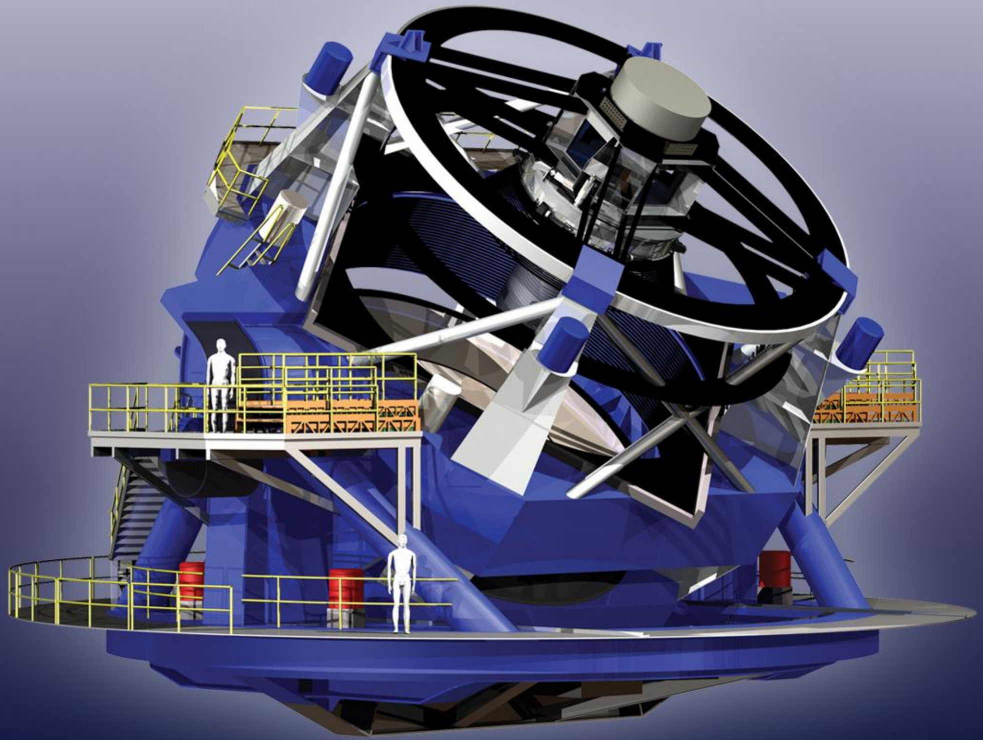
LSST

Large Synoptic Survey Telescope



R. Van Berg

January 18, 2011

Synoptic?

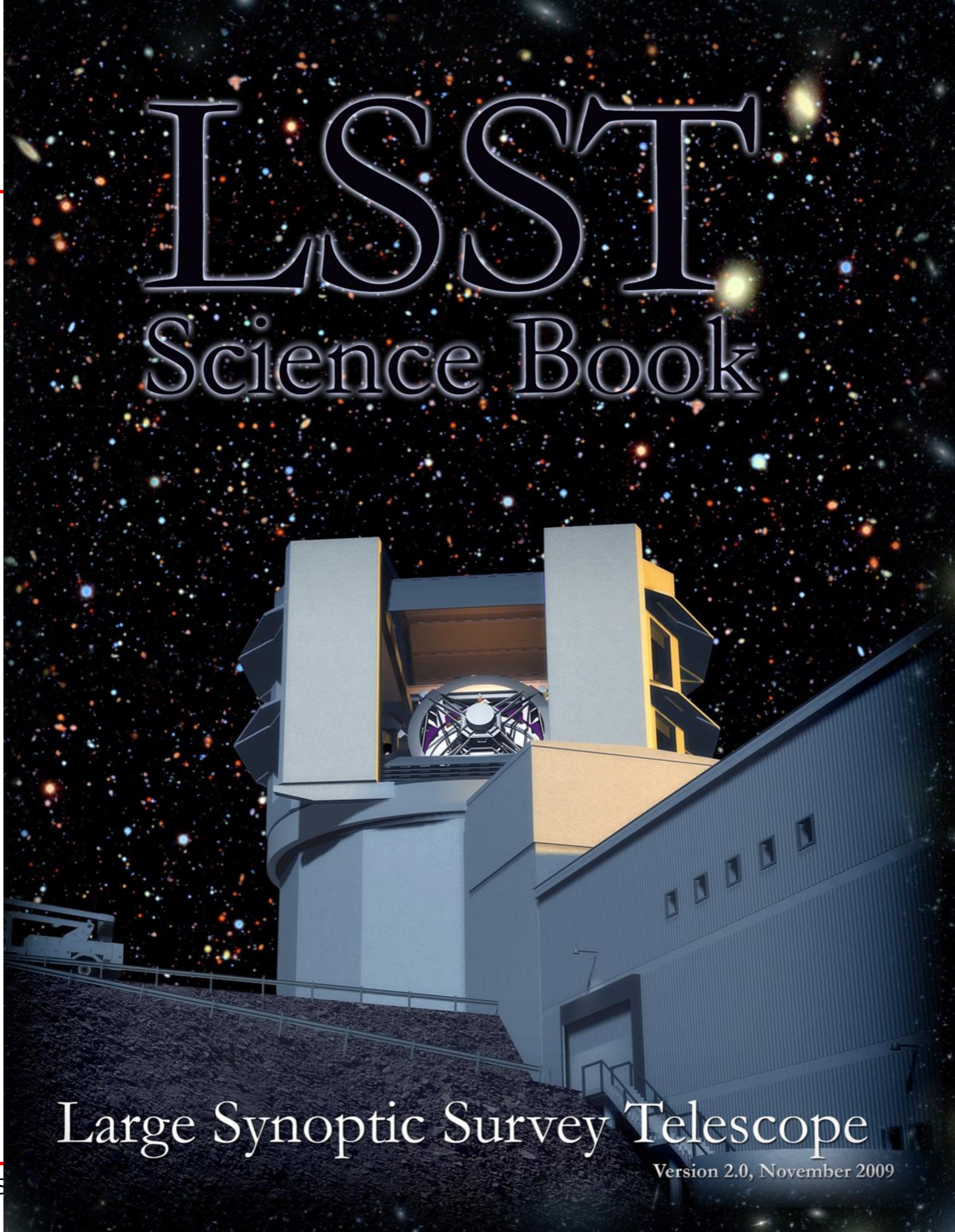
- syn·op·tic (s-nptk) also **syn·op·ti·cal** (-t-kl)*adj.*
- **1.** Of or constituting a synopsis; presenting a summary of the principal parts or a general view of the whole.

συνοπτικοσ

Preface
Introduction
LSST System Design
System Performance
Education and Public Outreach
The Solar System
Stellar Populations
Milky Way & Local Volume Structure
The Transient & Variable Universe
Galaxies
Active Galactic Nuclei
Supernovae
Strong Lenses
Large-Scale Structure
Weak Lensing
Cosmological Physics

Dark Energy

www.lsst.org/lsst/scibook



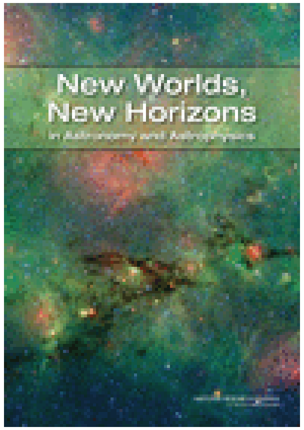
Decadal Survey

Large Synoptic Survey Telescope

"The committee recommends that LSST be submitted immediately for NSF's Major Research Equipment and Facilities Construction (MREFC) consideration with a view to achieving first light before the end of the decade.

The top rank accorded to LSST is a result of (1) its compelling science case and capacity to address so many of the science goals of this survey and (2) its readiness for submission to the MREFC process as informed by its technical maturity, the survey's assessment of risk, and appraised construction and operations costs. Having made considerable progress in terms of its readiness since the 2001 survey, the committee judged that LSST was the most ready-to-go."

August 13, 2010



The LSST Project – ~π x $\$10^8$

Large Synoptic Survey Telescope

- Telescope & Site
  - Telescope Mount
  - Mirrors (M1, M2, M3)
  - Observatory + base facility +….
- Data Management
  - Data movement, storage, analysis

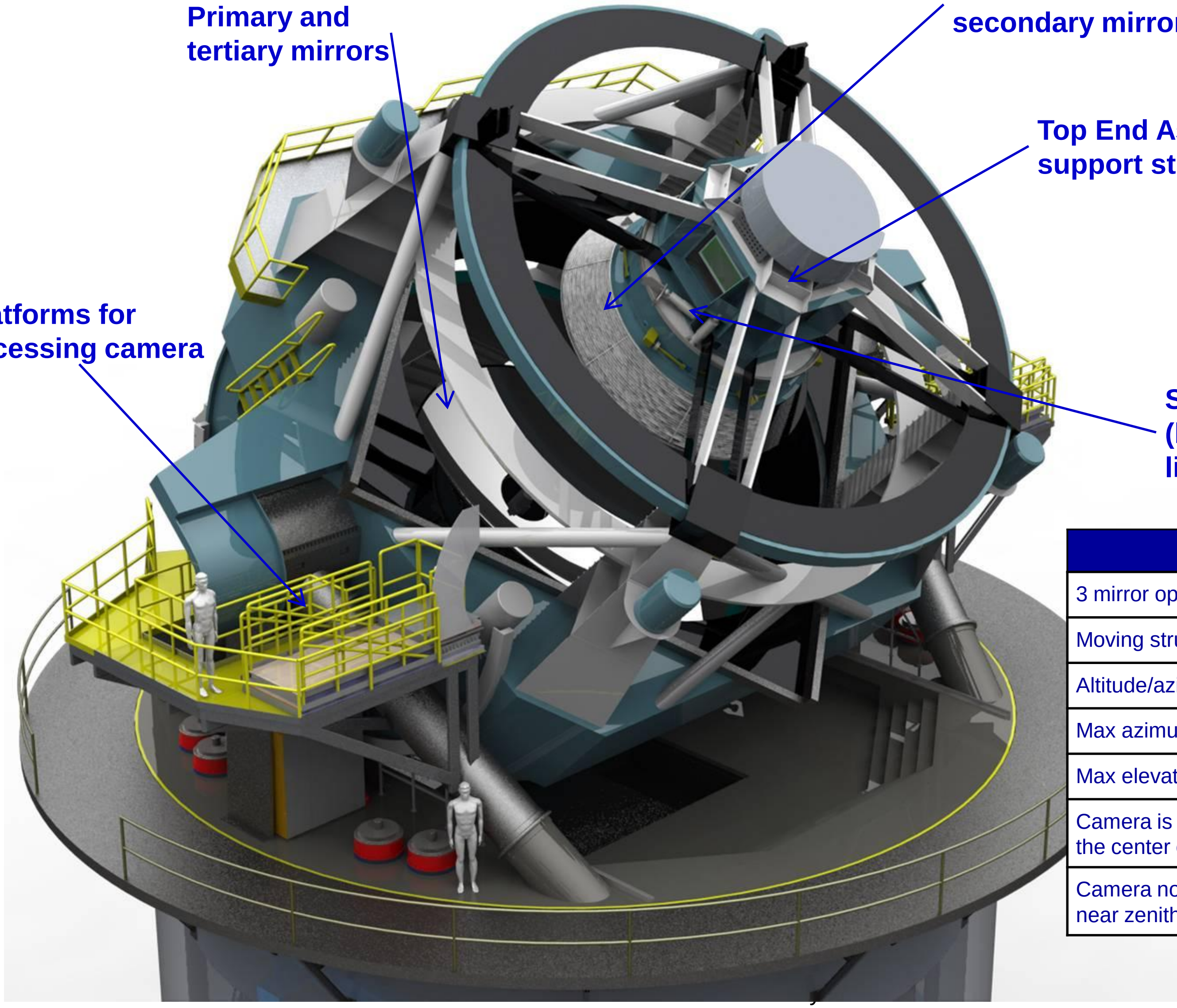
NSF

- Camera
  - Lenses, filters, sensors, electronics, etc.

DOE

NGC7331

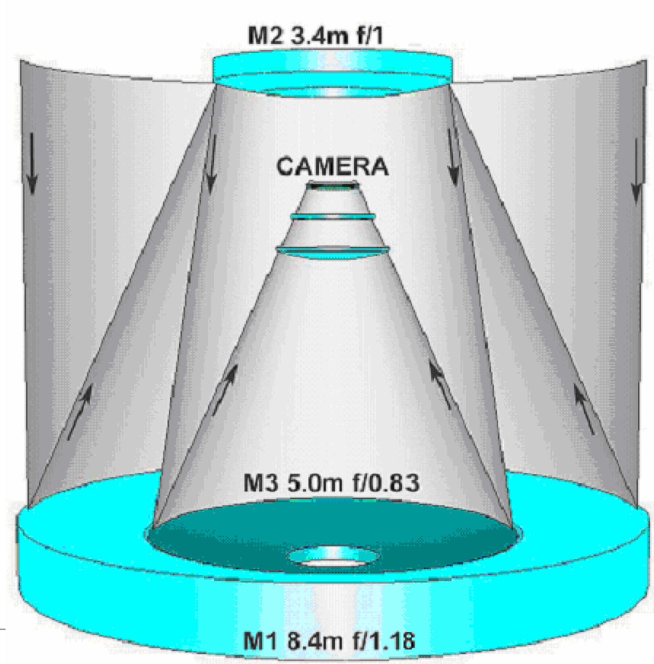
The LSST Telescope

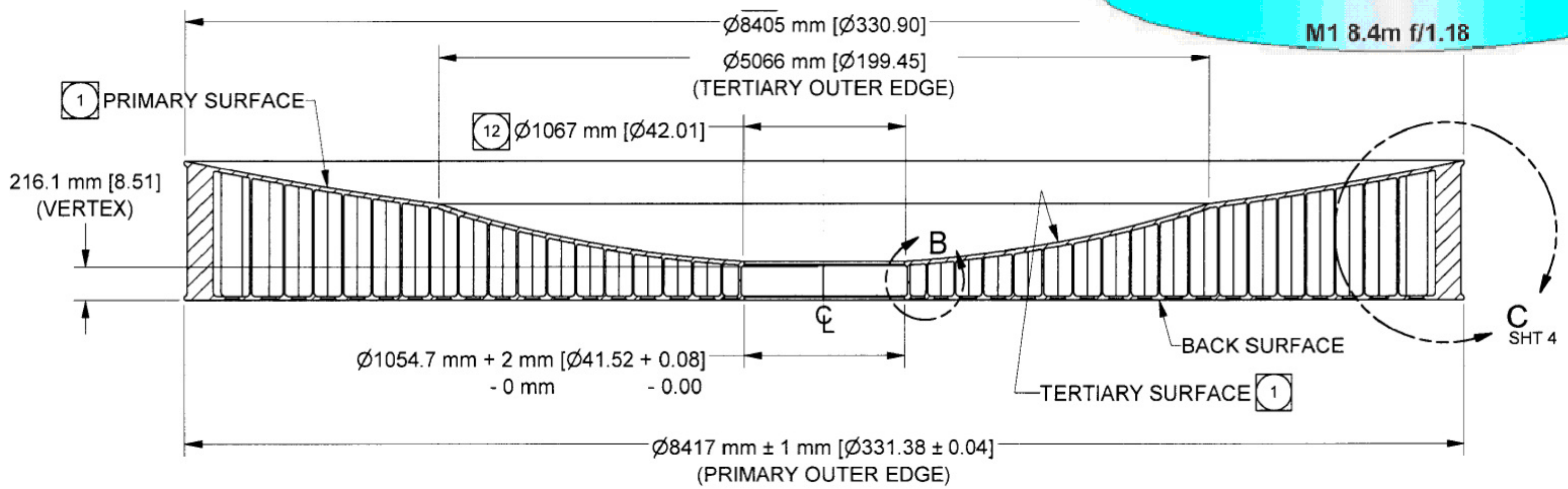


Relevant Telescope Features
3 mirror optical design
Moving structure: 300 tons
Altitude/azimuth rotation axes
Max azimuth axis accel: 10.5 deg/sec^2
Max elevation axis accel: 5.25 deg/sec^2
Camera is cantilevered off the Top End Assembly near the center of rotation
Camera normally looks down when telescope is pointing near zenith

Telescope Optics

- *f / 1.23*
- < 0.20 arcsec FWHM images in six bands: 0.3 - 1 μm
- 3.5 FOV
- Etendue = 319 m^2deg^2



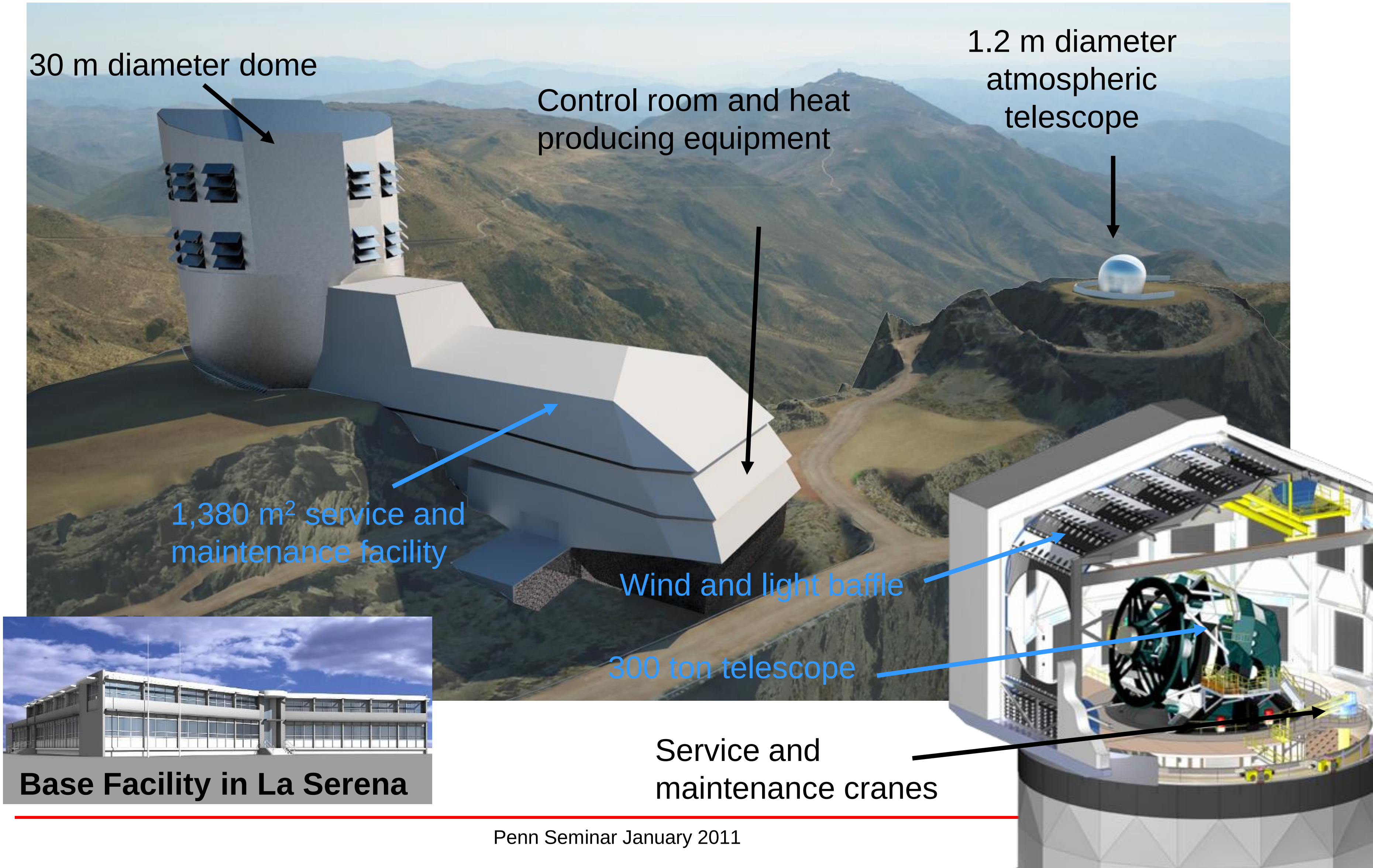


Primary/Tertiary Mirror (in fabrication)

Large machinery, large piece of glass, nm precision

Large Synoptic Survey Telescope

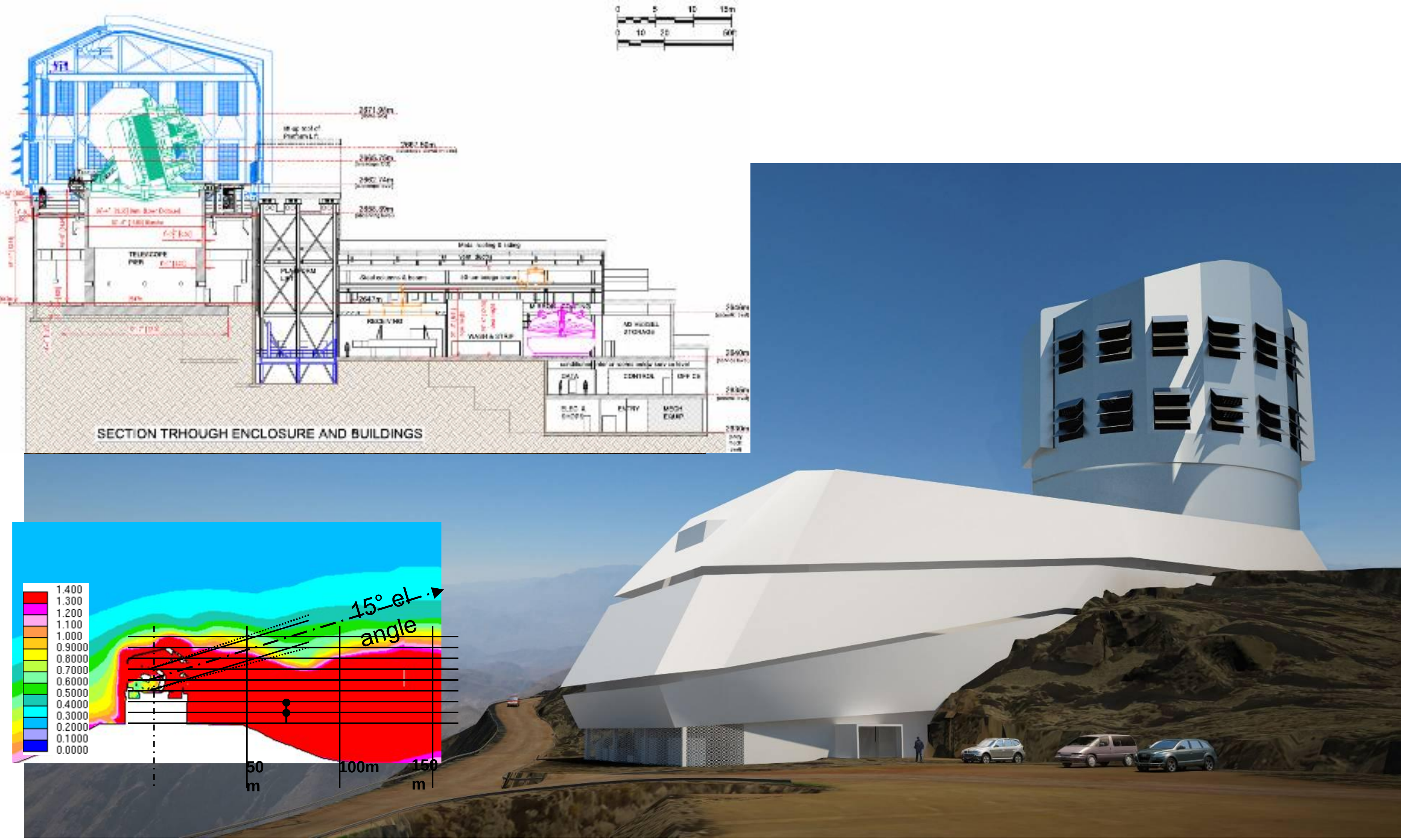
The Telescope and Site includes the summit and base facilities, telescope system, & calibration hardware



