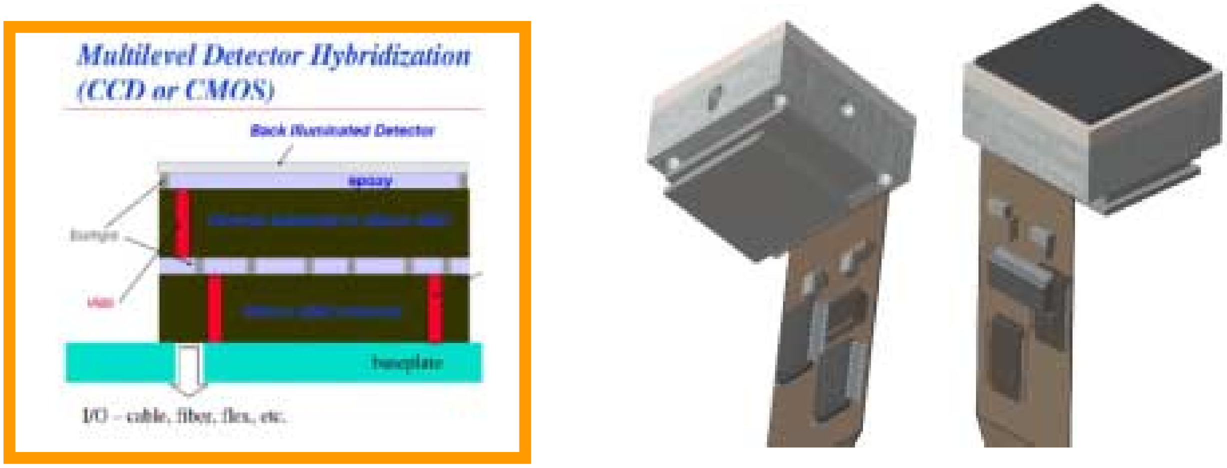

Figure 8. Device Interface. *Illustrates the current options for device interface. On the left, ASIC technology bump bonded as a hybrid to the detector. On the right device interface using standard commercial components mounted on rigid-flex cable.*

7. IMAGE DATA ACQUISITION

The task of acquiring the “detector-limited” image data is handled by the MONSOON Image Acquisition System. MONSOON is based on a scalable network of powerful yet low-cost LINUX-based PCs, each supporting a commercial 2.4Gb/s fiberoptic link. This architecture shown in Figure 11 yields an attractive digital communications and processing platform for large imaging systems such as LSST. MONSOON has been specifically designed from conception to handle large scale systems such as LSST.