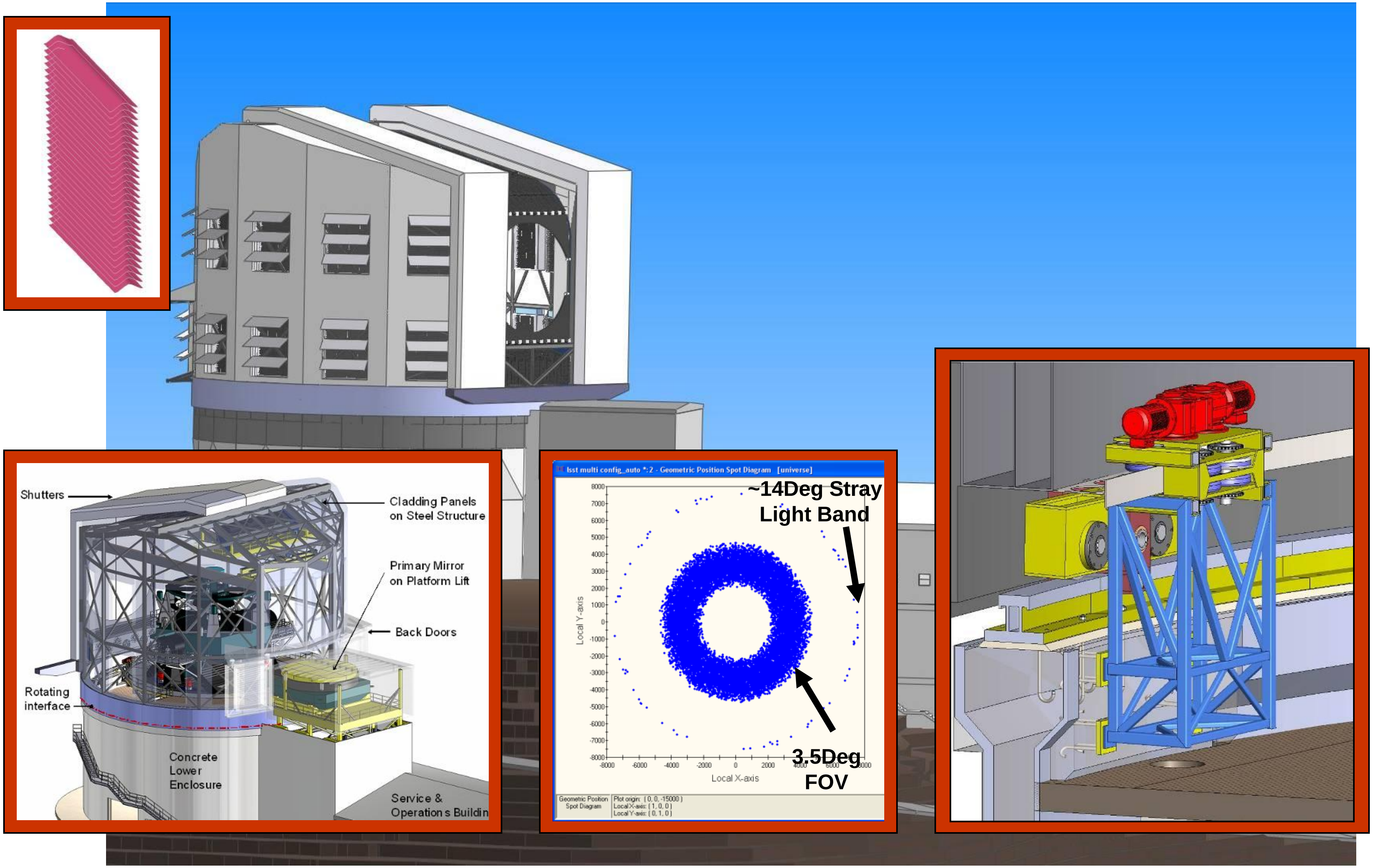
Base Facility in La Serena

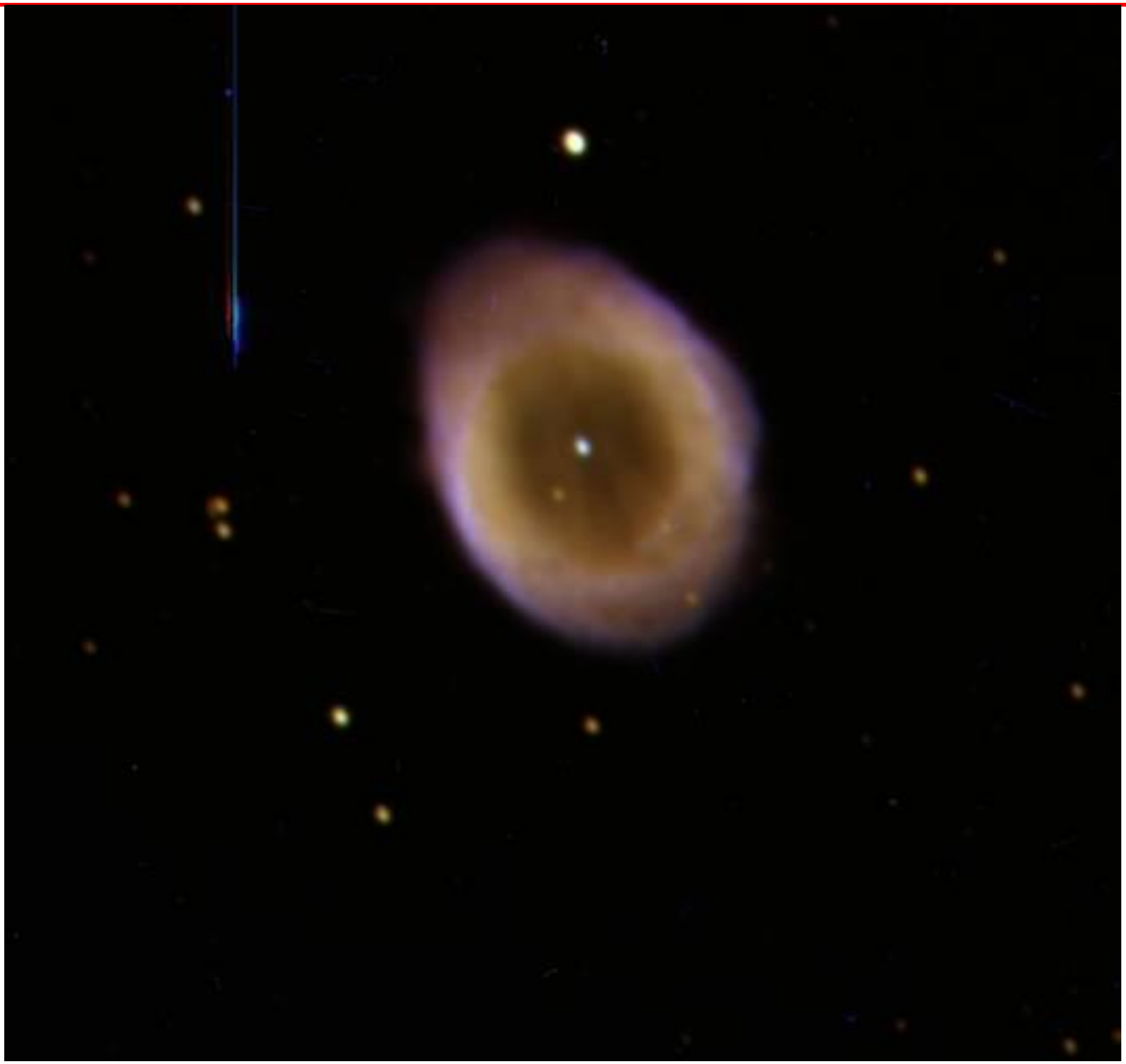
The site has been chosen on Cerro Pachón, Chile

Summit facility final design under contract with ARCADIS Geotecnica, Santiago Chile



Telescope Dome – an interesting set of challenges





M57

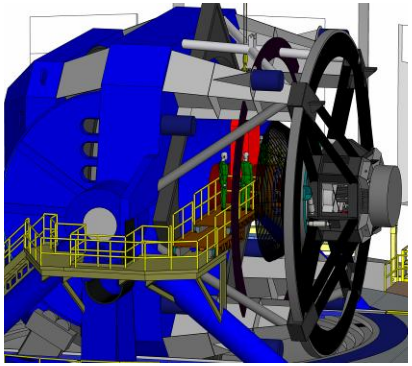
Telescope Mount

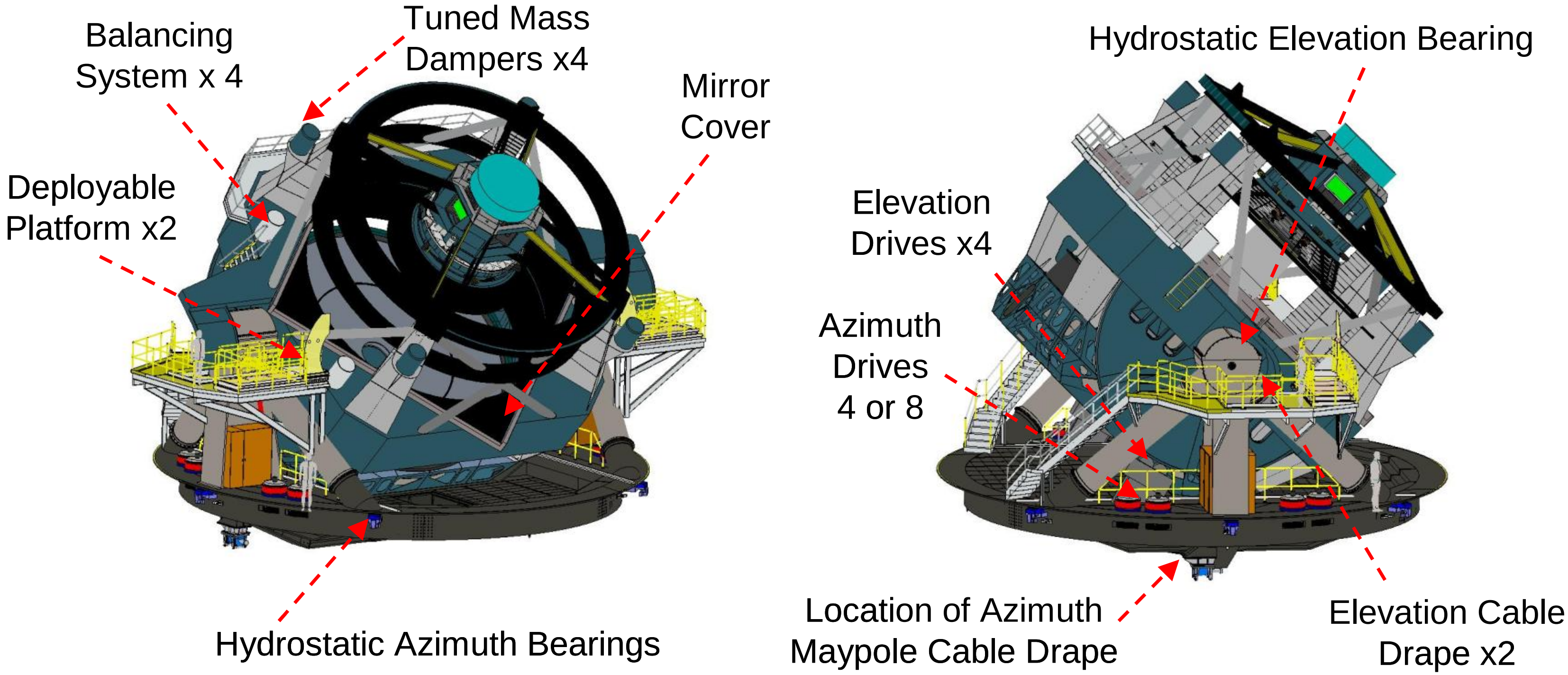
Moving structure: 300 tons

Drive power: 450 hp

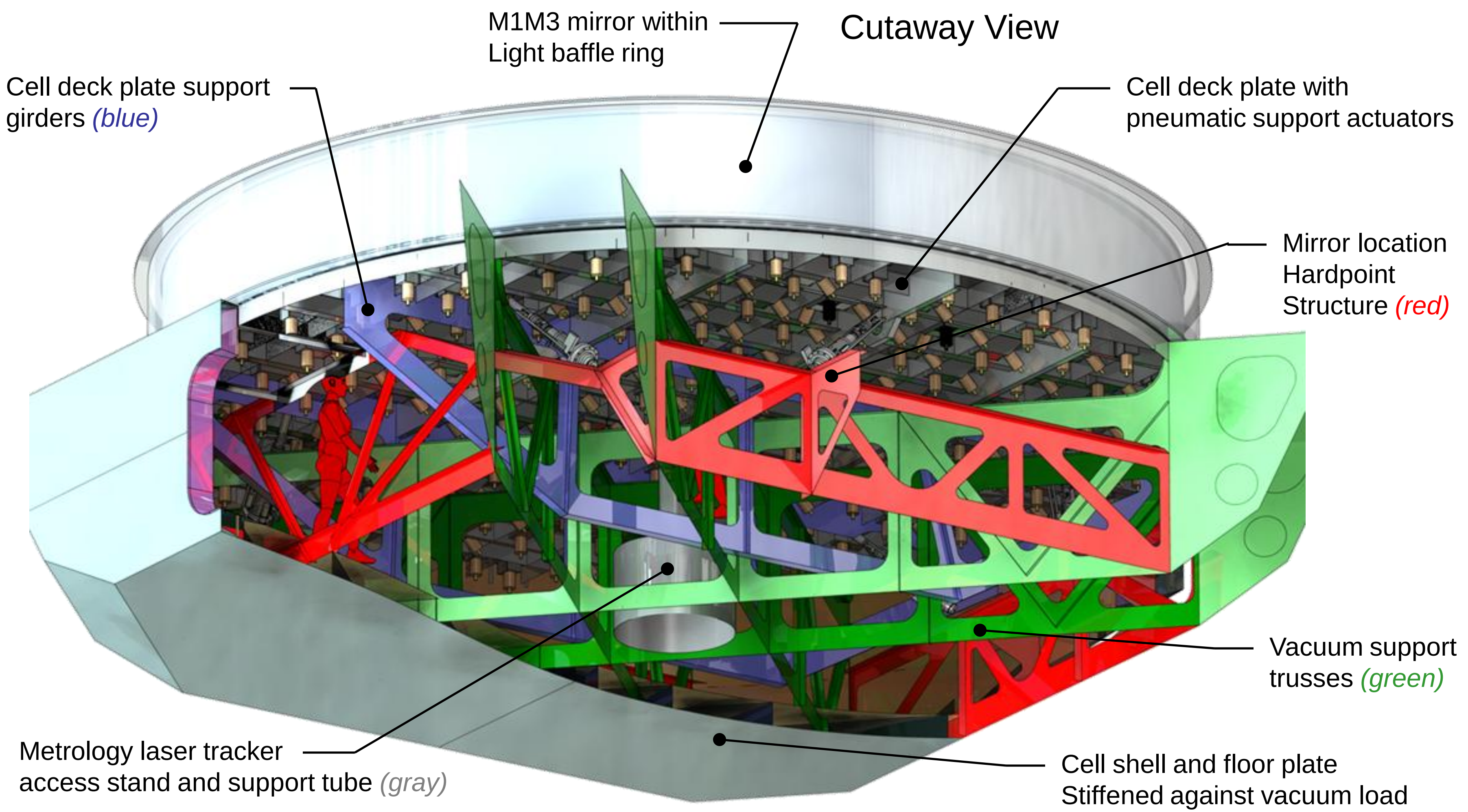
Damping: Tuned masses raise damping to 5%

First Frequency: 8.2 hz (loaded structure on bearings, pier, and summit rock)

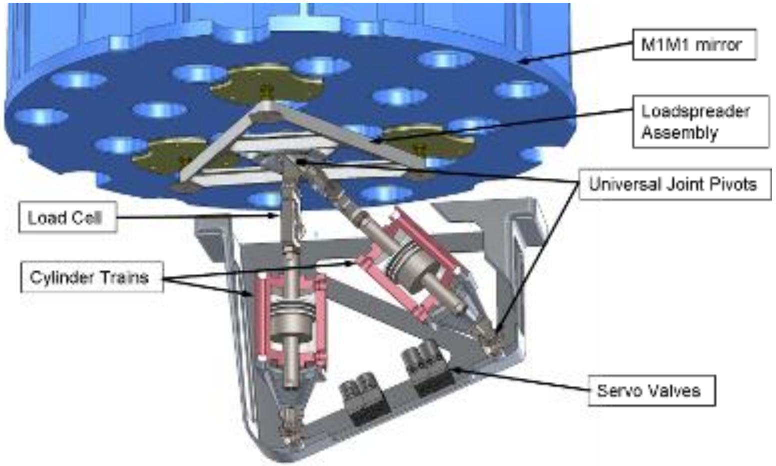


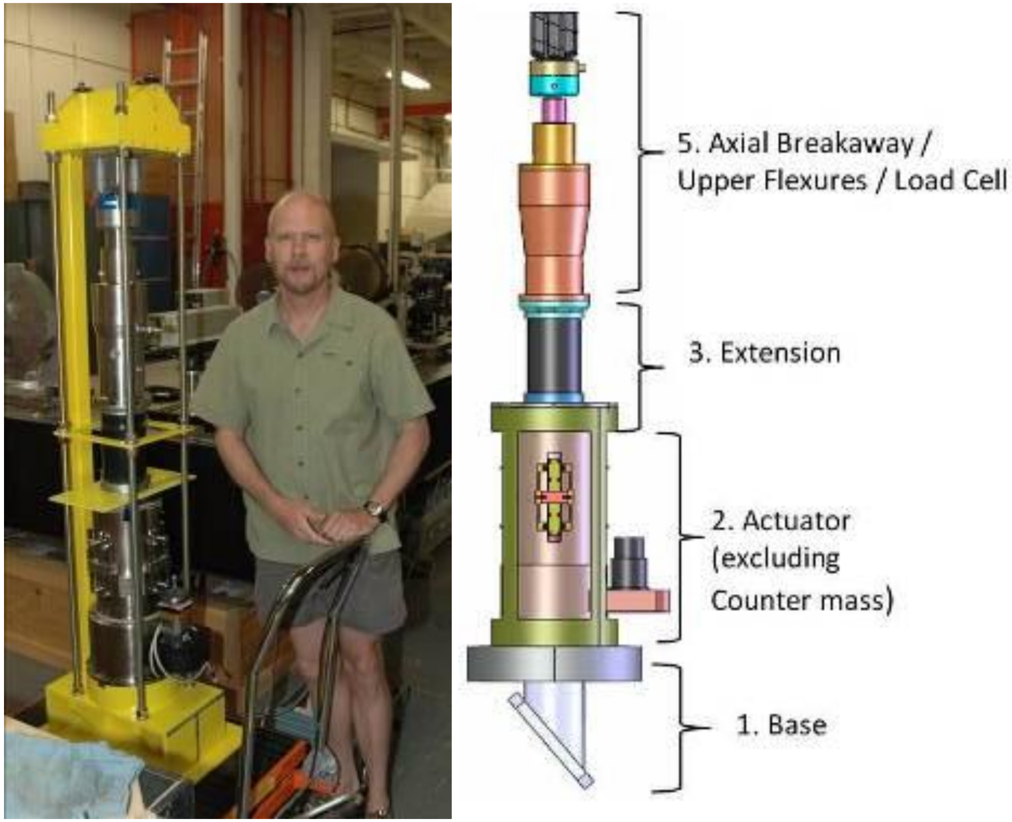


M1M3 System


M1M3 mirror within
Light baffle ring
Cutaway View
Cell deck plate support
girders (blue)
Cell deck plate with
pneumatic support actuators
Mirror location
Hardpoint
Structure (red)
Vacuum support
trusses (green)
Metrology laser tracker
access stand and support tube (gray)
Cell shell and floor plate
Stiffened against vacuum load

Mirror supports and actuators





M2 Substrate purchased and completed by Corning using LSST non-federal funding

Large Synoptic Survey Telescope

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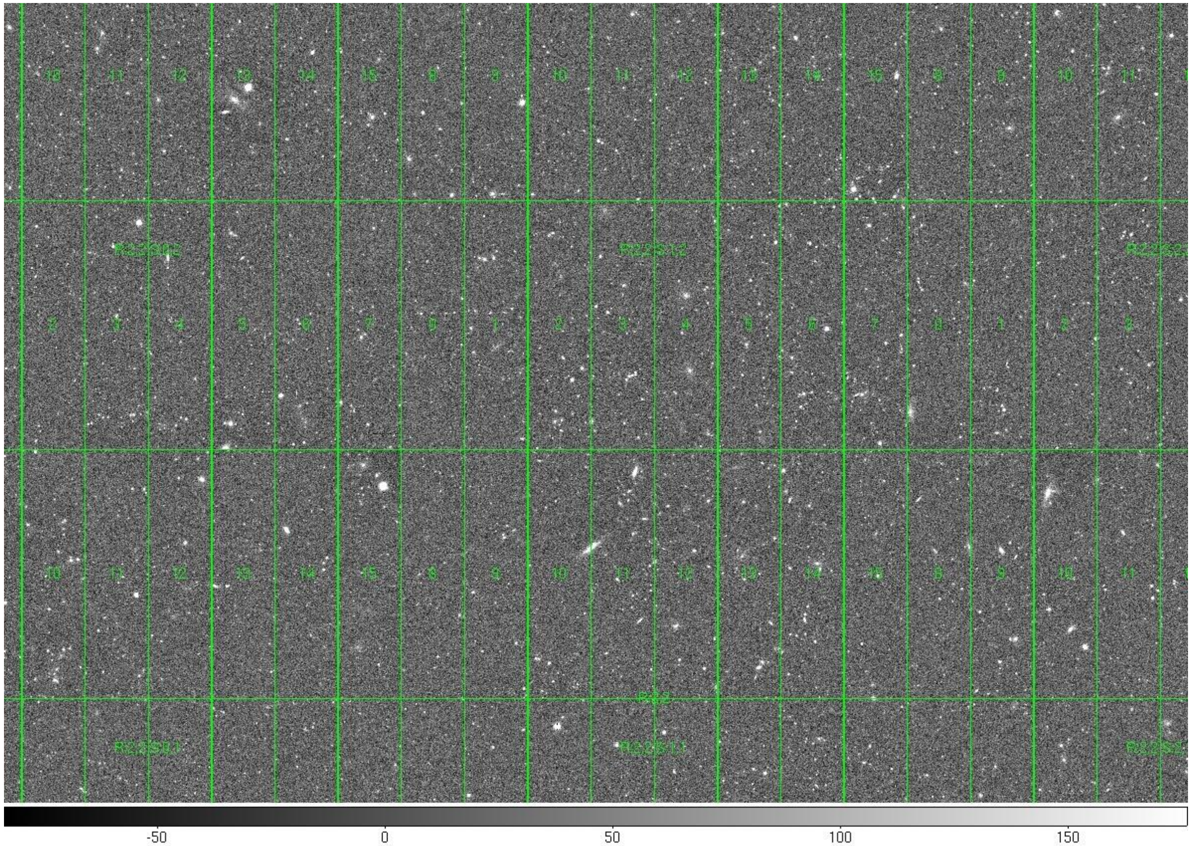
Hickson92

Data Management

- Data from Camera –
  - 3 GigaPixels, 2 Bytes/Pixel = 6GB – every 18 s (no “Trigger”!!!)
  - 1200 GB / hour → 12 TB / observing night (ATLAS ~ 16TB/day)
- However, LSST must do fast alerts to Astronomical Community! Image stream from camera generates real-time transient alerts
  - Difference image based
  - 60s latency, requires ~37 TFLOPS
- Process <u>entire</u> survey data annually to produce a Data Release
  - Self consistent set of data products, all w/same algorithms
  - Full survey depth to SRD requirements
  - 68 PB images in survey year 10, requires ~ 300 TFLOPS
- Produce calibration data products needed by above
  - Support challenging SRD photometry requirements

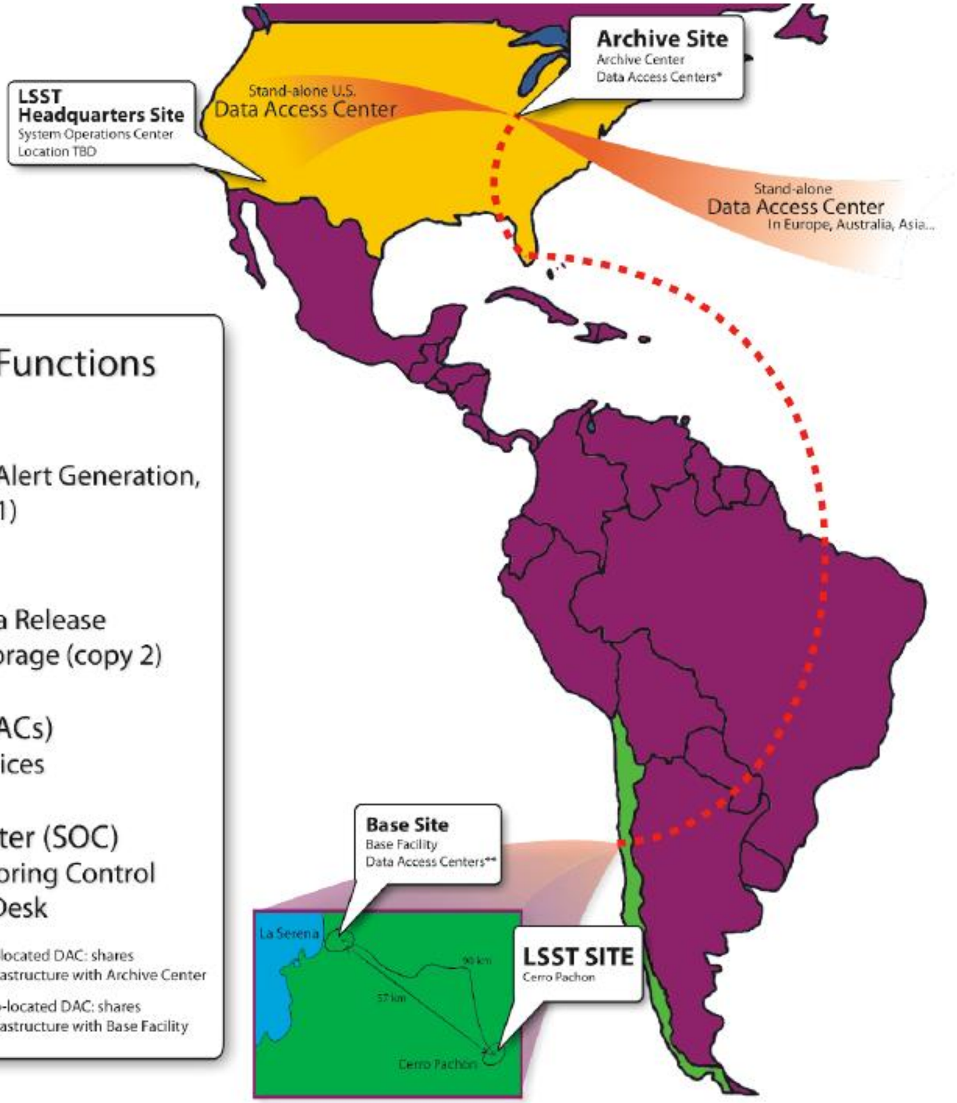
Data Management II

- Make data available to scientists, with enough processing cycles and support to make it useful
  - ~57 TFLOPS, 13 PB storage dedicated for users



Processed from single full Imsim focalplane, binned 4x4, with the markings for the individual amplifiers, ccds.

Data Management World View

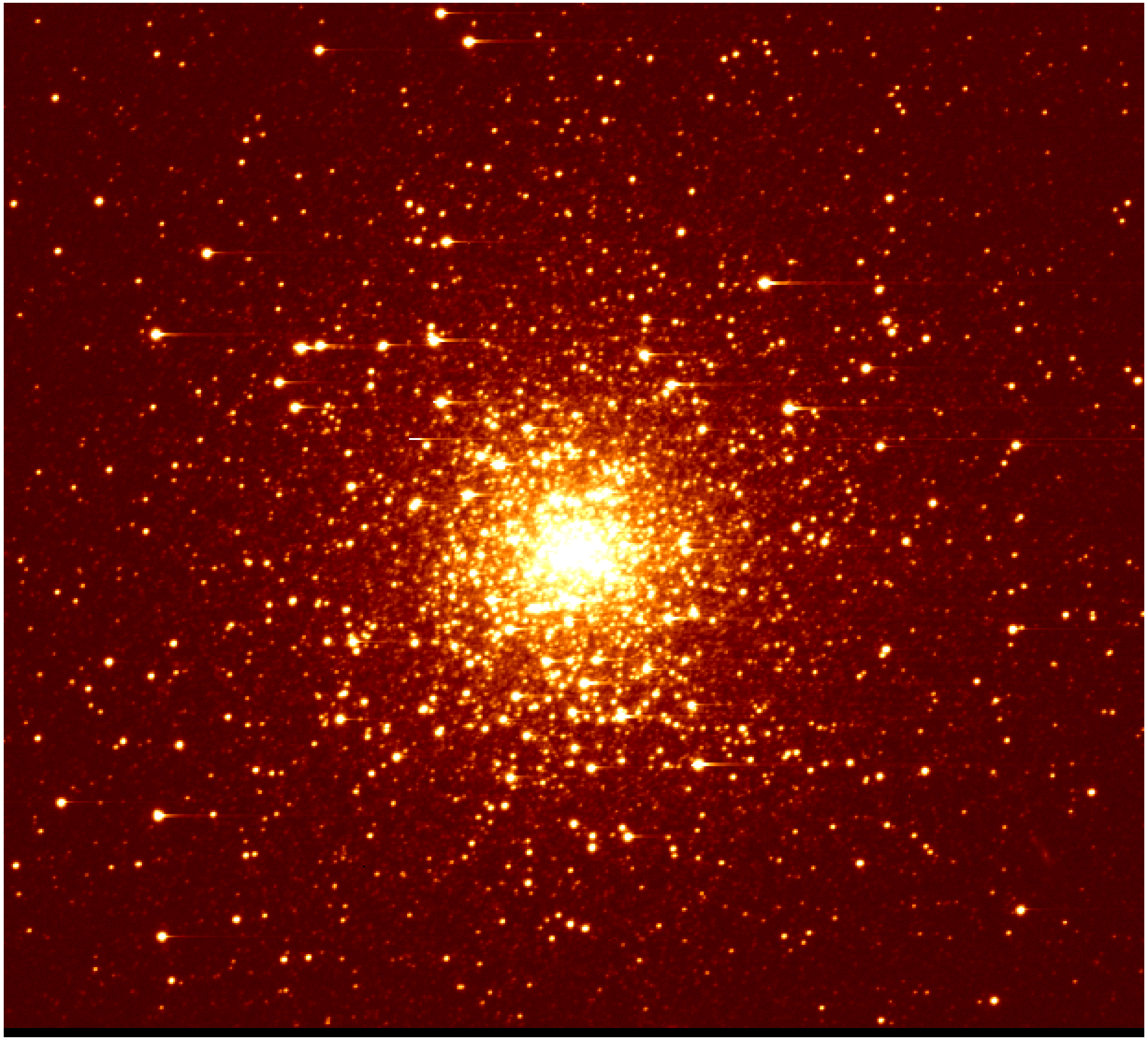


Site Roles and their Functions

- Base Facility
  Real-time Processing and Alert Generation, Long-term storage (copy 1)
- Archive Center
  Nightly Reprocessing, Data Release Processing, Long-term Storage (copy 2)
- Data Access Centers (DACs)
  Data Access and User Services
- System Operations Center (SOC)
  System Supervisory Monitoring Control & End User Support/Help Desk

* Co-located DAC: shares infrastructure with Archive Center

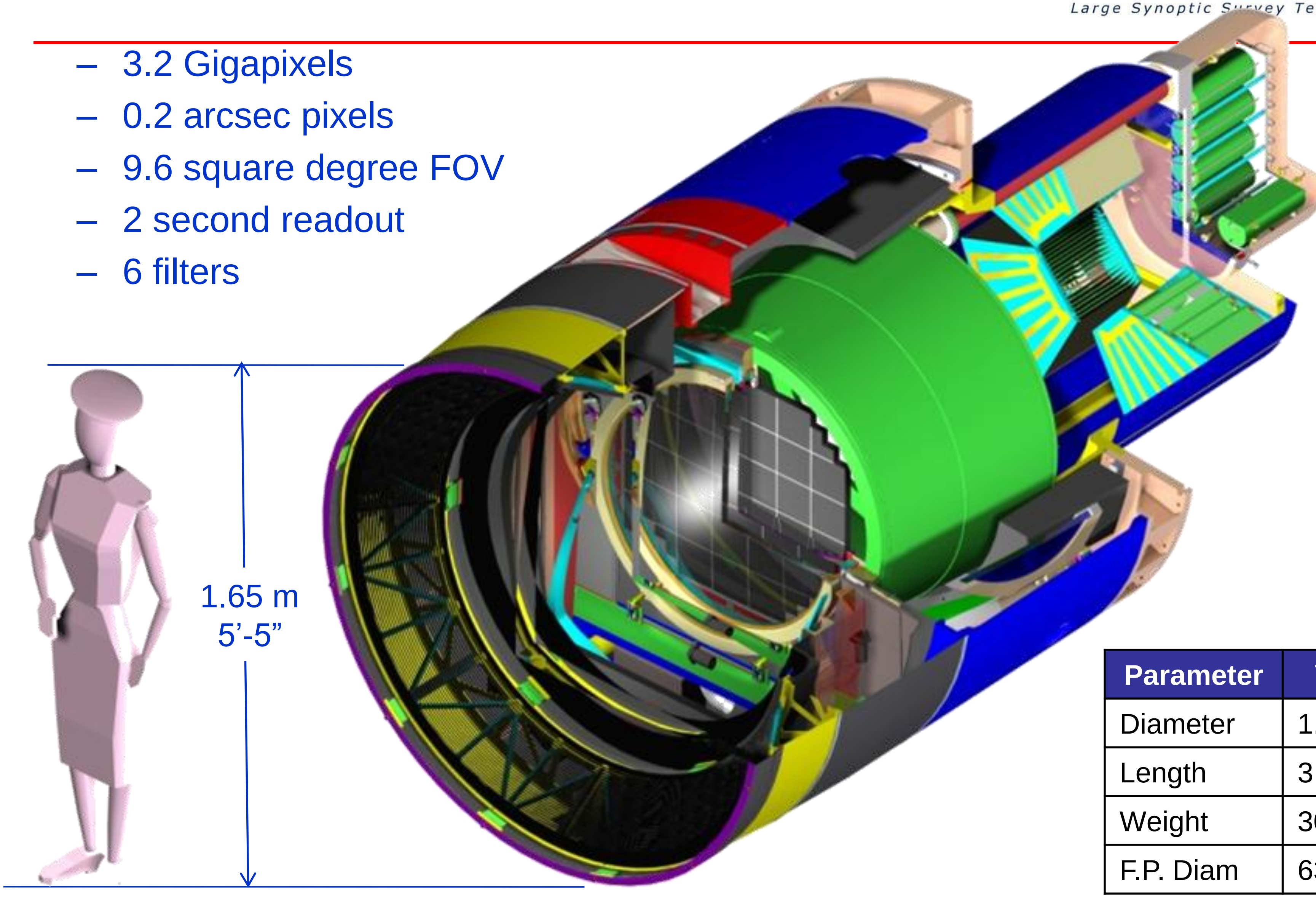
** Co-located DAC: shares infrastructure with Base Facility



M15

The Camera……

- 3.2 Gigapixels
- 0.2 arcsec pixels
- 9.6 square degree FOV
- 2 second readout
- 6 filters

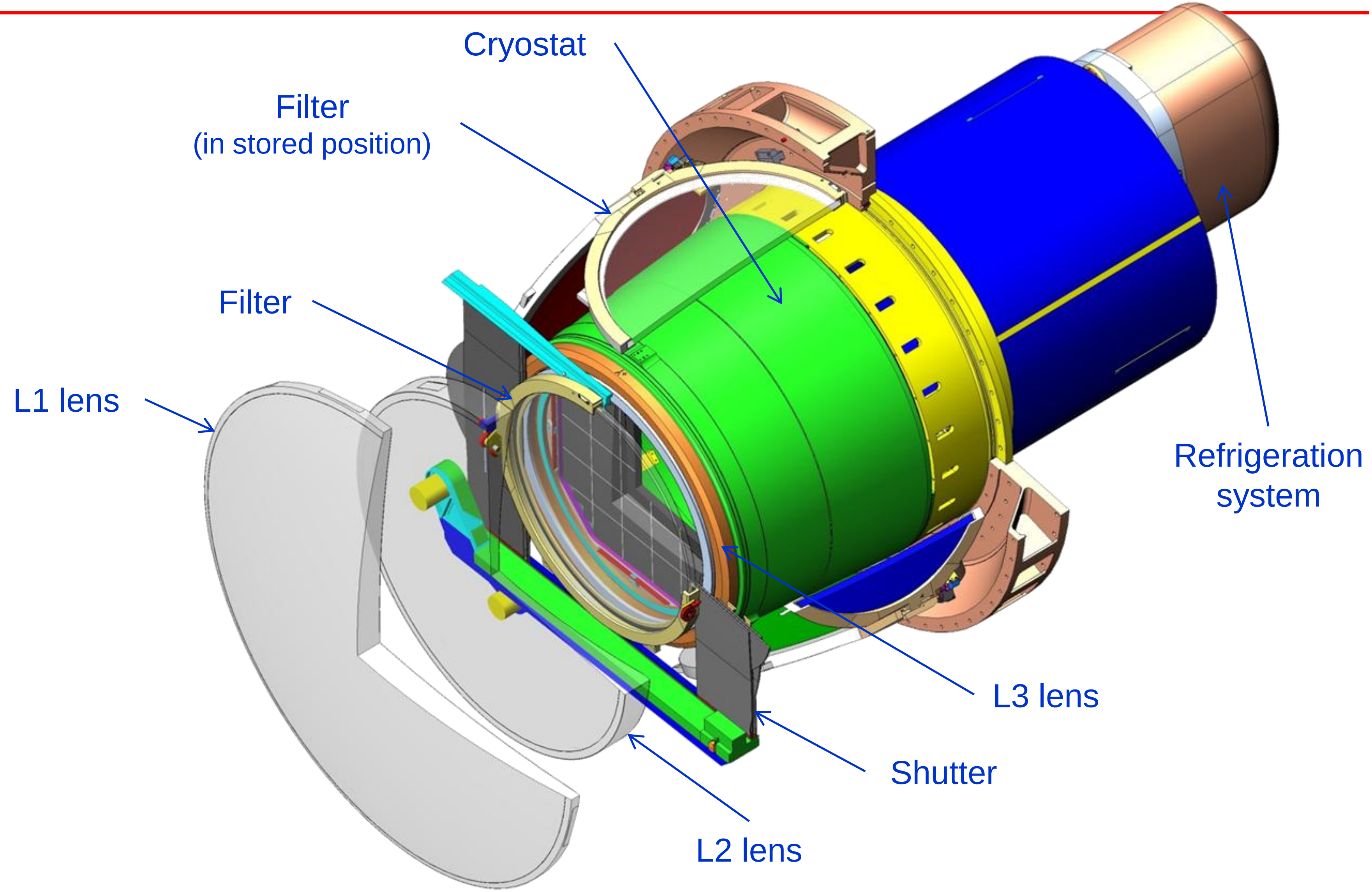


Parameter	Value
Diameter	1.65 m
Length	3.7 m
Weight	3000 kg
F.P. Diam	634 mm

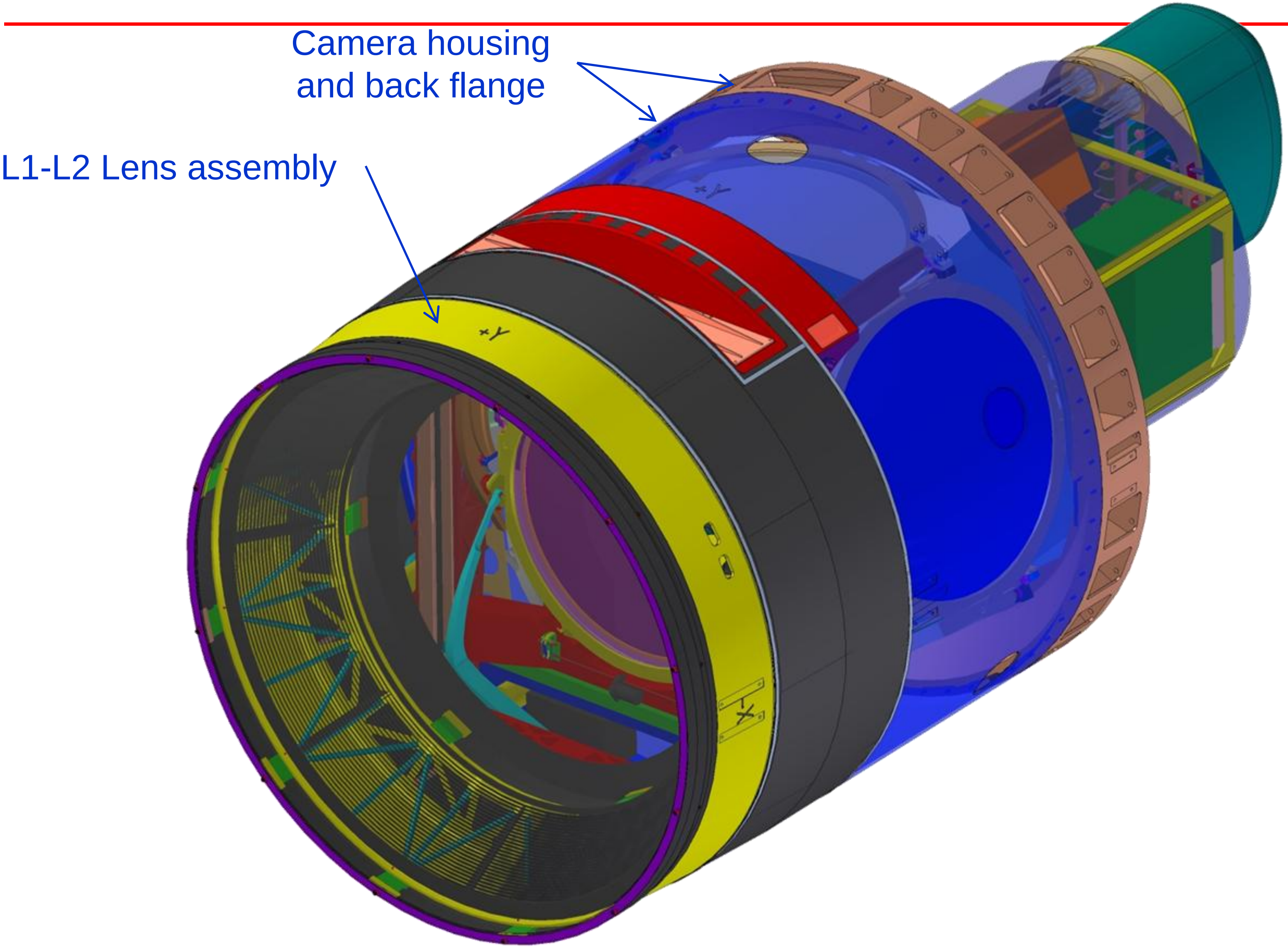
Unique technical challenges drive camera design

- Very large field of view (9.6 square degree FOV) implies a physically large focal plane (64-cm diameter) with small (10 μm) pixels
  ⇒ Mosaic of a large number (189) of sensors with narrow interchip gaps (250 μm)
- Fast f/1.2 beam leads to short depth-of-focus
  ⇒ Tight alignment and flatness tolerances (15 μm p-to-v) on the sensor array
- Broad spectral coverage (350 – 1040nm)
  ⇒ Deep, fully depleted CCDs, but with minimal charge spreading; 6 filters
- Fast readout to maintain high efficiency given the short exposures (3.2 Gigapixels in 2 seconds)
  ⇒ Parallelized design and sensors which are highly segmented (16 readout ports)
- Large number of signal lines and large cryostat & low noise
  ⇒ Electronics must be implemented in the cryostat
- Camera located in the telescope beam
  ⇒ Tight constraints on envelope, mass, & heat dissipation

Integrated complex sub-systems tightly packaged within the telescope's optical constraints