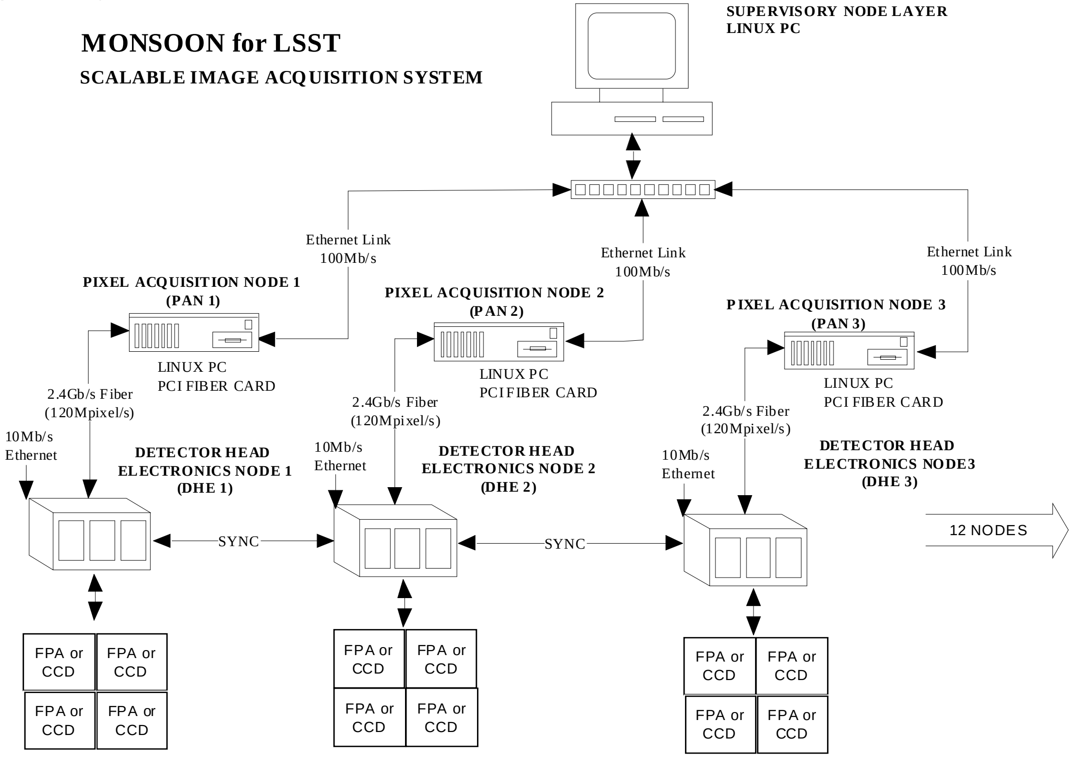

Figure 9. MONSOON Scalable Image Acquisition System Architecture. *Illustrates a possible 12 node 2.4Gb/s fiberlink implementation. A 12 node implementation would exceed the required 1.1Gpixel/s readout rate of LSST.*

There are three layers within the MONSOON architecture: the Supervisor Layer, the Pixel Acquisition Node (PAN) Layer, and the Detector Head Electronics (DHE) Layer. These layers and their functionality are described in more detail in another paper is this proceedings [12]. Care has been taken to develop a system architecture, both hardware and software, that has well-defined interfaces, a rational partitioning of functionality, a framework for expandability or adaptation to differing needs, and support for both hardware and software component evolution. In addition the critical issues of error detection and recovery, fault tolerance, system diagnostics and maintenance, and robust operation have been cornerstones of the design effort from its inception at the end of calendar year 2000.

One of the key issues with focal plane mosaics is tight synchronization of the clocking of individual focal plane devices. Noise from clock transitions will destroy low-noise performance unless this tight synchronization is maintained and pixel sampling occurs only during quiet times of the pixel clocking cycle. With the 2s readtime requirement this issue is of increased importance to previous systems where the readout rate was slower and timing margins more relaxed. MONSOON has addressed the important issue of tight synchronization between readout of multiple detectors. Referring to Figure 11 notice the SYNC line running between Detector Head Electronic (DHE) nodes. This is a high-speed controlled impedance LVDS signal pair with clock skew management that allows hard-synchronization of readout to the ns level. Please note that for LSST the analog interface circuitry will be in close proximity to the detector as discussed above in Section 6. So in effect the DHE is now distributed over the flex-circuit interconnects. This is in essence simply a repackaging of known working MONSOON designs appropriate for systems of LSST scale.