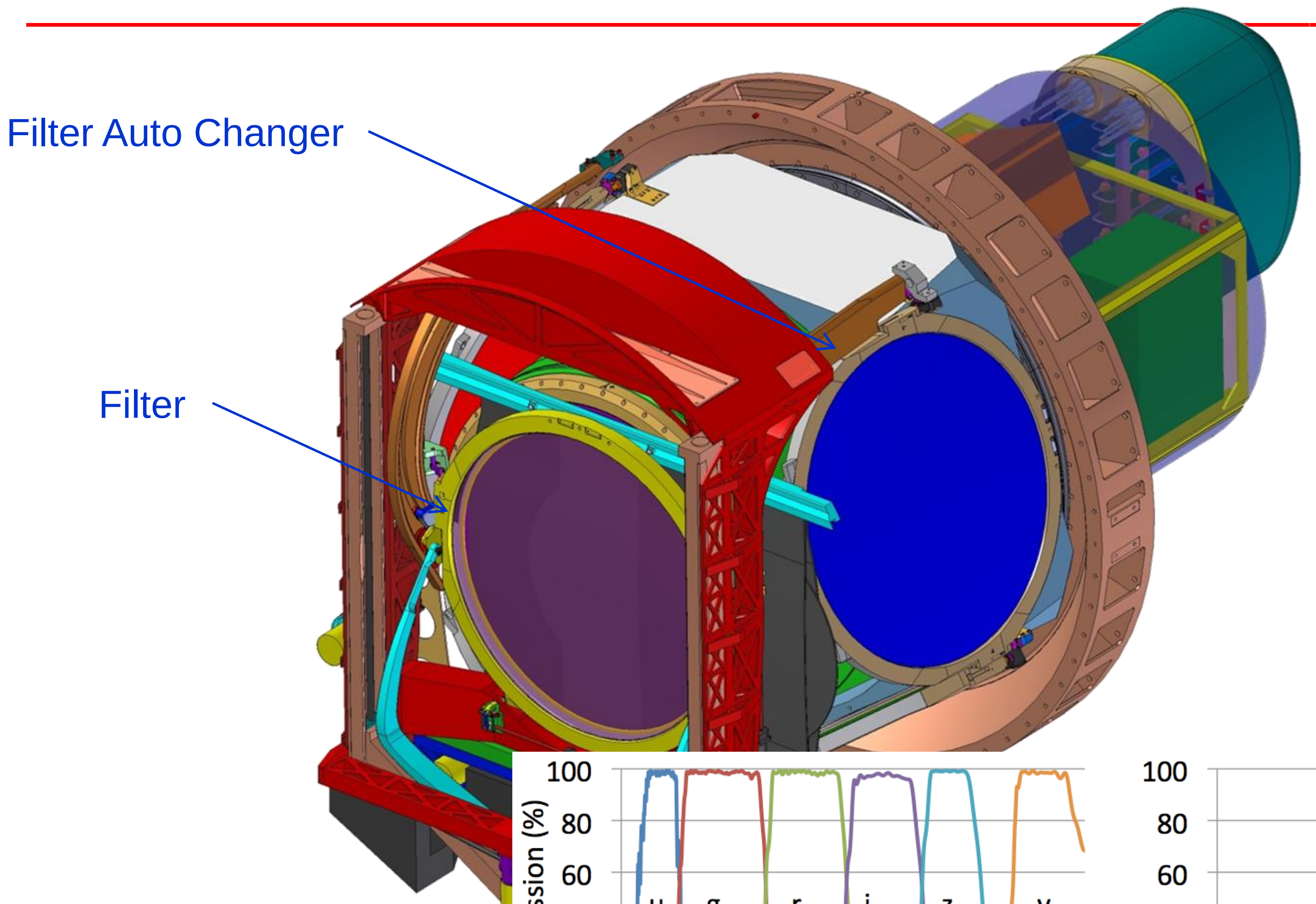


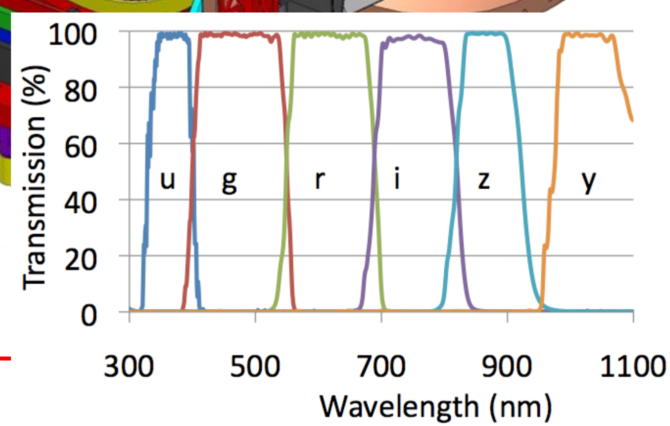
Walk-through 1: Overall view

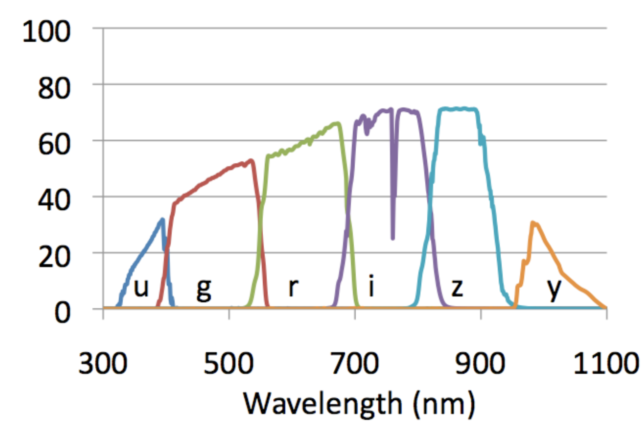


Walkthrough 2: Camera partial assembly showing Auto Changer

Large Synoptic Survey Telescope

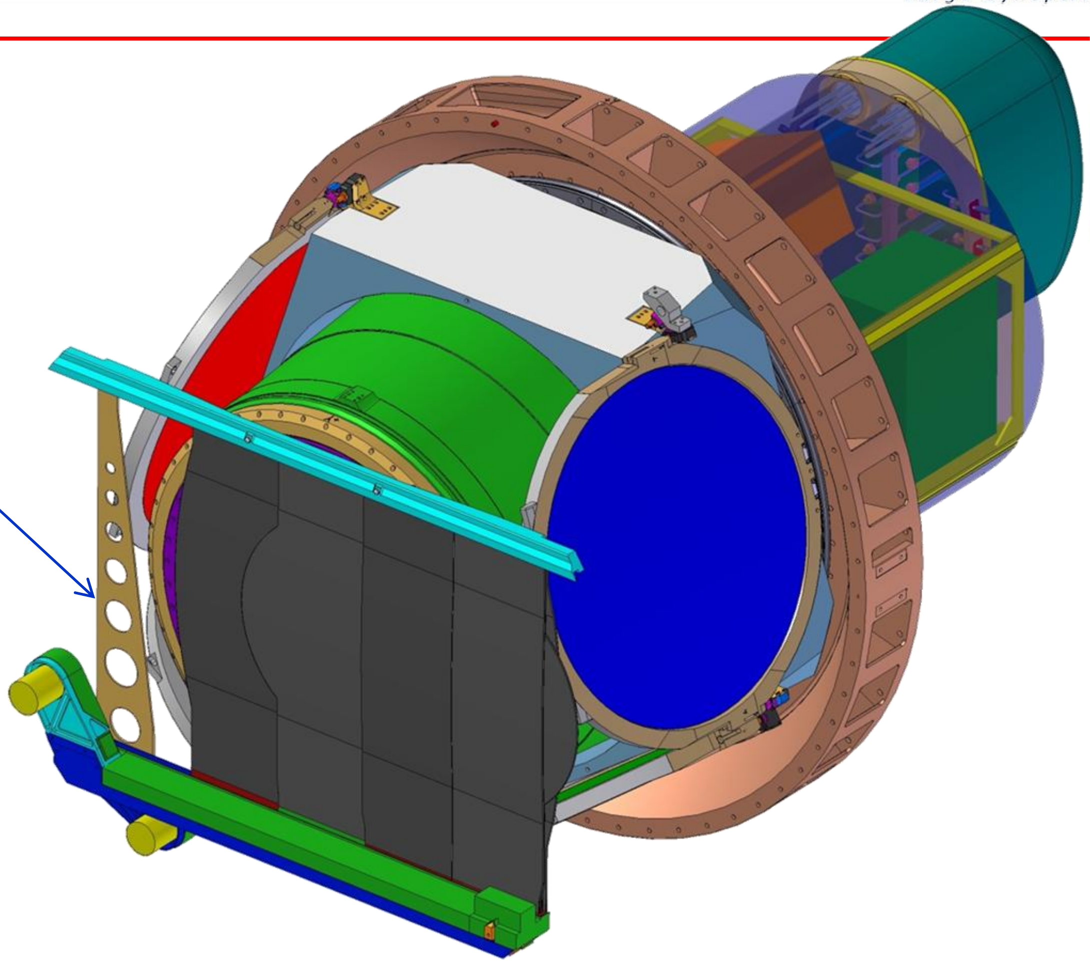




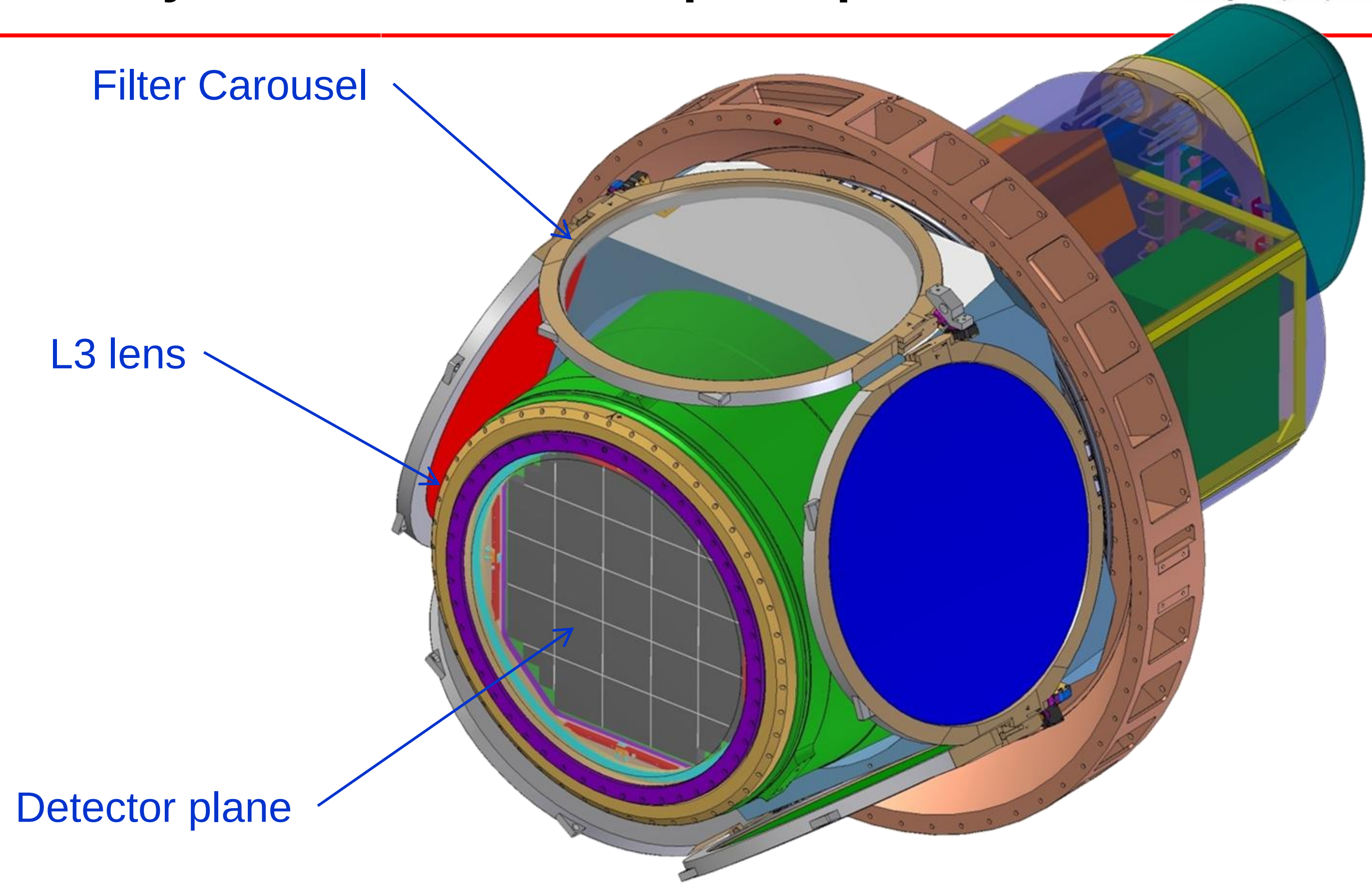


Walkthrough 3: Camera partial assembly showing Shutter

Shutter

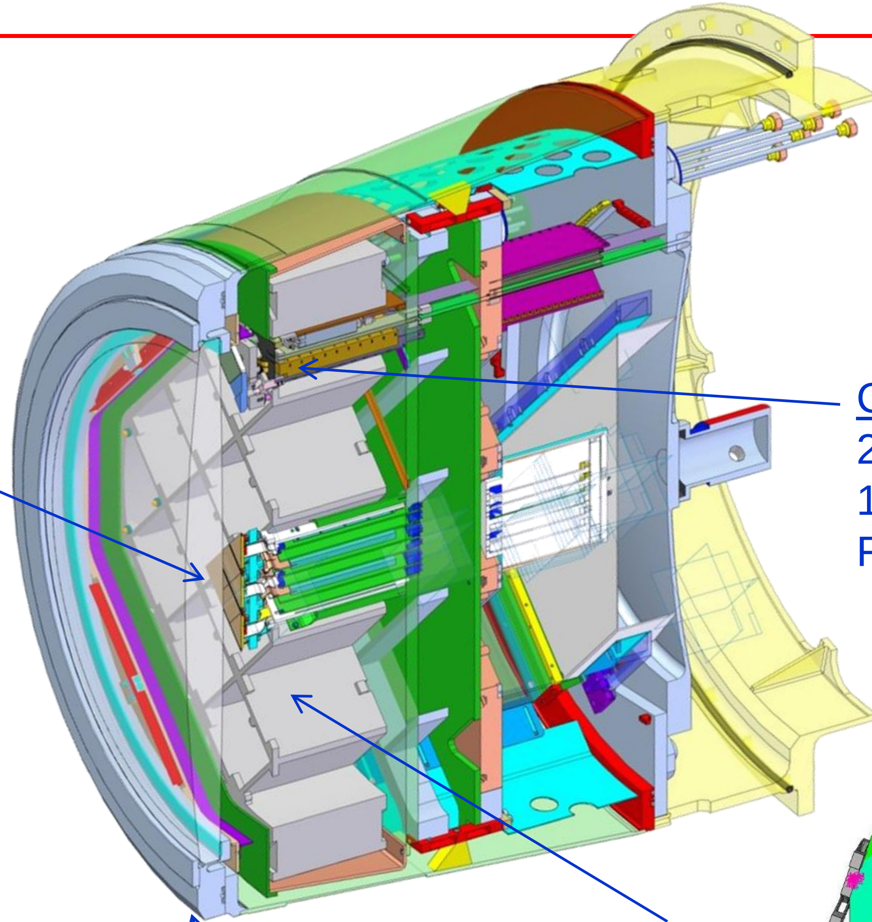


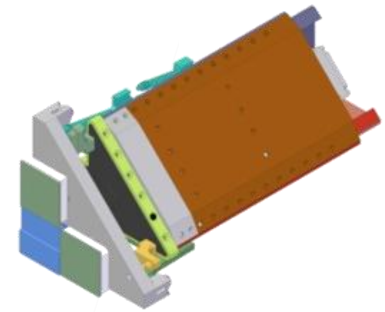
Walkthrough 4: Camera partial assembly showing Carousel, Cryostat, and detector plane past L3 lens



Walkthrough 5: Cryostat section showing detectors, structure and thermal control elements

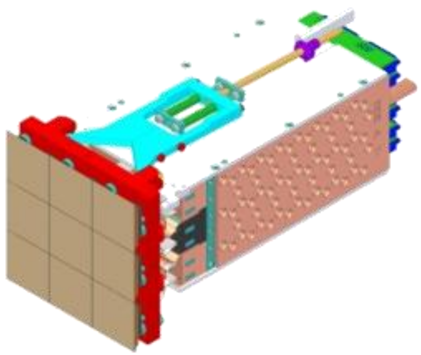
Large Synoptic Survey Telescope

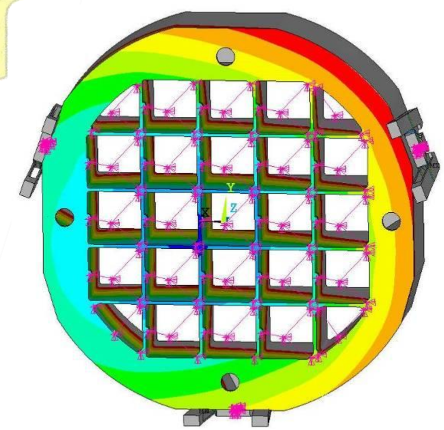




Corner Raft Tower
2 guide sensors
1 wavefront sensor
Front end electronics

Science Raft Tower
3 x 3 array of science sensors
Front end electronics





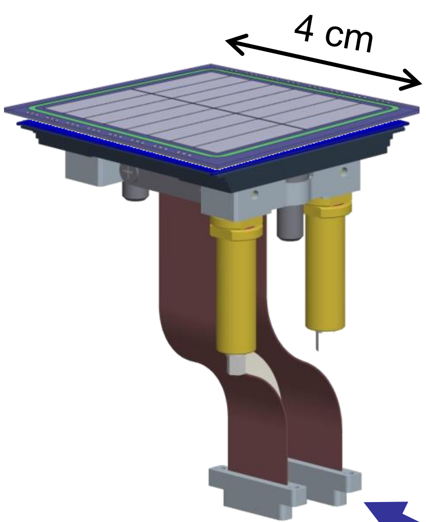
Grid assembly
Cesic ®

L3 lens assembly

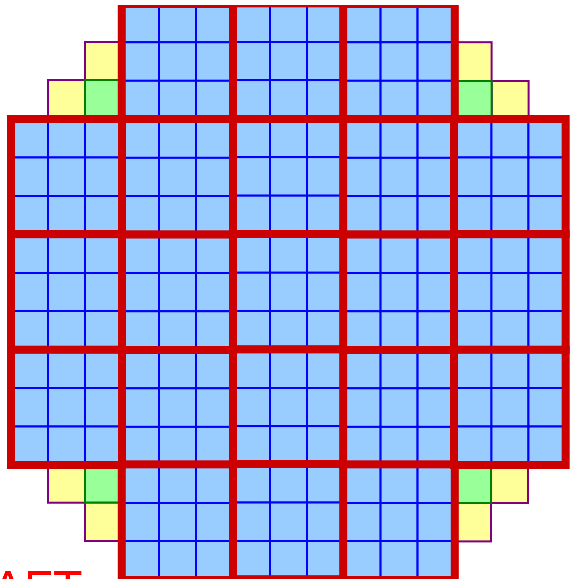
The Sensors subsystem consists of the 21 “science rafts” that make up the 3.2Gpix focal plane

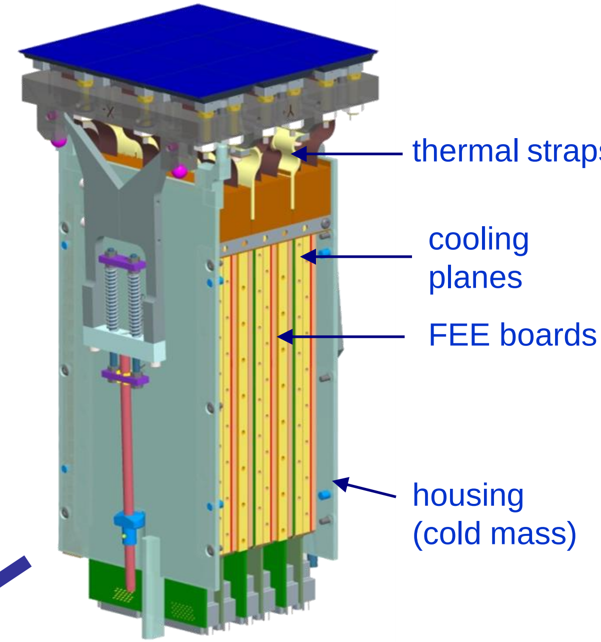
4K x 4K CCD

10µm pixels, .2 arc sec
extended red response
16 outputs
5µm flatness
Back-side illuminated



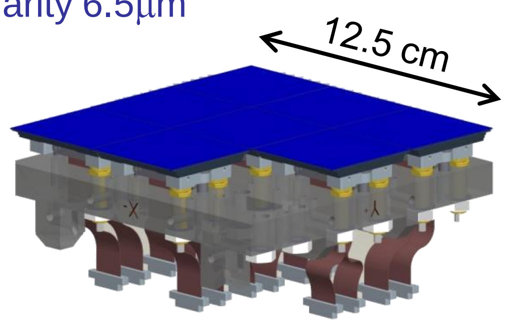
FOCAL PLANE WITH 21 SCIENCE RAFTS + 4 CORNER RAFTS





RAFT

9 CCDs
coplanarity 6.5µm



TOWER

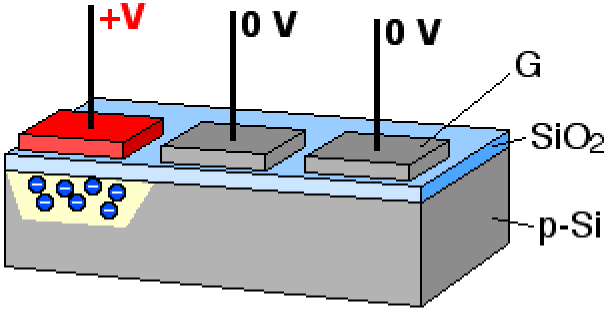
CCDs + front end electronics
180K operation
An autonomous, fully-testable and serviceable 144 Mpixel camera

M1

CCDs

Large Synoptic Survey Telescope

- Charge Coupled Devices –
  - Willard Boyle, George Smith (invented 1969, Nobel 2009)
- Areal array –
  - “parallel shifts” – data to output register (2k)
  - “serial shifts” – data to electronics (512)



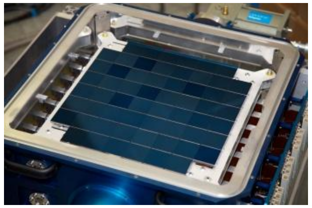
CCD Challenges

Large field of view implies physically large focal plane (64cm Φ)	Modular mosaic focal plane construction	21 rafts × 9 4K CCDs/raft 189 CCDs total 3.1Gpix
Fast f/1.2 beam, shallow depth of focus	Tight alignment and flatness tolerance	Flatness: 5μm Alignment (z axis): 10μm
Plate scale 20”/mm	Small pixels, close butting	Pixel: 10μm Chip-chip gap: 250μm
Fast readout (2s) with low noise (5 e^-)	Highly parallel readout electronics	16 amplifiers/4K CCD
Broadband, high spectral sensitivity	Thick silicon sensor, back illuminated, AR coat	100μm thickness for IR sensitivity Thin conductive window
Seeing-limited image quality	Internal electric field to minimize diffusion	High resistivity, biased silicon (> 3 kΩ-cm, -50V)

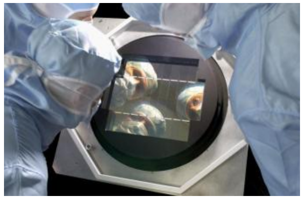
LSST's high throughput goals

- The largest focal plane
  - LSST: 3.2Gpix (189 CCDs)
  - PanSTARRS GPC1: 1.4Gpix (60 CCDs)
  - HyperSuprimeCam: 940Mpix (112 CCDs)
  - DECam: 500Mpix (60 CCDs)
  - CFHT MegaCam: 340Mpix (36 CCDs)
- The fastest focal ratio
  - LSST: f/1.23
  - SuprimeCam: f/1.87
  - DECam: f/2.7
  - PanSTARRS: f/4
  - CFHT MegaCam: f/4.2
- The fastest readout time
  - LSST: 2s
  - PanSTARRS GPC1: 6s
  - DECam: 17s
  - CFHT MegaCam: 40s
  - Suprime-Cam: 18s

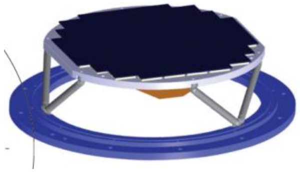
LSST



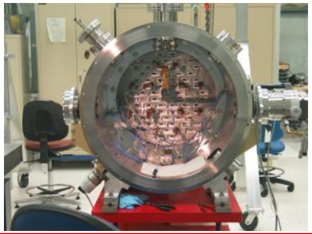
GPC1



MegaCam

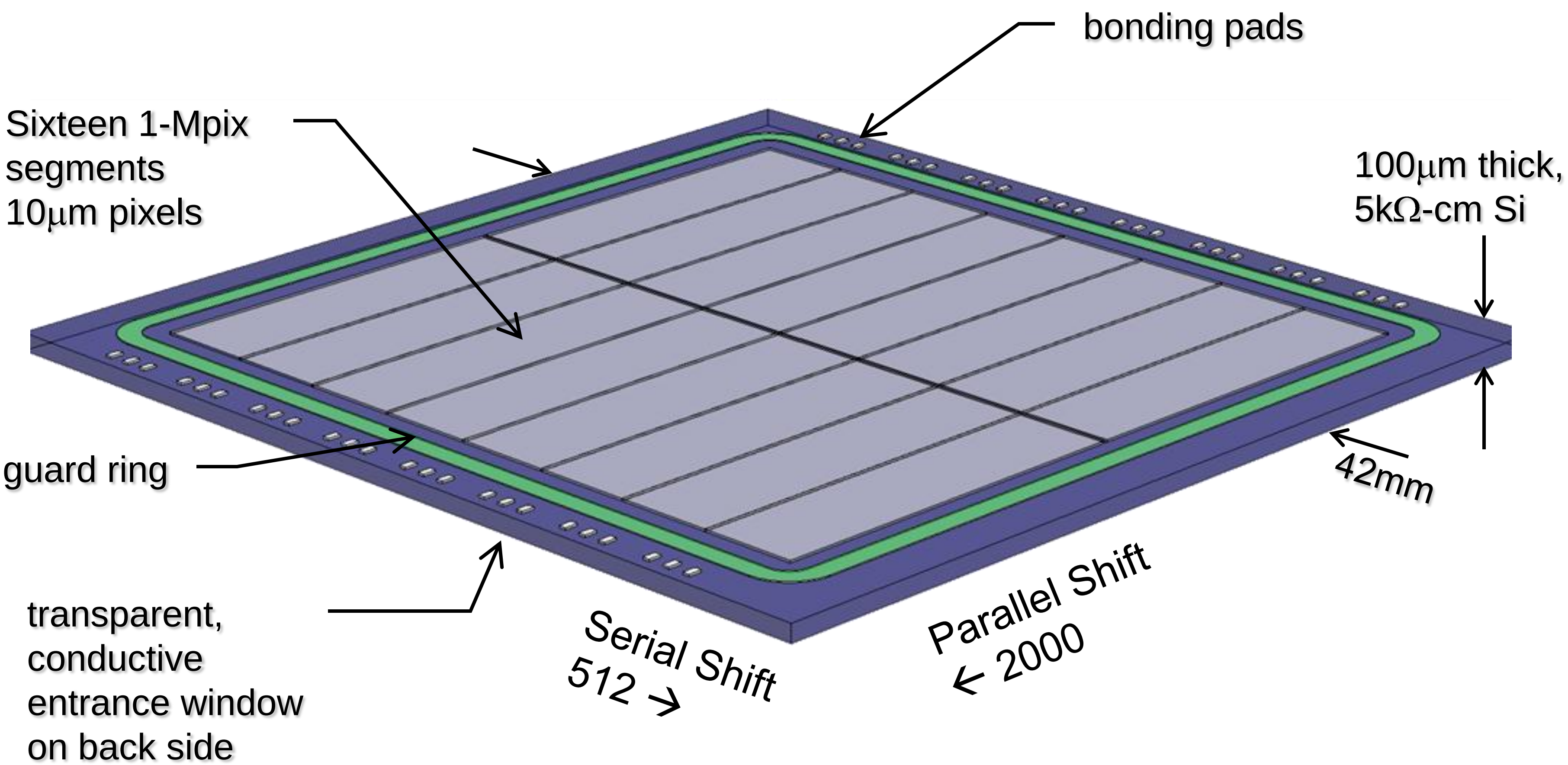


HSC

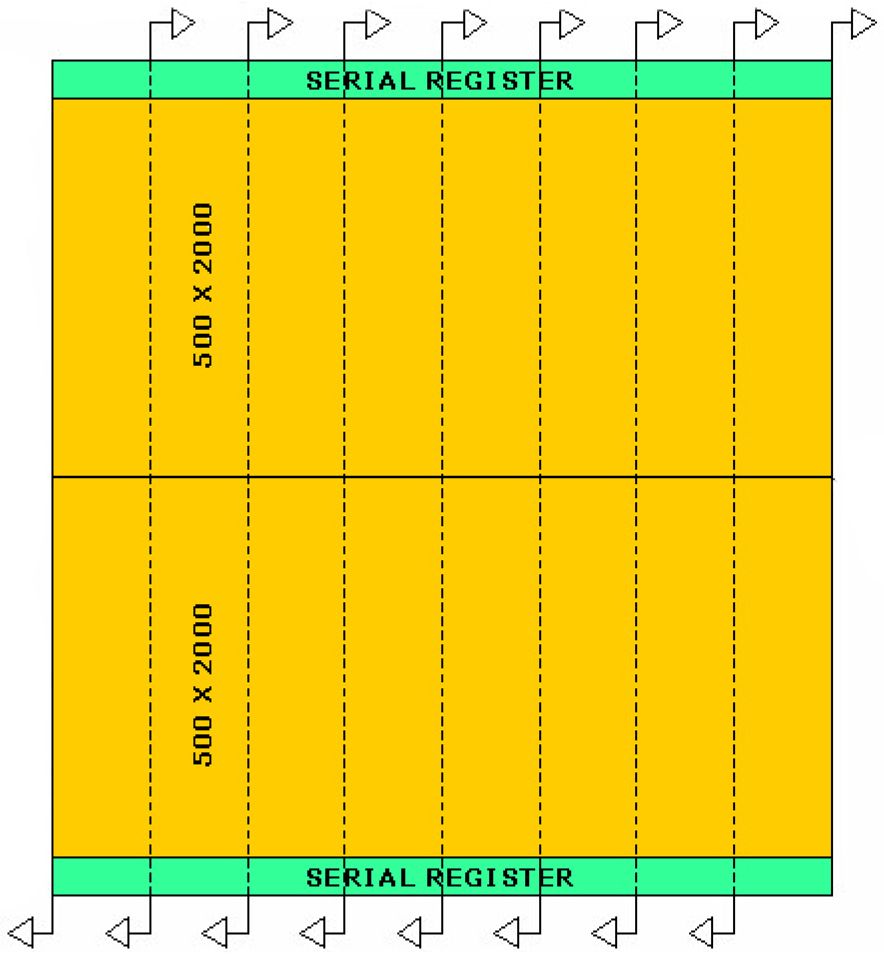


DECam

The 4K x 4K LSST sensor reference design



LSST CCD Layout



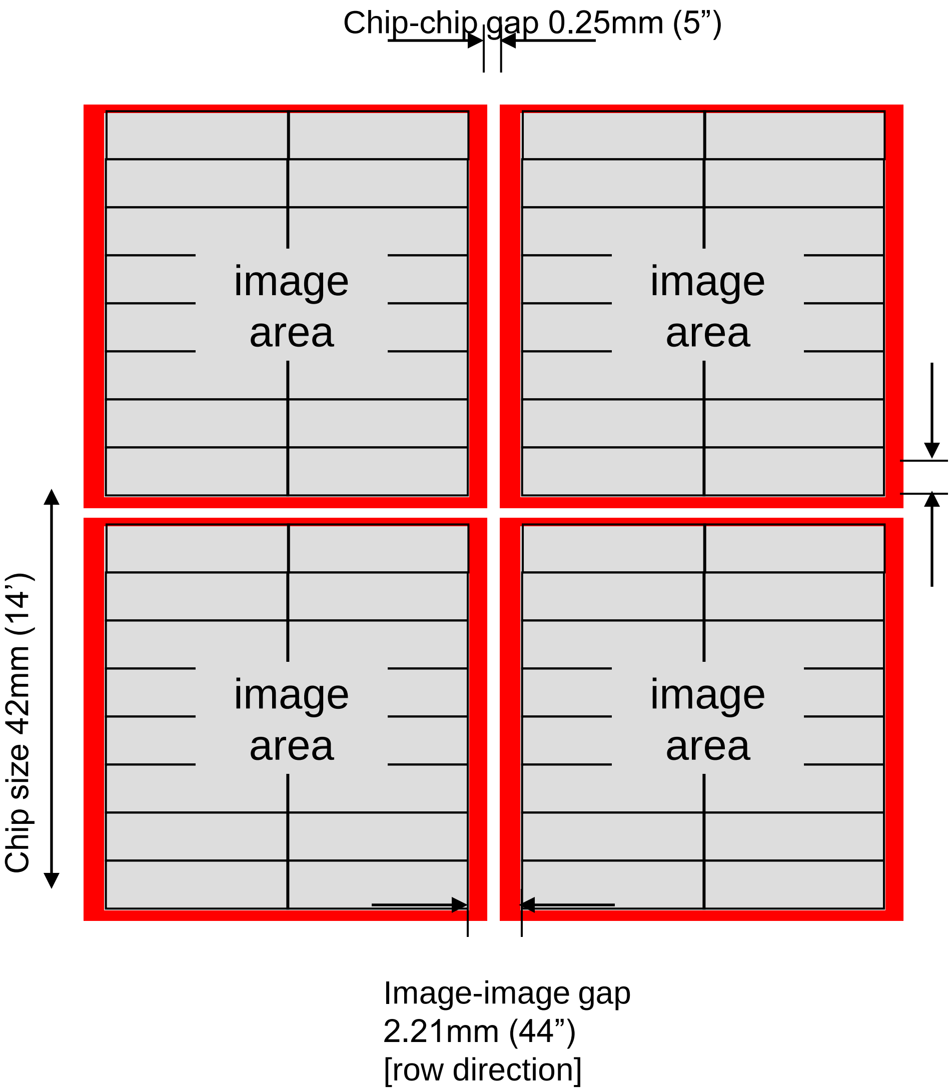
New technology needed for LSST sensors

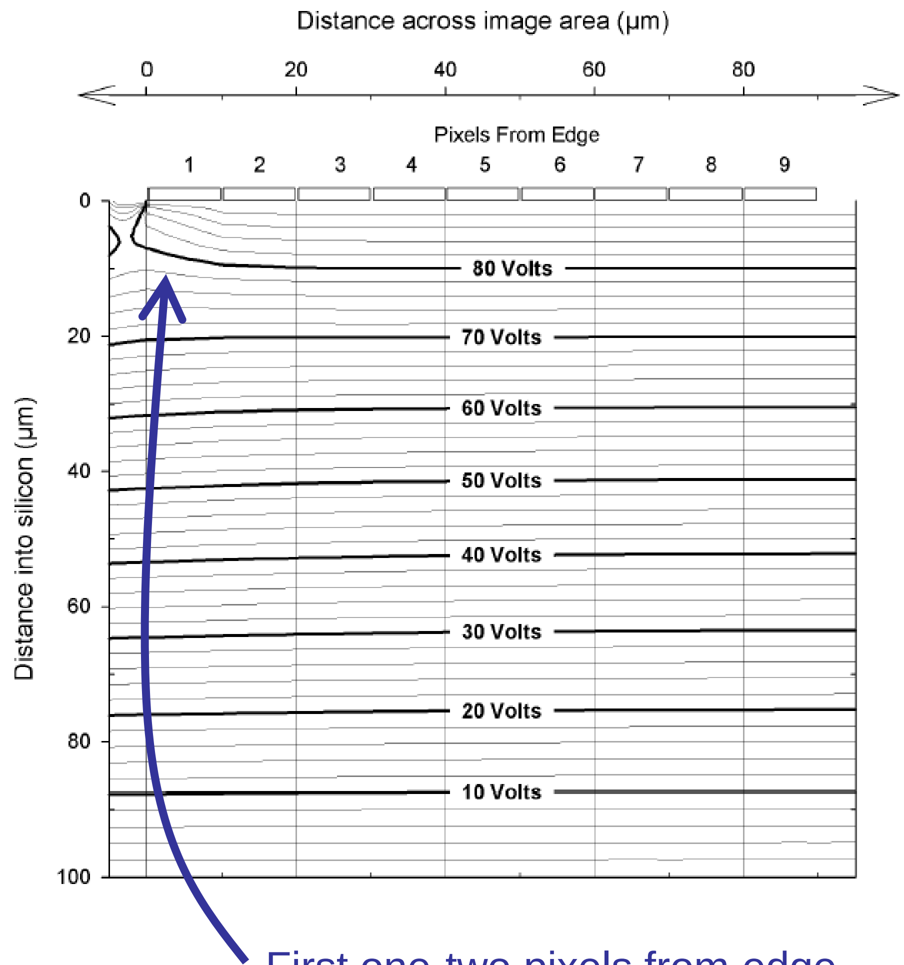
Large Synoptic Survey Telescope

Thick, high-ρ bulk Si	100μm, > 3kΩ-cm
Highly transmissive, biased window	<<10nm, -50V
Flat Si surface	5μm peak-valley
Package dimensional control	|| optic axis: 1.5μm $\perp$ optic axis: 5μm Chip-chip gap 250μm Thermally stable
Parallel, multiport readout	16 amplifiers
Low-noise outputs	< 6e^- at 500kHz
Reproducible and high yield	No individual device tuning

semiconductor *mechanics* *amplifiers* *production*

Edge effects



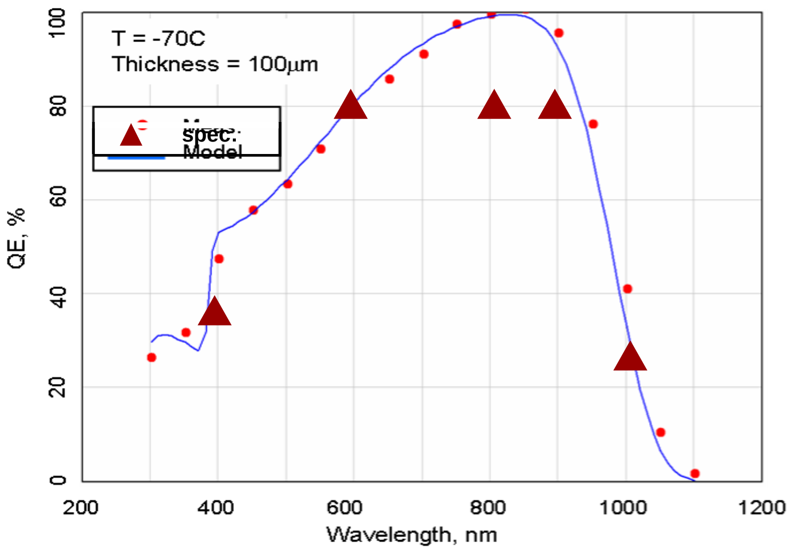


First one-two pixels from edge will have larger effective area due to field distortion

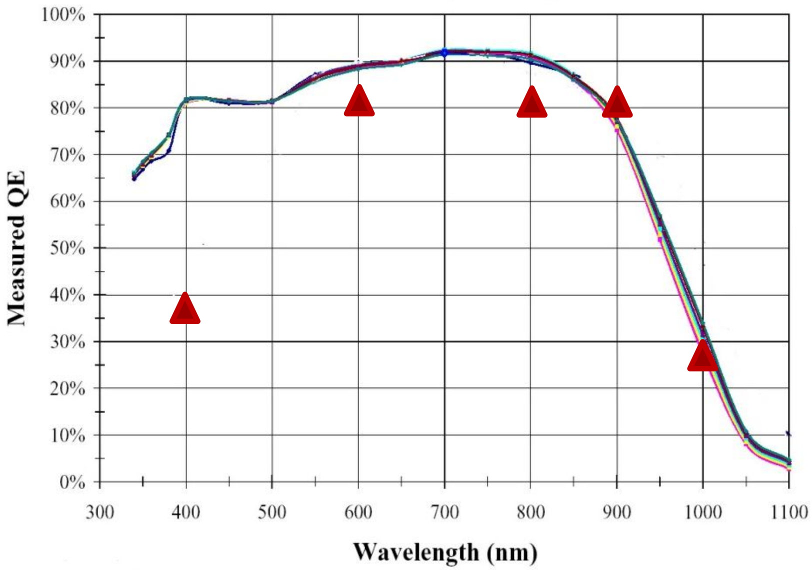
Phase 1 device tests -- laboratory

Quantum efficiency

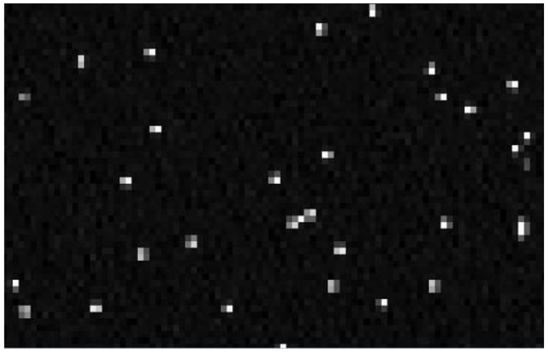
e2v

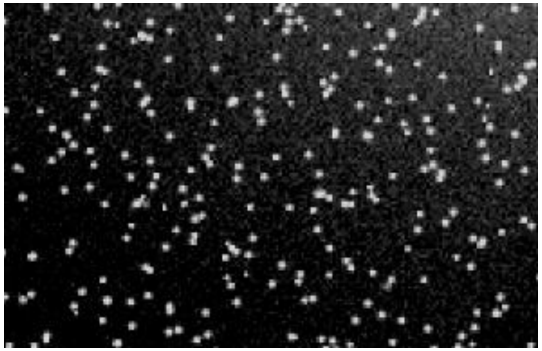


STA/ITL



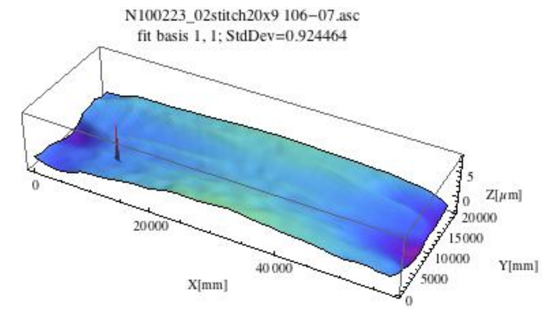
Charge diffusion (xray PSF)