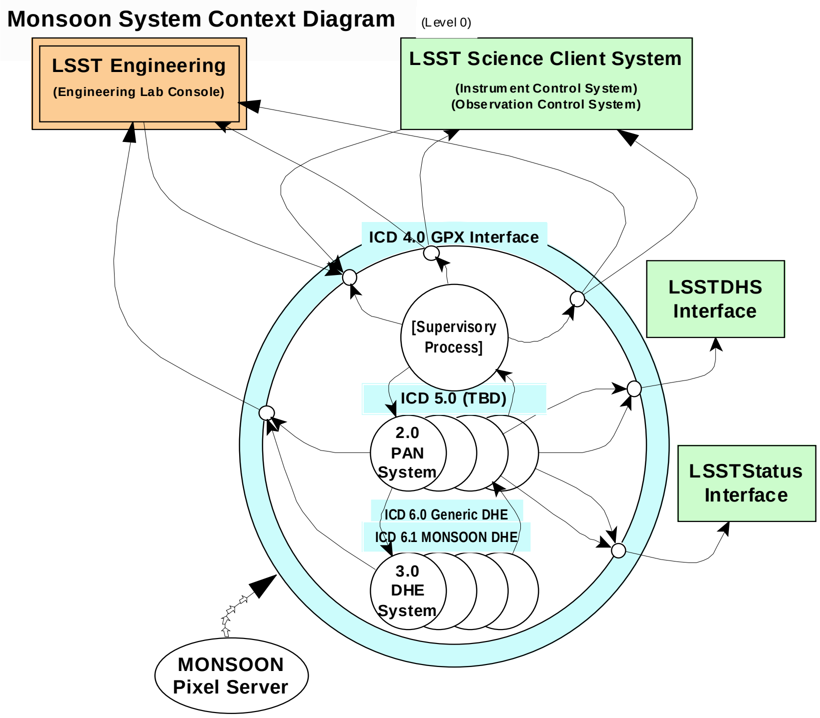

Figure 10. MONSOON Pixel Server Architecture. *Illustrates the MONSOON context level data flow diagram for LSST.*

The MONSOON architecture partitions the system into 2 fundamental subsystems, the image data acquisition system (digital domain, non-sensor specific) and the detector interface. It is well known that the amount of time spent in software development efforts and duplication of efforts is enormous for systems of this type. Every attempt has been made to establish a rational modular software as well as hardware architecture which will be composed of basic separable elements, and leverage these development efforts, regardless of detector technolgy used, or optical wavelength.

Most software systems at astronomical observatories can be modeled after client-server based architectures. A “client” requests a service or data product from a defined “server”. In the case of MONSOON, that data product is an image or a collection of pixels. Therefore MONSOON fulfills the role of a “pixel server” within the LSST system. Specifically this means that it restricts its scope to managing the acquisition of highest quality image data, at peak efficiency. One external client to MONSOON will be the LSST Observatory Control System. This client will define the image or image set that MONSOON will acquire. Another external client will be the LSST Data Handling System (DHS). The issues of data pipelining and data mining are handled down-stream of MONSOON by the LSST Data Handling System (DHS). This clear definition of subsystem boundaries and rational partitioning of system functionality is key to a well-designed and robust overall system.

MONSOON can support the required 2s readout rate, along with supporting whatever detector readout modes are required. Image coaddition and image descrambling naturally fit within the MONSOON “pixel server” boundary. MONSOON has been designed to address the issues raised by large scale imaging systems such as LSST. These issues include the following: 1) physical size and form factor; 2) power dissipation and cooling near the telescope; 3) system assembly, test, and integration time; 4) reliability and the total cost of operation; and, 5) data integrity, stability, and verification.

8. FILTER MECHANISM

The 60cm diameter filters in the LSST will need to be ¾ to 1” thick for the necessary rigidity and will weigh approximately 40 to 50 pounds each. The instrument is designed to support a set of four filters, one in the beam, three stored at the side of the dewar. This design was chosen due to the rigorous space constraints placed on the instrument volume and the need to exchange 2-4 filters on a time scale of a few minutes. The mechanism utilizes a compound movement of a translation plus rotation of the filter as it is positioned either in the beam or returned to stored position. The structure and movement resembles petals on a flower in that the filters slide up the side of the dewar and are rotated into position in front of the beam. There will be a locking and positioning mechanism for the filter within the beam in order to provide precise filter repositioning and support when in place and the telescope is repositioned. The filter is not expected to be moved while the telescope is in slew. Initial FEA analysis indicates that based on common materials, glass filters, steel support arms, and slide mechanisms that the mechanism meets the space envelope requirements at the 3 primary gravitational load positions. The first order analysis of torques present at the various points have been calculated and have been found to be acceptable and well within the range of material choices available and motor drive capabilities.