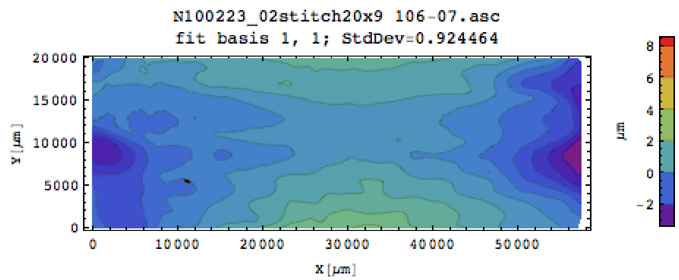


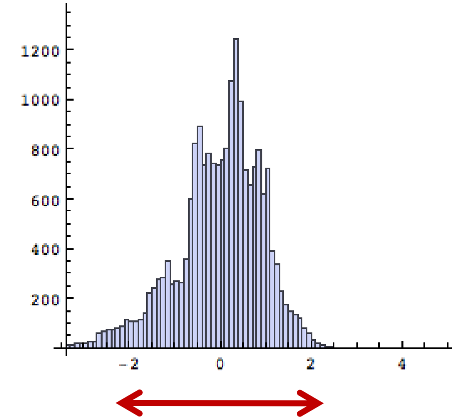


Phase 1 sensor flatness

e2v

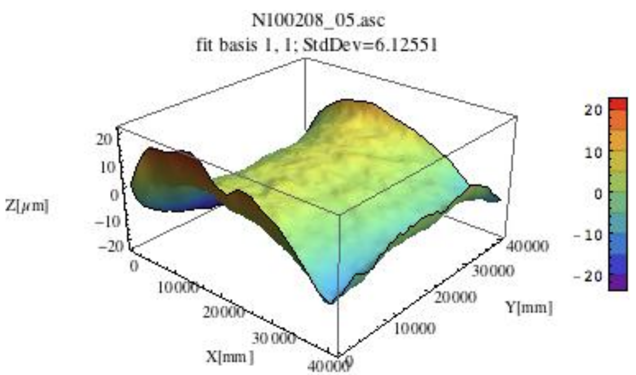


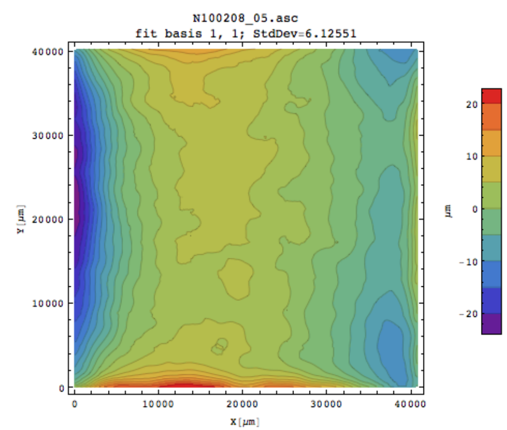


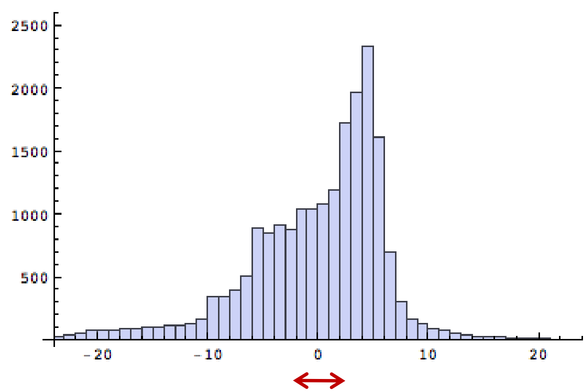


spec

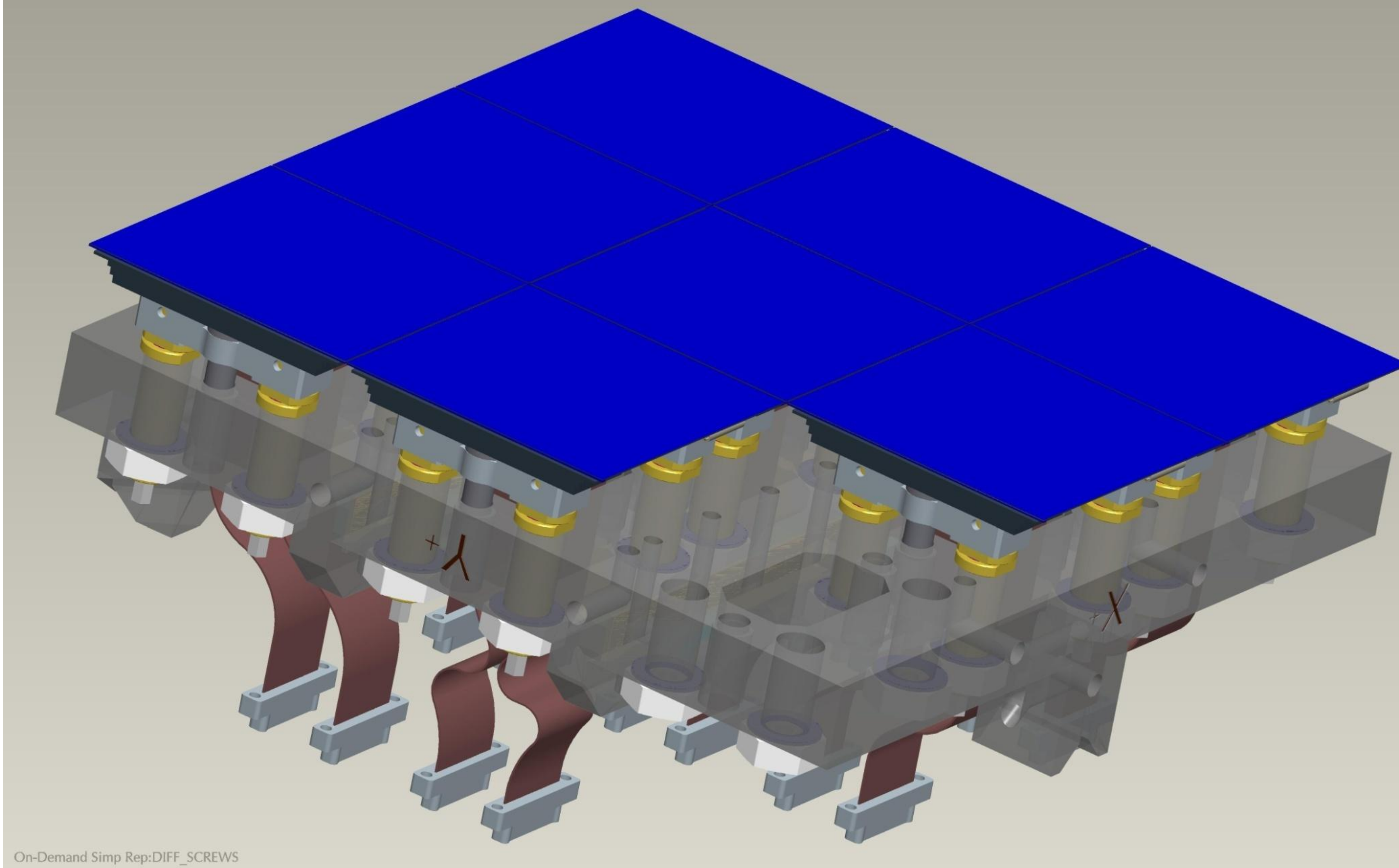
ITL



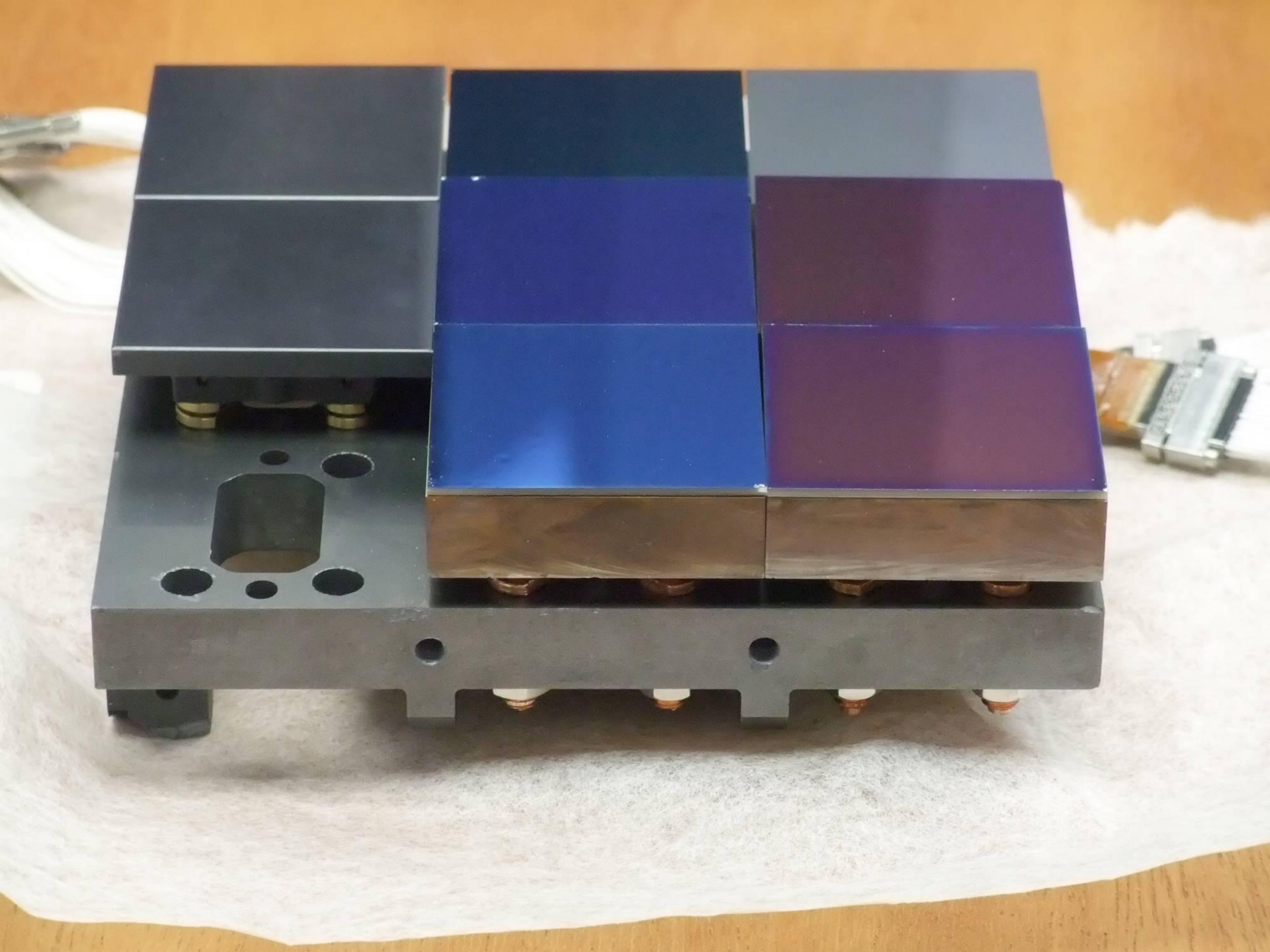




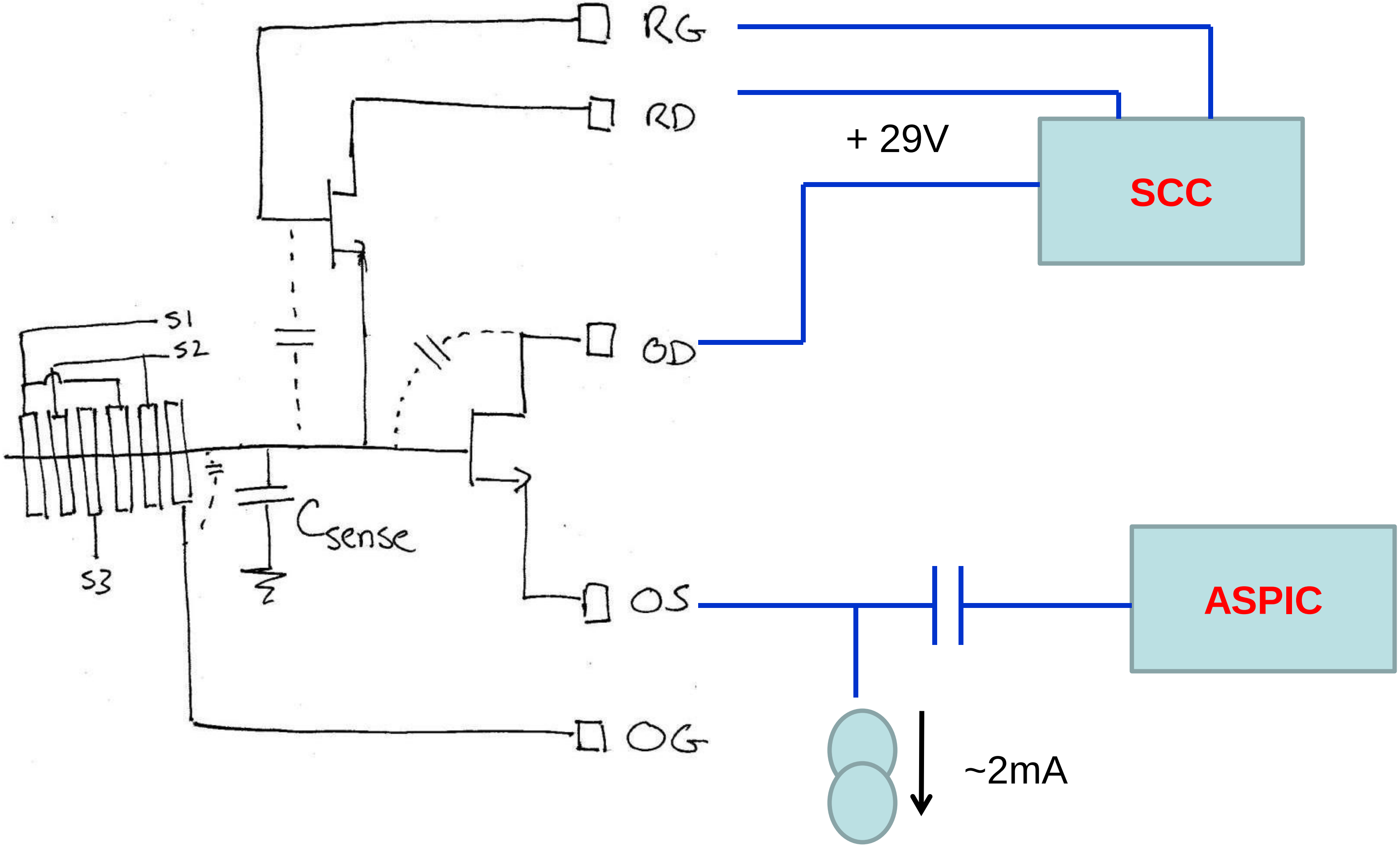
measurements by P. Takacs, BNL



On-Demand Simp Rep:DIFF_SCREWS



A CCD Electrically…..

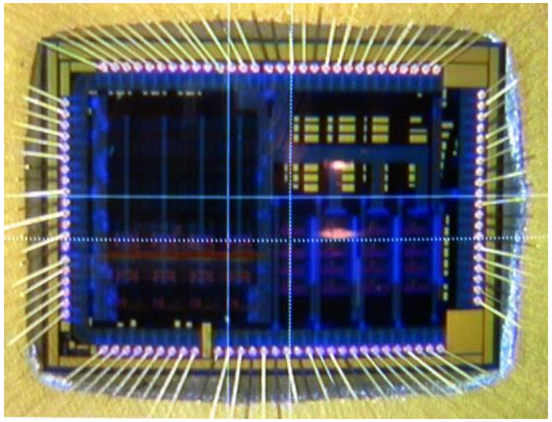


NGC891

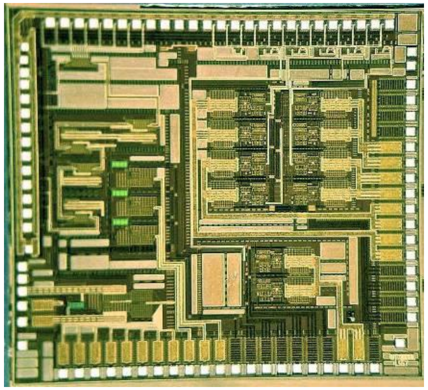
Highly integrated, in-cryostat electronics

- Total of 3.024Gpix in focal plane
- Goal is 2s readout with 6e- noise
- CCD readout rate must be below ~600kHz to achieve noise figure
  → CCDs must be segmented into 1-Mpix segments with individual readout amplifiers
- Choose 4Kx4K CCD format with 16 2048 x 512 pixel segments
  – Total wire count to CCDs ~15,000
- Impractical to take this many wires through vacuum barrier
  →Implement compact (ASIC-based) electronics chain in cryostat

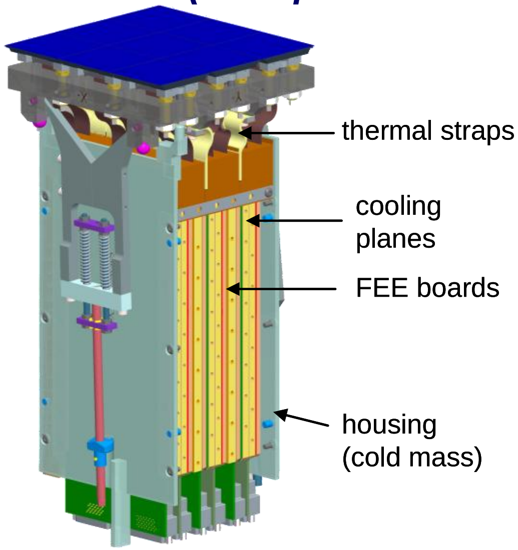
ASPIC ***(video processing)***



SCC ***(clock/bias generation)***



TOWER ***(144Mpix FPA module)***



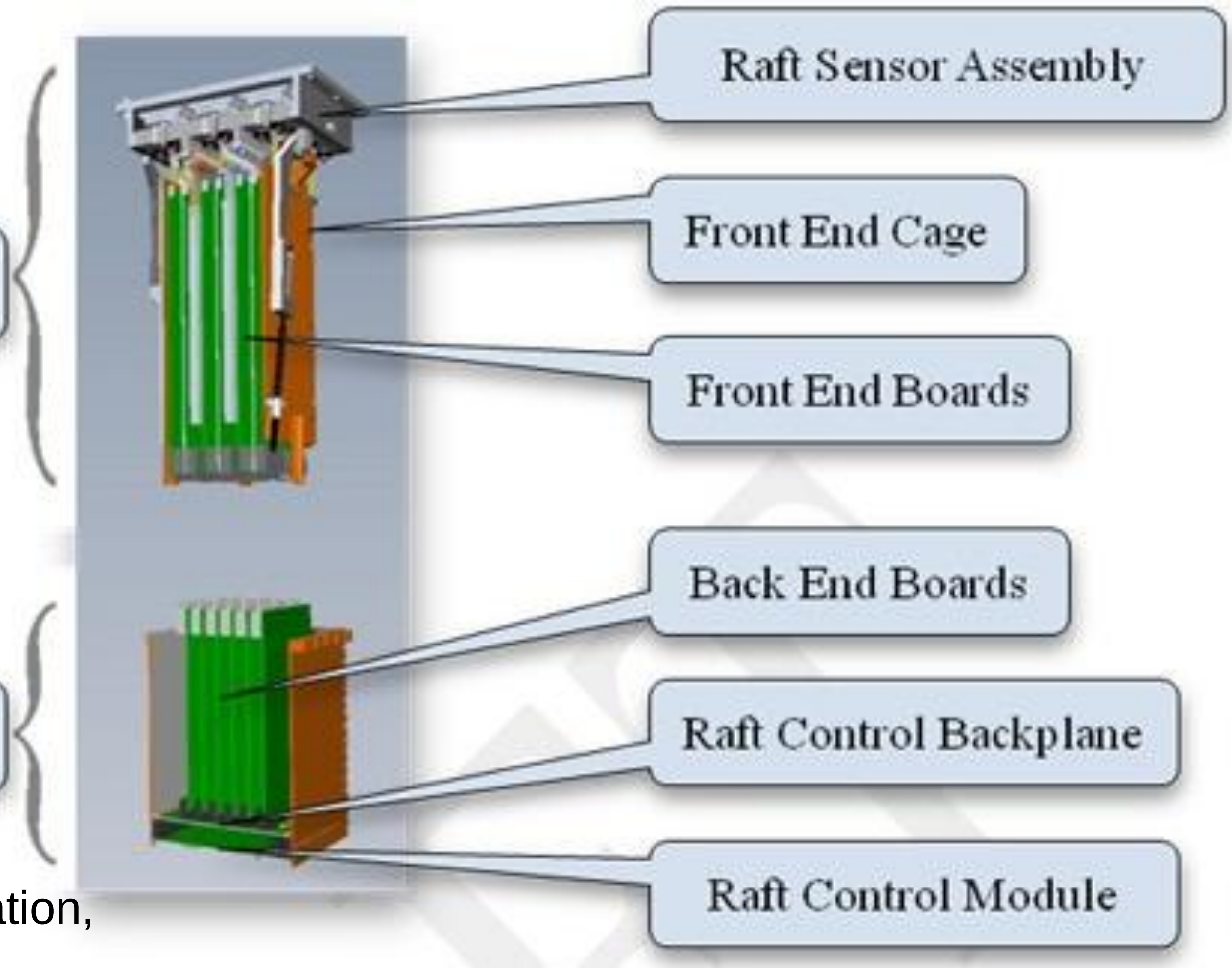
Raft-Centric Electronics System

Sensor Head Assembly

Sensors + Analog Processing + Clock and Bias drive
-100C

Raft Control Crate

Digitization, digital muxing, power regulation, clock generation, etc.
-40C

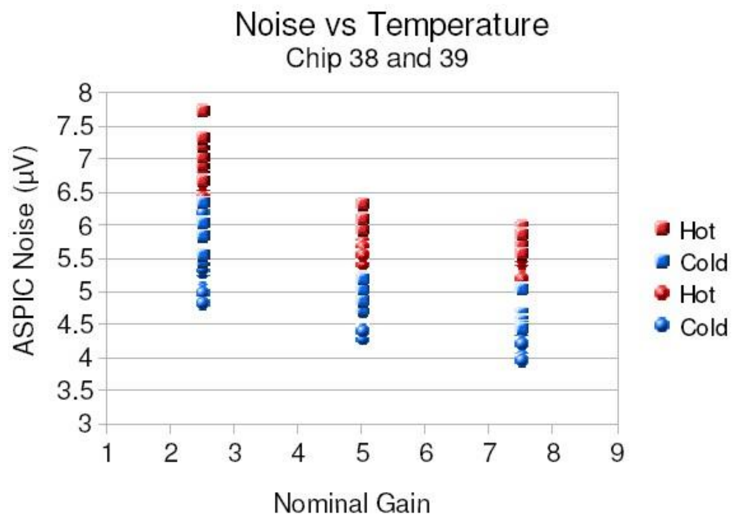


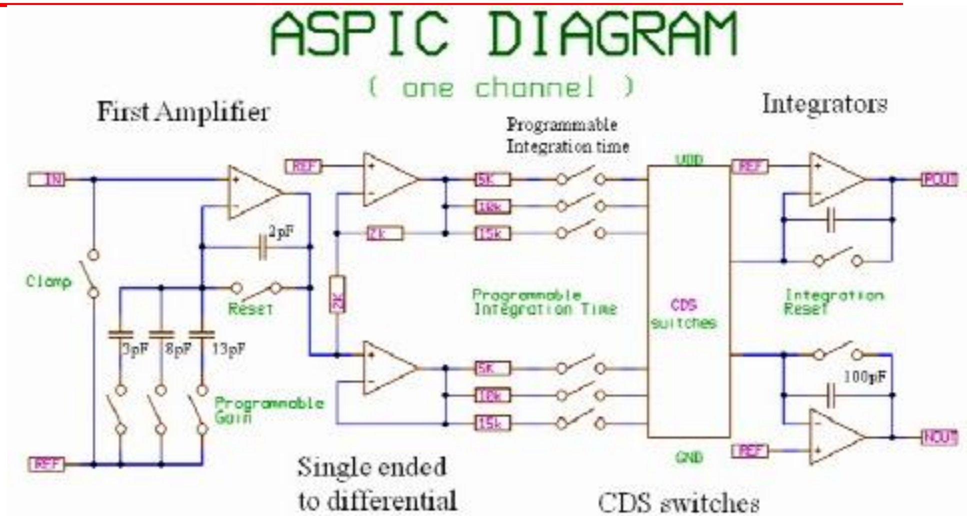
ASPIC Specifications – IN2P3*
(Analog Signal Processing Integrated Circuit)

- Operates at a temperature of 173K
- Noise :
  - en < 5nV/sqrt(Hz) maximum noise density
  - enc < 7µVrms maximum input noise @ 500ns integration time (~2e¯)
  - Note : Either or both of the above may be met. If, for example, at very long integration time, en will rise but enc will fall, and still be an advantage.
- Operation @ 250kHz to 500kHz
- 0.05% maximum crosstalk between channels @ 500kHz
- 100k e¯ full well capacity (350 to 400 mV maximum input)
- 0.5% linearity (defined over 0 to 100k e¯)
- Differential output
- Output load 50pF // 1k
- Power supply 5V / Gnd - reference Vref = 2.5V
- Power dissipation 25mW / channel
- The ASPIC is designed in 0.35µm 5V CMOS technology from AMS.

* With some help from Mitch and John Oliver

ASPIC – Correlated Double Sampler / Dual Slope Integrator





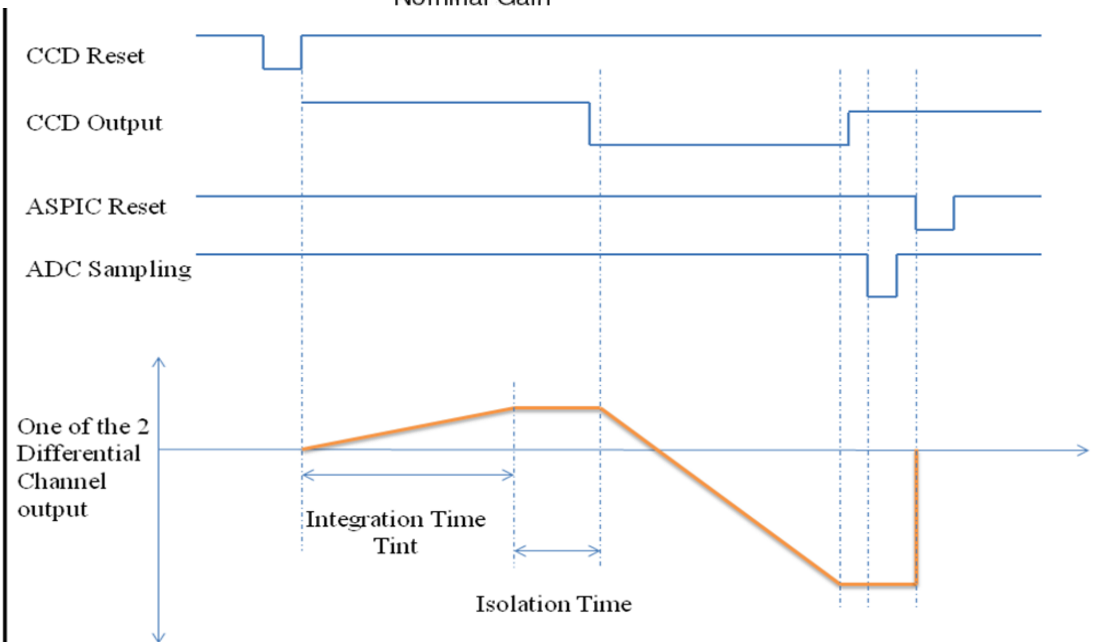
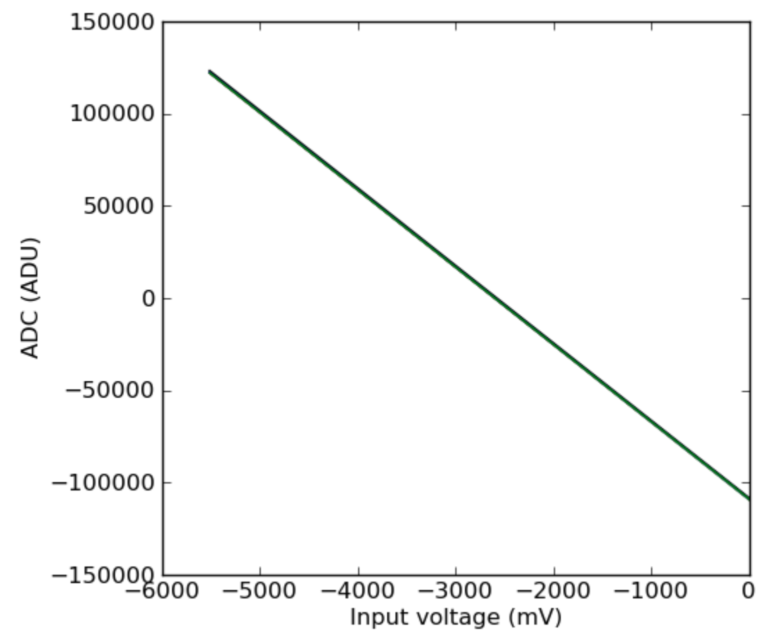
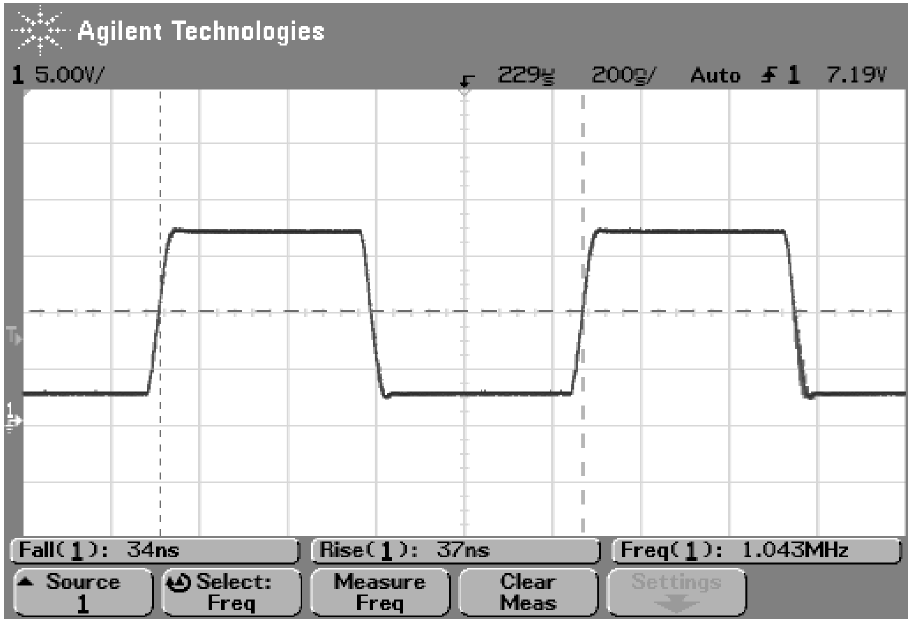


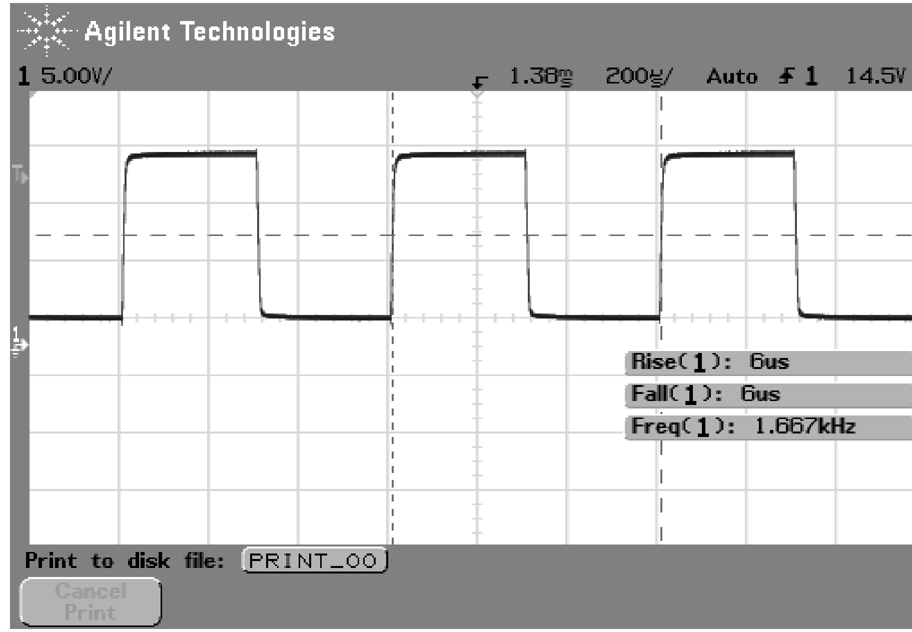
Fig 1 Dual Slope Integration sequence



SCC - ORNL
(Sensor Control Chip)