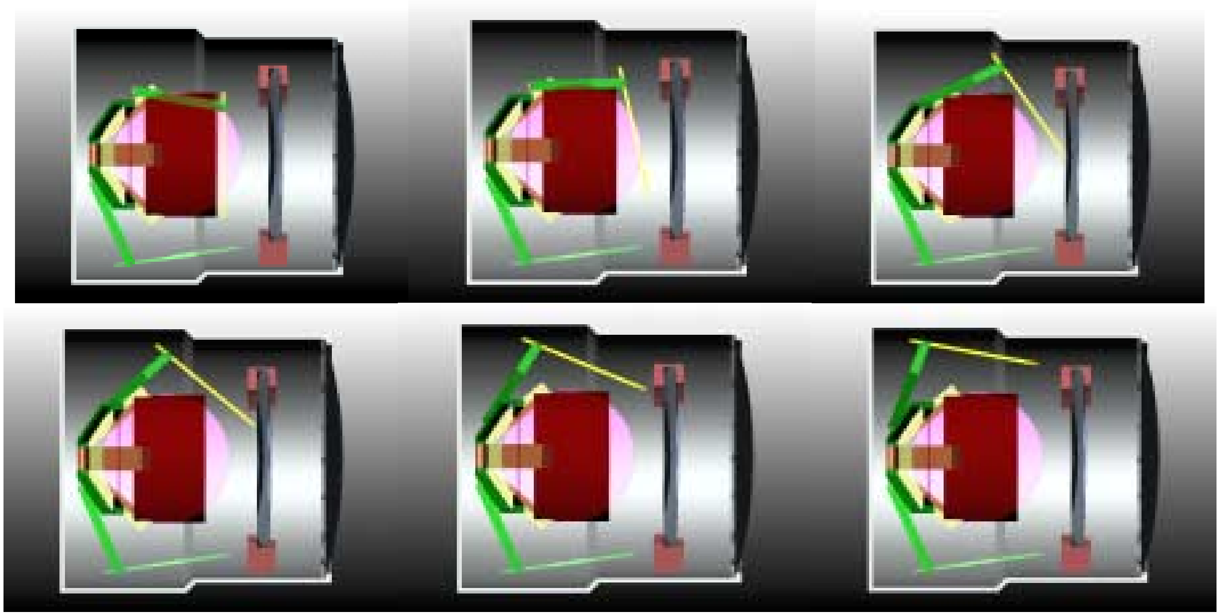

Figure 11. The filter mechanism. *Illustrates from top left to bottom right the movement of a filter from in the beam to its stowed position.*

The LSST filter system will consist of four individual mechanisms, one for each filter. Each mechanism will have a linear table for translational movement, a "rotator", for rotational movement and "arms" that connect the filter to the rotating and translating mechanism. The linear tables will be "off the shelf" units available from several commercial vendors. The four linear tables will be mounted in a common "saddle" at one end, and to the four quadrants of the inner dewar at the other, in a "pyramid" fashion. A benefit to the configuration is that the four linear tables will add structural support to the filter mechanical system in the axial direction. The filter position is defined using a separate set of mechanisms to lock the filter into kinematic mounts relative to the front of the inner dewar.

9. DEWAR CONSTRUCTION

The inner dewar as described previously will contain the focal plane assembly as well as the detector interface circuitry, and associated temperature control components. The dewar will have roughly a 60 cm window providing the optical input aperture. As mentioned previously this window will provide optical power and maybe constructed of fused silica. Fabricating this dewar as a classic fully-evacuated dewar will pose some significant issues for this window due to the atmospheric loading effects. For example, the atmospheric load would be approximately 12,000 to 14,000 lbs. The dewar window is directly in front of a focal plane fully populated with valuable detectors. To address this concern the instrument concept presented here uses a back-filled dewar versus an evacuated dewar. This will relieve the issues of mechanical stress on the window but raise other issues which must be addressed. There is a long history of using non-evacuated dewars for other imaging applications.

There are four primary sources of heat load for the cooling mechanism of this instrument, the radiation load of the focal plane as it looks at the dewar window, the conduction losses through the electrical wires providing interface to the detectors, the power dissipated internally due to detector and detector interface electronics, and the convective losses through the dewar partial pressure gas back fill. Before the cooler technology can be selected, the cooling requirements must be defined. The calculations below assume –40C for the focal plane assembly and laboratory operations at 25C ambient temperature. Operating at –20C focal plane and a cold observatory dome the heat load is significantly less.

With a 55cm focal plane, the area is ~ 0.25 m^2, and assuming a worst-case emissivity and shape factor = 1, and an operating temperature of –40C (223K).

$$Q_{rad} = (1)(1)\,(5.66X10^{-8}\ W/m^2K^4)\,(.25\ m^2)\,[(300\ K)^4 - (223\ K)^4] = 79.6\ W$$

The proposed gas for the inner dewar is Xenon. It is of interest here because of its noble gas properties and its relatively low thermal conductivity. Assuming convection is limited to the front surface of the focal plane assembly only and using a thermal convection coefficient of 7.29W/m^2K for Xenon.

$$Q_{conv} = (7.29W/m^2K)\,(0.6)\,(.25\ m^2)\,[(300\ K) - (223\ K)] = 84.4\ W$$

The conductive losses through the wires interfacing to the focal plane can be minimized through the use of integrated device interface electronics, whether ASIC based or not, and providing an minimized interface, such as Gigabit LVDS serial signaling technologies through flexible circuit vacuum feedthrough assemblies. By using this approach conductive loading for electrical wires are manageable. We must also include power dissipated by the detectors and electronics. There is a wide range here depending on the technology chosen. This needs to be scaled by the duty cycle of course as little if any power is dissipated when devices are not clocked. As in integration, duty cycle = readout time / total time ~ 10%.

There are two potential focal plane cooling technologies currently under consideration, thermoelectric (TE) and thermoacoustic wave (CRYOTIGER®). If TE coolers are used, the heat removed from the focal plane assembly must be removed from the instrument using an additional heat exchange system, such as glycol based circulating coolant. Furthermore the efficiency (40-70%) of the cooler must be factored into the total heat load that must be serviced by the waste heat cooling system. The use of CRYOTIGER technology requires the plumbing of cryogas delivery lines to the instrument, but has the advantage of no additional heat load being generated in the optical beam. The closed cycle system consists of a cold end or ends, a compressor, and two gas transfer lines. Electricity is the only utility required for the compressor (the cold end does not require any electricity). The cold end has no moving parts thereby producing almost no vibration, allows for long-life operation, and eliminates the need for any scheduled maintenance or service.

The cold head can be used in any orientation and located over 150 feet from the compressor by utilizing copper lines. Mean time between failure is more than 100,000 hours.

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REFERENCES

1. D. E. Groom, "Recent Progress on CCDs for astronomical imaging", SPIE 4008-70, pp. 634-645, 2000.
2. S. Holland, et al "Overview of CCD Development at Lawrence Berkeley National Laboratory", Proceedings of the Workshop Scientific Detectors for Astronomy, 2002.
3. B. Burke, et al "Broadband (200-1000nm) Back-Illuminated CCD Imagers", Proceedings of the Workshop Scientific Detectors for Astronomy, 2002.
4. J. Janesick, "Dueling Detectors", SPIE OE Magazine, pp. 30-33 February 2002.
5. L.Kowzloski, et al, "Progress in Ultra-low Noise Hybrid and Monolithic FPAs for Visible and Infrared", Proceedings of the Workshop Scientific Detectors for Astronomy, 2002.
6. P. Love, et al "Megapixel and Larger Readouts and FPAs for Visible and Infrared Ground-based Astronomy", Proceedings of the Workshop Scientific Detectors for Astronomy, 2002.
7. J. Tonry, et al "The Orthogonal Transfer Array", Proc. of the Workshop Scientific Detectors for Astronomy, 2002.
8. M. Lesser, J.A. Tyson, "Focal plane technologies for LSST", SPIE Vol. 4841, these proceedings to be published 2002.
9. M. Lesser "Back Illuminated 4k x4k CCDs", Proceedings of the Workshop Scientific Detectors for Astronomy, 2002
10. B. Starr, et al "The Design of the CFH12k: 12k x 8k CCD Mosaic Camera for the CFHT Prime Focus", SPIE 4008-163, pp. 1002-1033, 2000.
11. B. Starr, et al "CFHTIR: 1k x 1k NIR Spectro-Imaging Camera for the CFHT", SPIE 4008-164, pp.999-1009,2002
12. B. Starr, et al "MONSOON: Image Acquisition System", SPIE Vol. 4841-66, 2002. www.noao.edu/ets/monsoon
13. W. Davison, et al "Large Synoptic Survey Telescope mechanical structure and design", SPIE Vol 4836-18, 2002
14. L.G. Seppala, "Improved optical design for the Large Synoptic Survey Telescope (LSST)", SPIE Vol 4836-19, 2002