Large Synoptic Survey Telescope





	Load	Frequency	Rise Time	Fall Time
Switch 1_2	340 pF	1 MHz	35.5 ns	32.5 ns

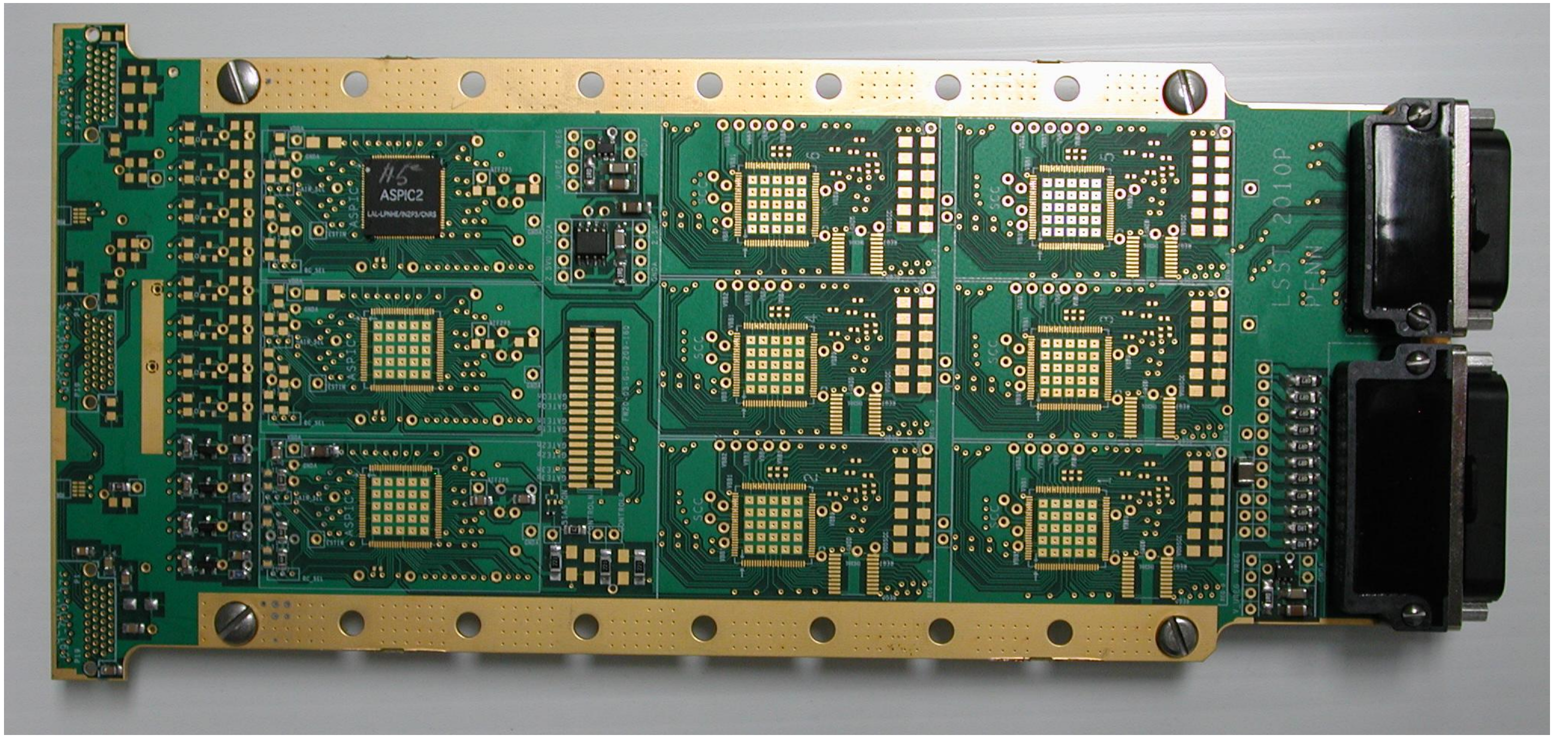
	Load	Freq	Rise Time	Fall Time
Switch 1_4	95 nF	1.6 kHz	7.3 us	7.5 us

Front End Board - Penn

3 ASPICs
(24 Channels)

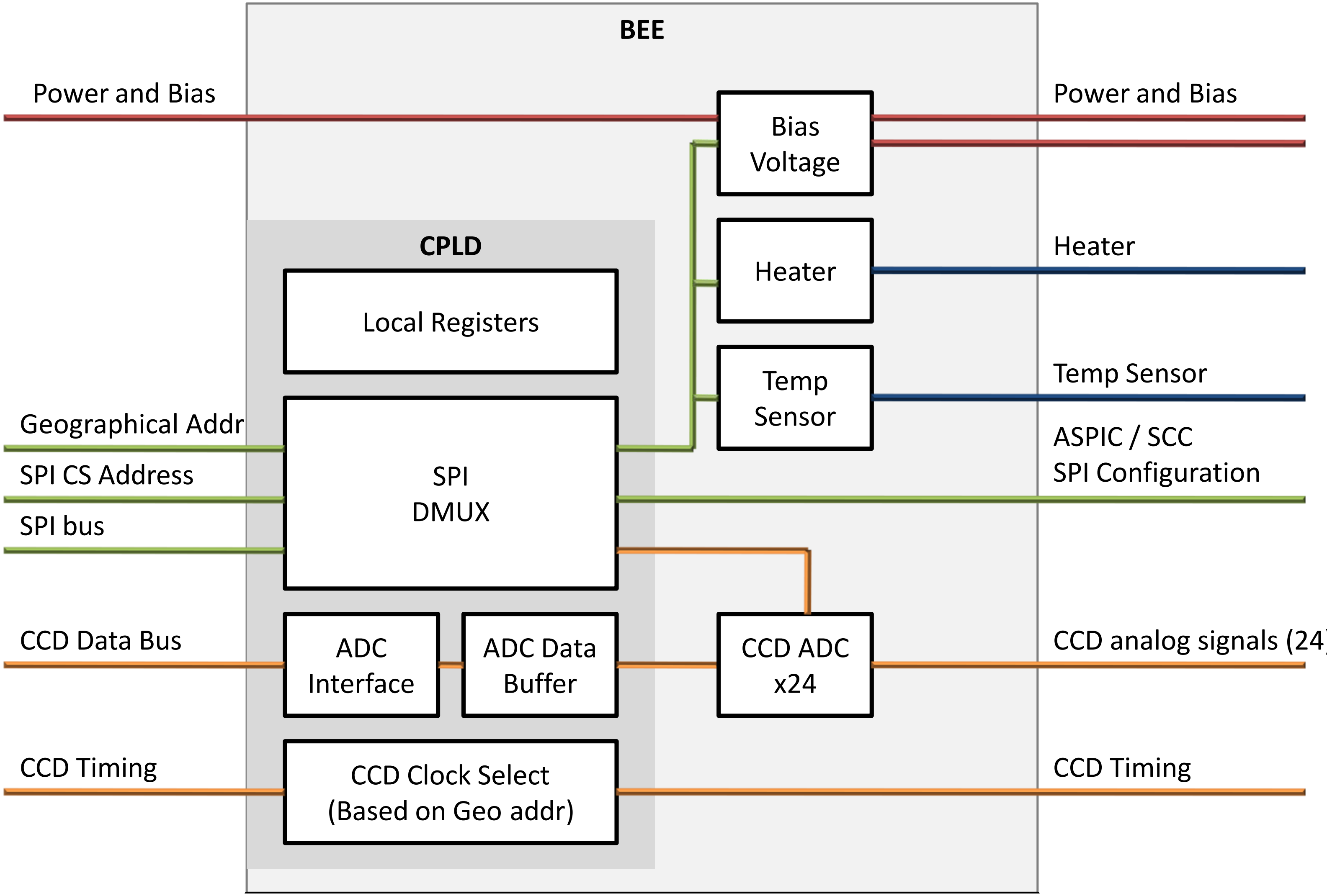
6 SCCs

To CCDs

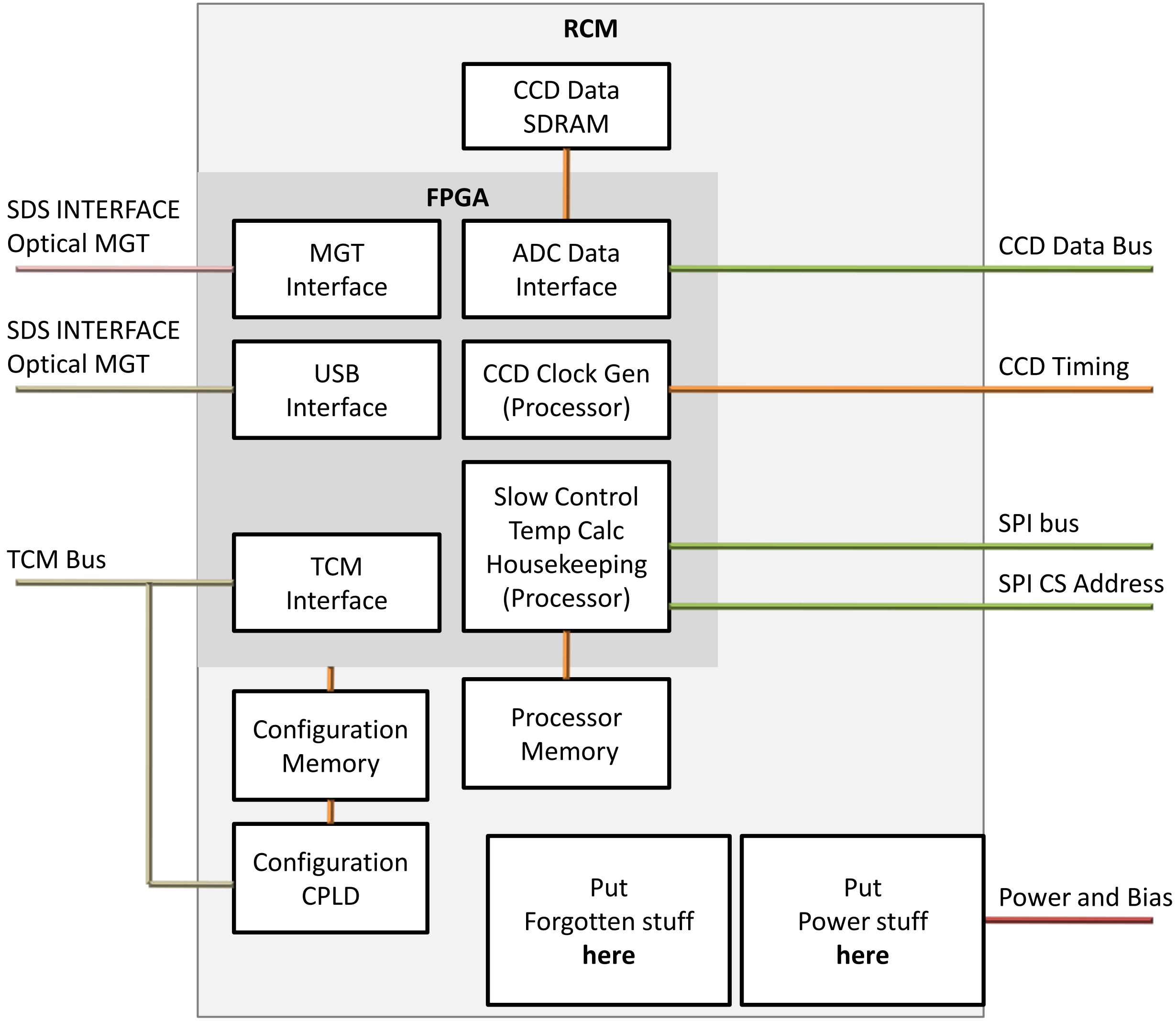


To BEBs

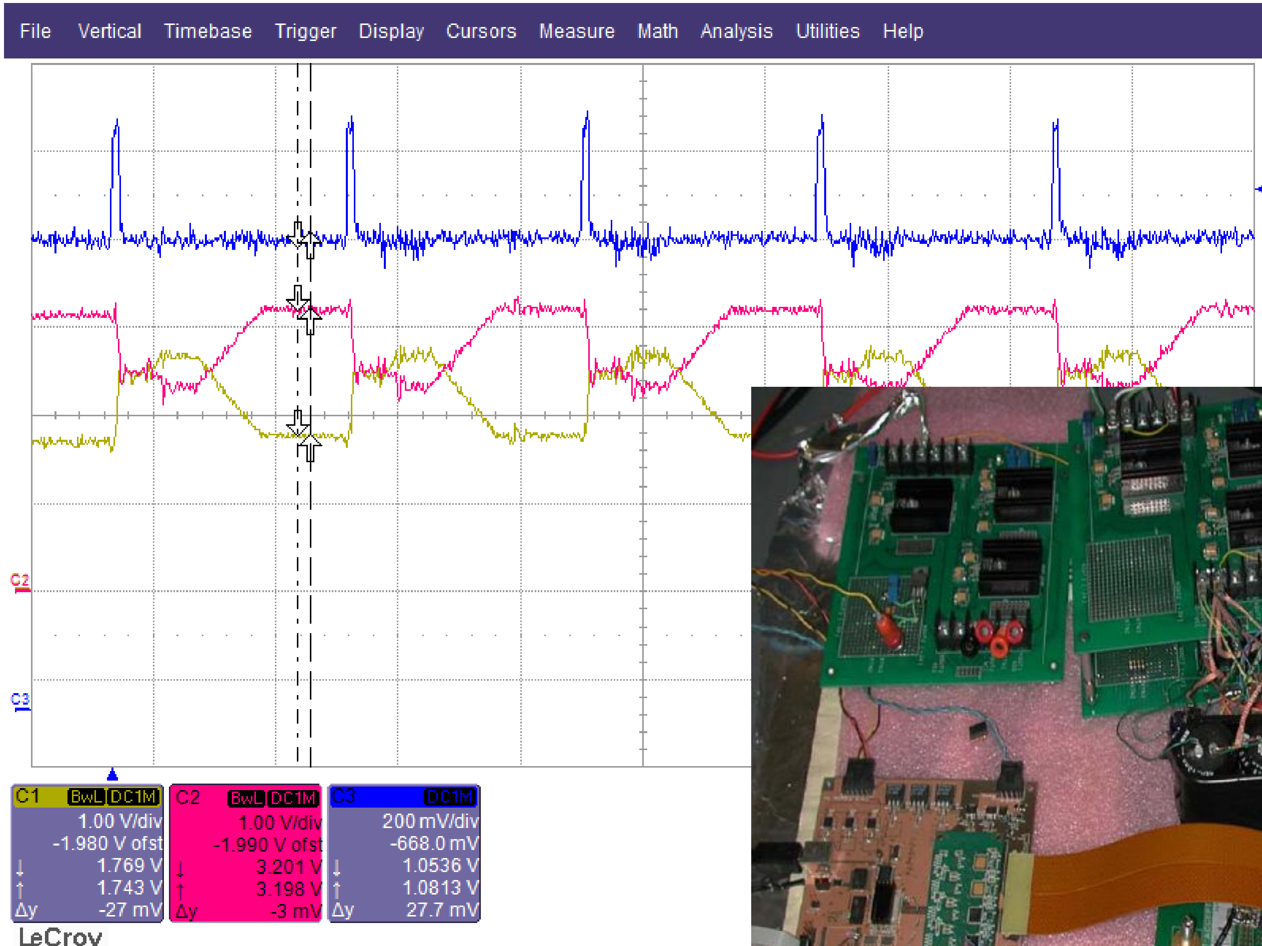
Back End Board - Harvard

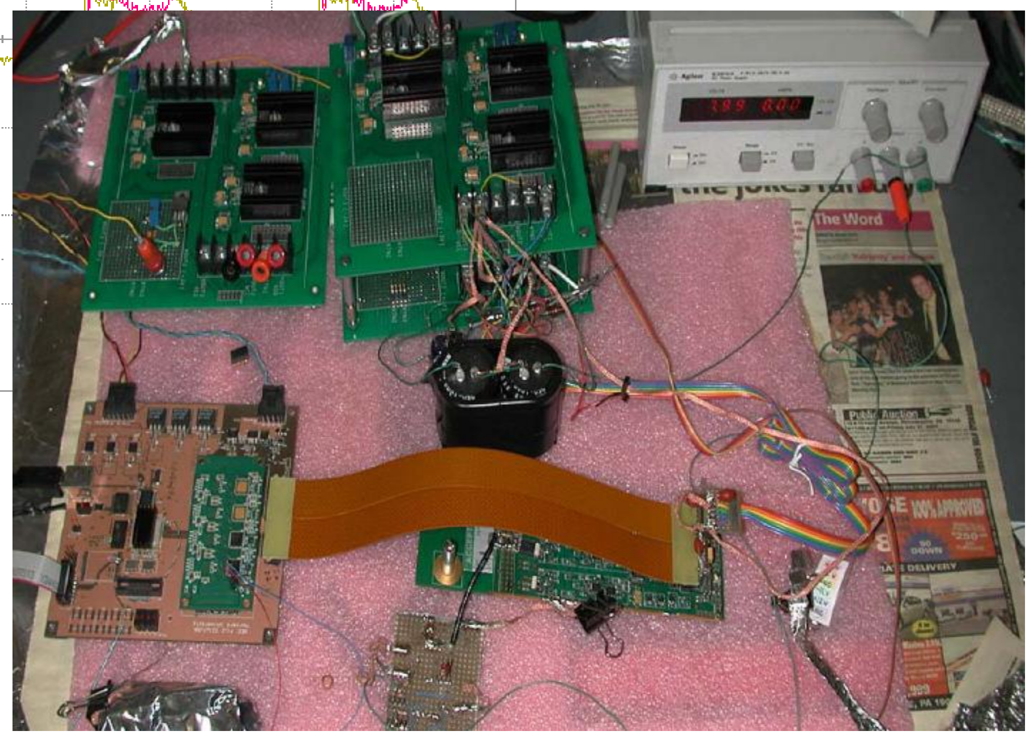


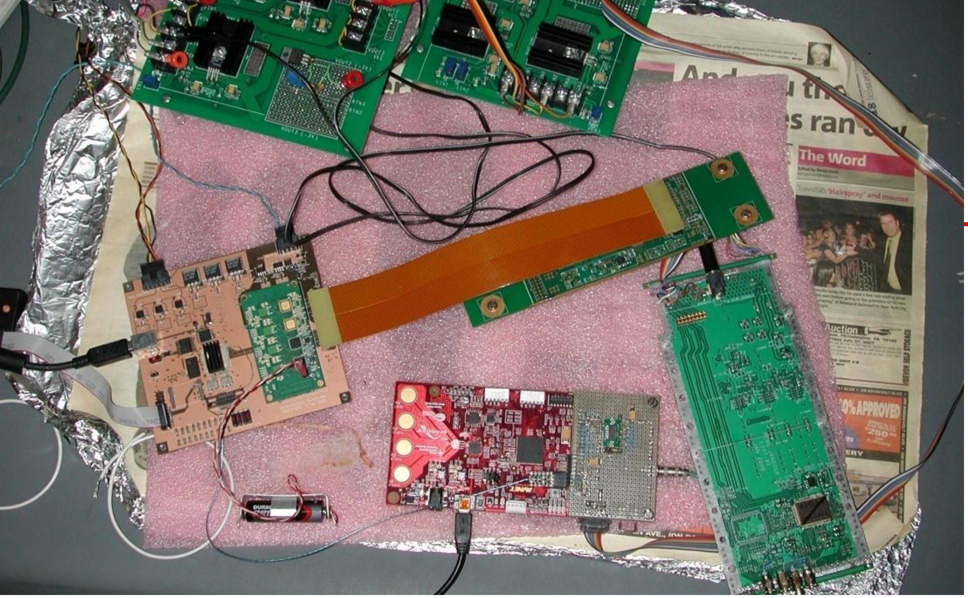
Raft Control Module - Harvard



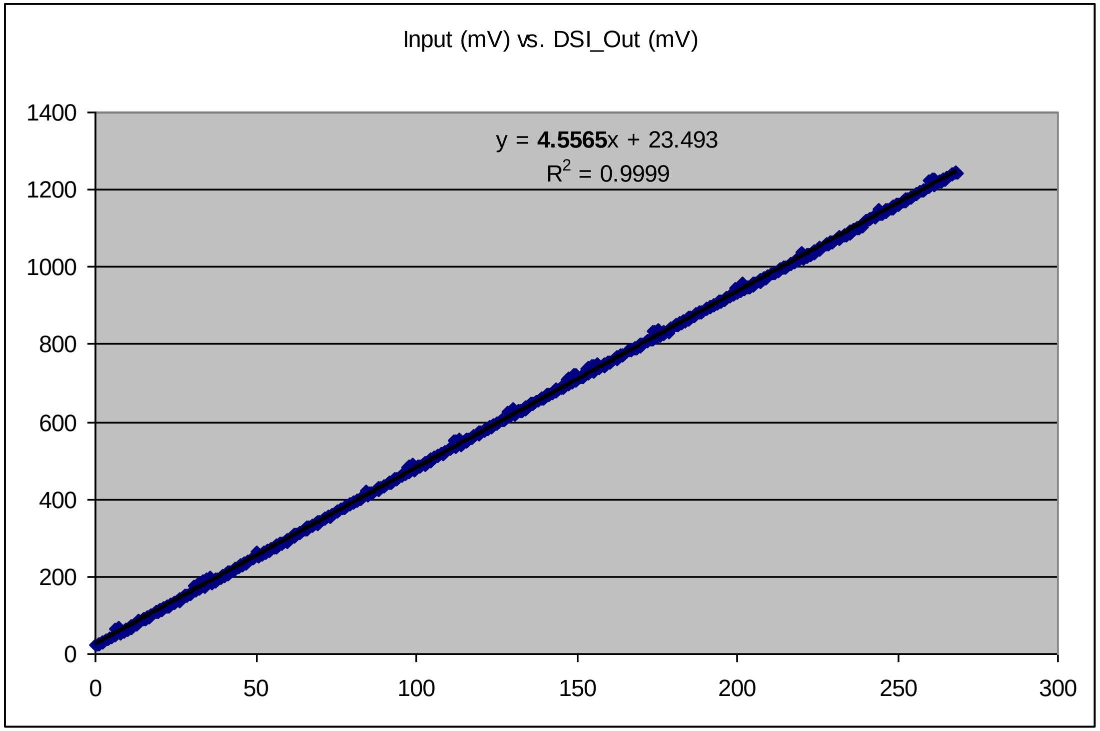
“Vertical Slice Tests” – Penn – ASPIC2







ASPC-1



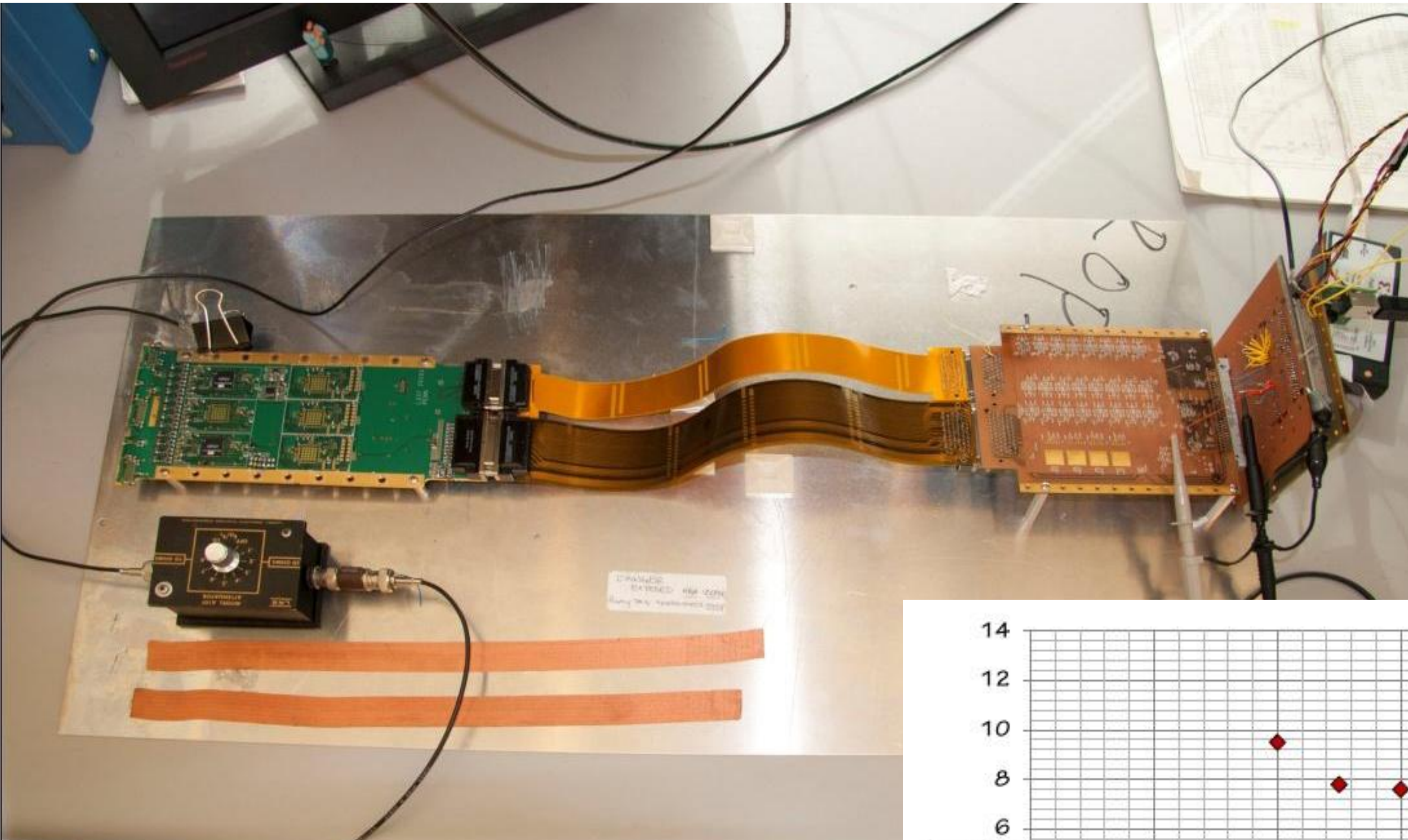
DSI_Out Gain:

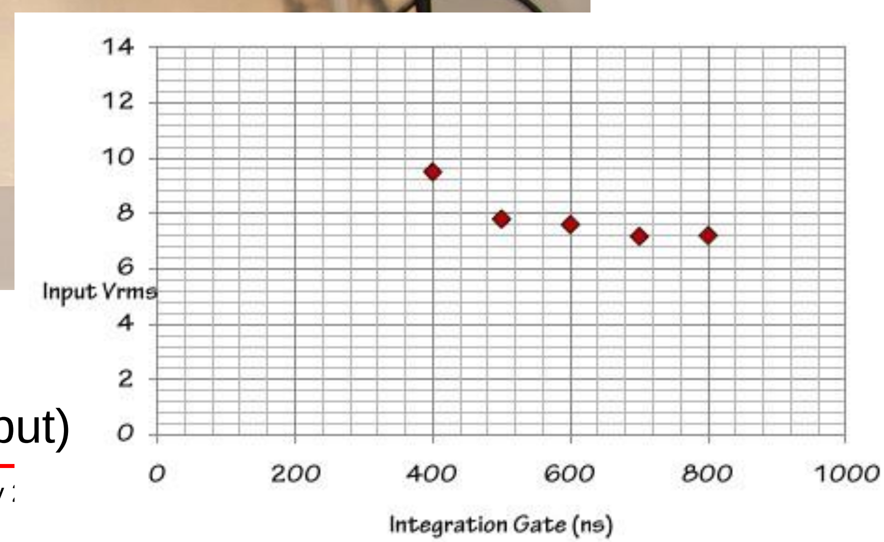
75 µV per count

Gain (Input vs. Output):

4.6 mV out per mV in

"Vertical Slice Test" - Harvard



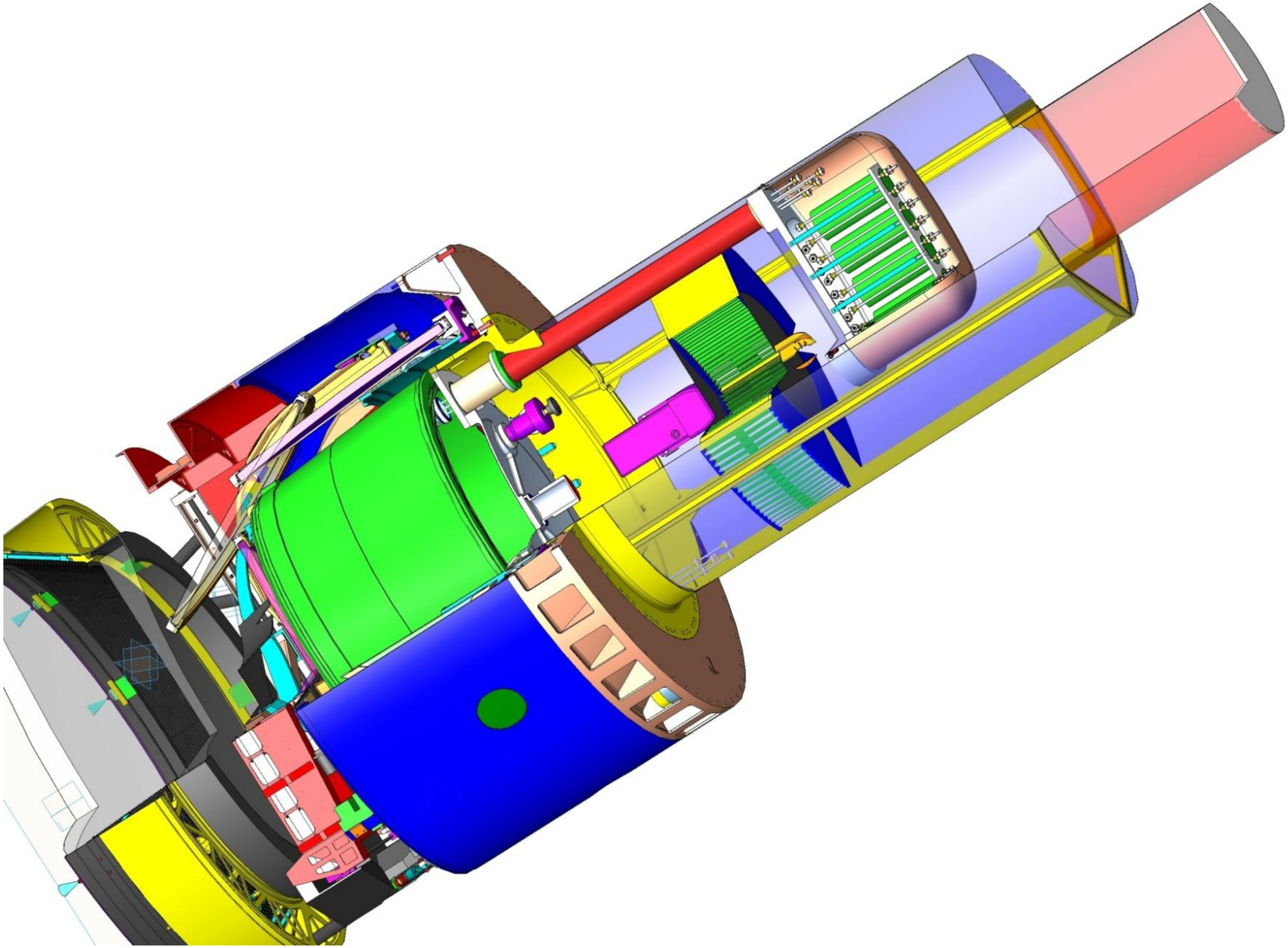


microV (referred to input)

Other LSST Electronics

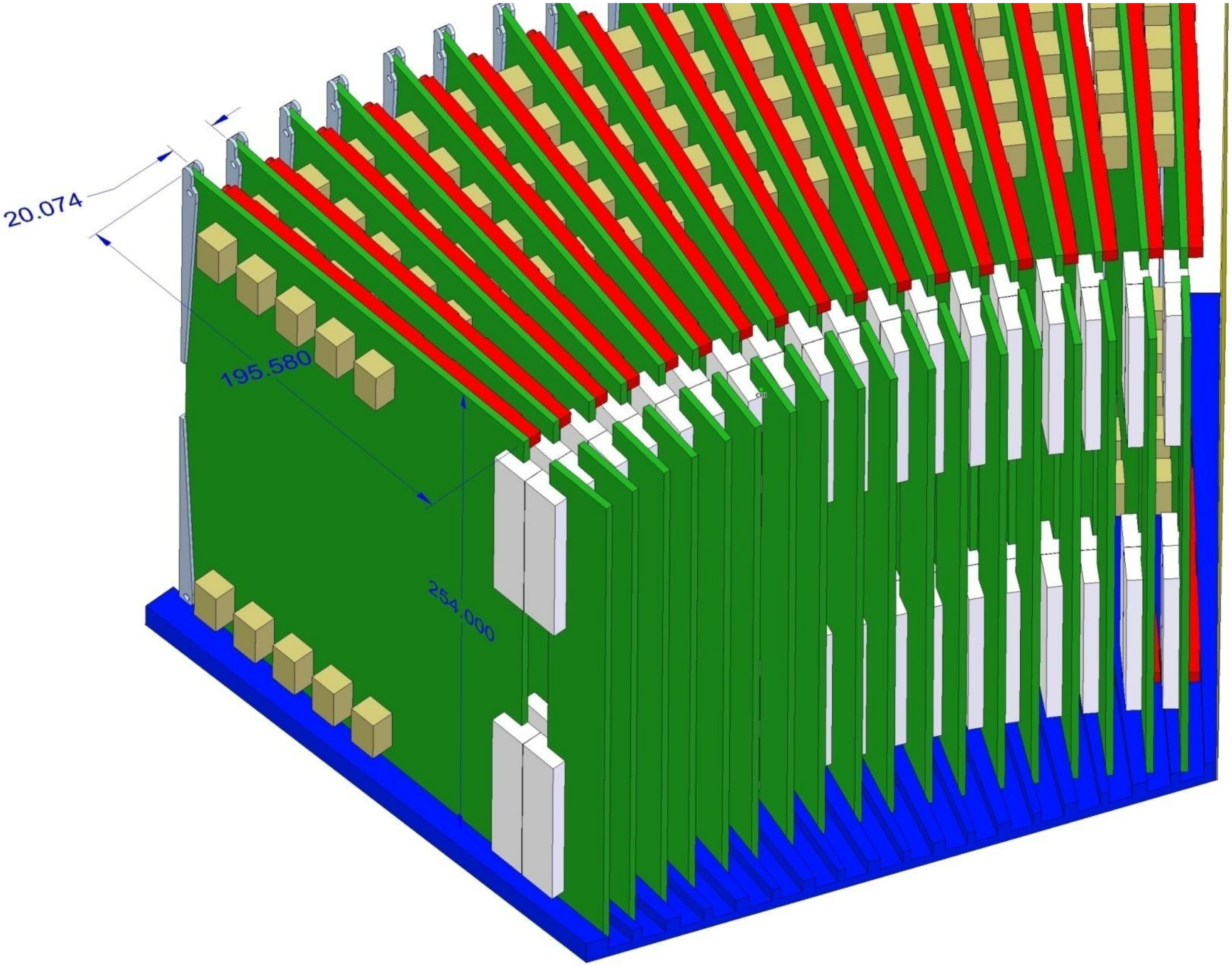
- Power Supplies
- Electro-Optical Converters (DAQ)
- Clock generation and distribution
- Controls for:
  - Shutter
  - Filters
  - Pumps
  - Cooling

Location, Location, Location



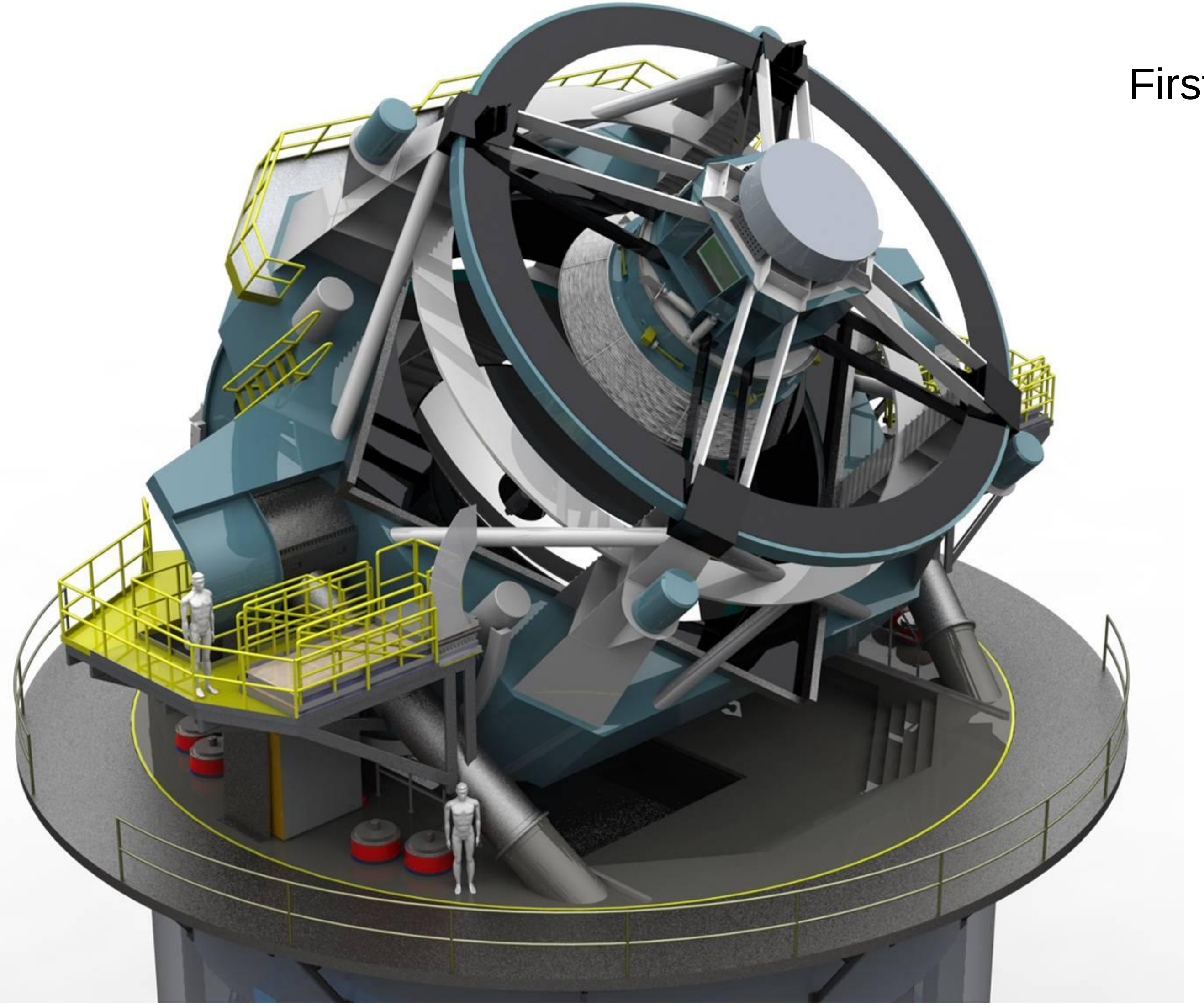
How to annoy traditionalists….

Large Synoptic Survey Telescope



Things not mentioned….

- Thermal design
- Grounding & Shielding
- Optical design / filter characteristics
- Camera and Observatory Control Systems
- Data Acquisition System
- Data bases – meta-data for everything
- Image processing (data cleaning and frame co-adding)
- Vacuum design
- Cleanliness, contamination control
- Focal Plane alignment (ppm!)
- Metrology
- Mechanical design
- Calibration
- Observing simulator / planner

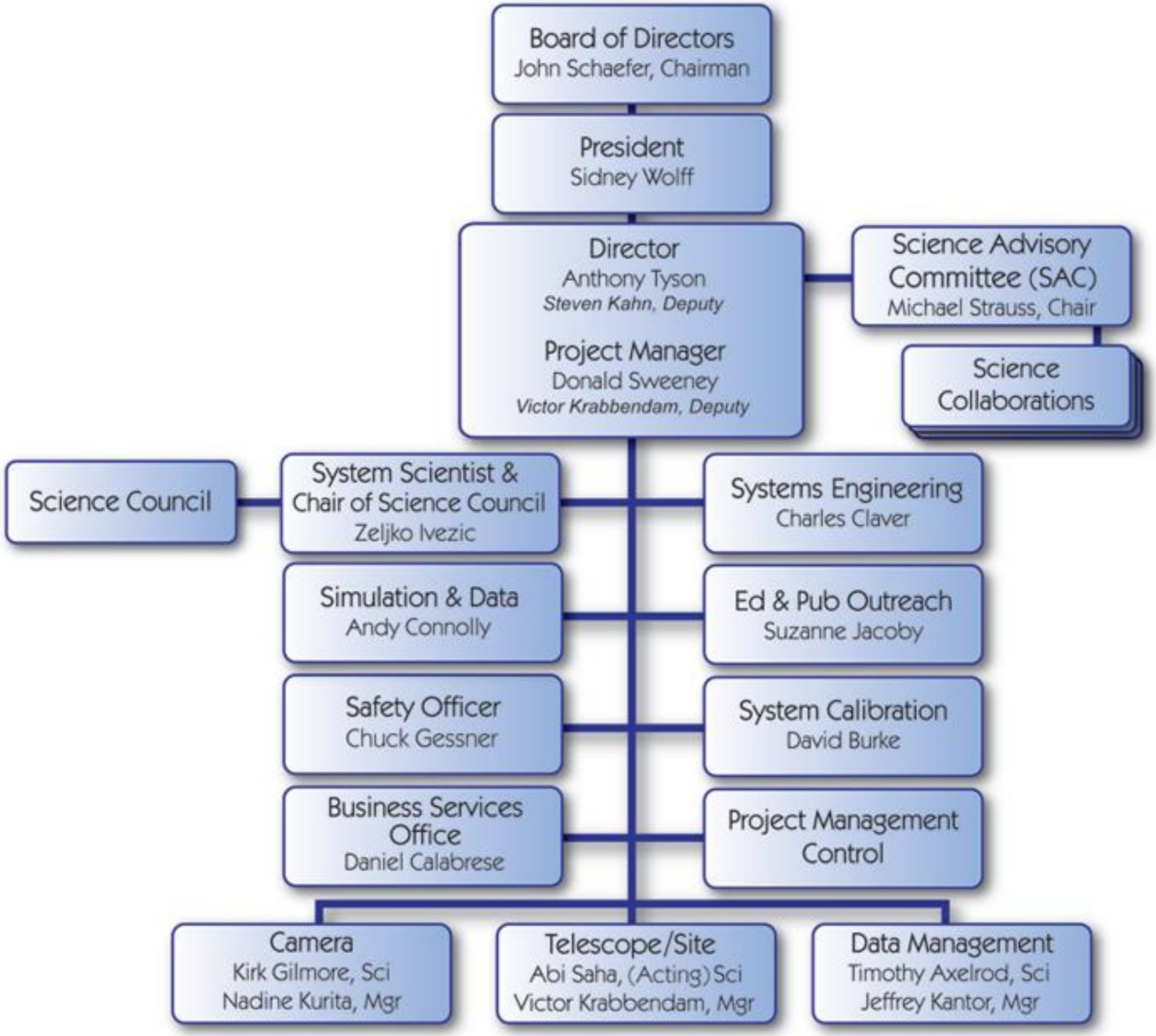


First Light – 2018???


Synoptic!

Backup……

LSST Boxes



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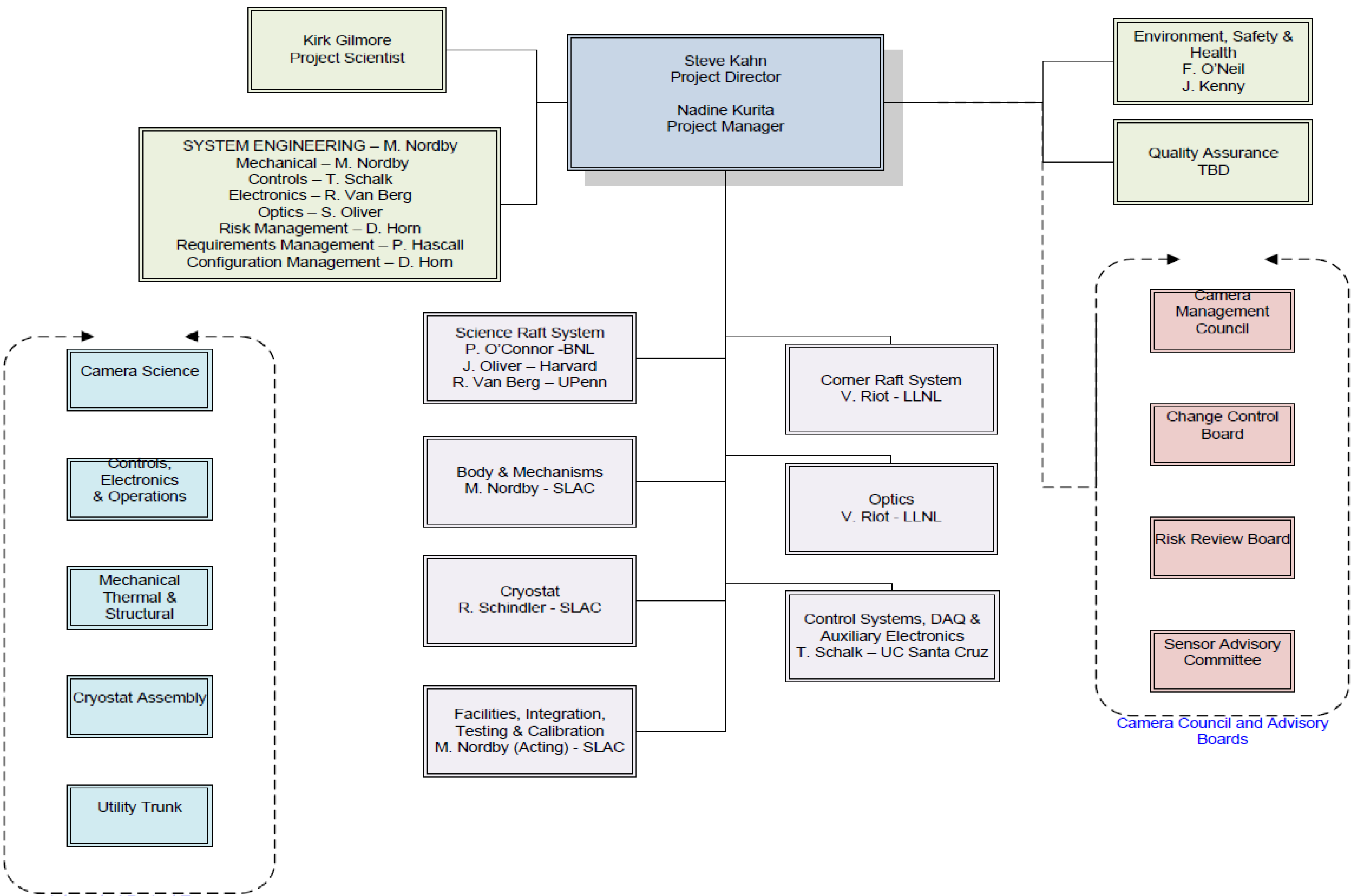
Camera Boxology



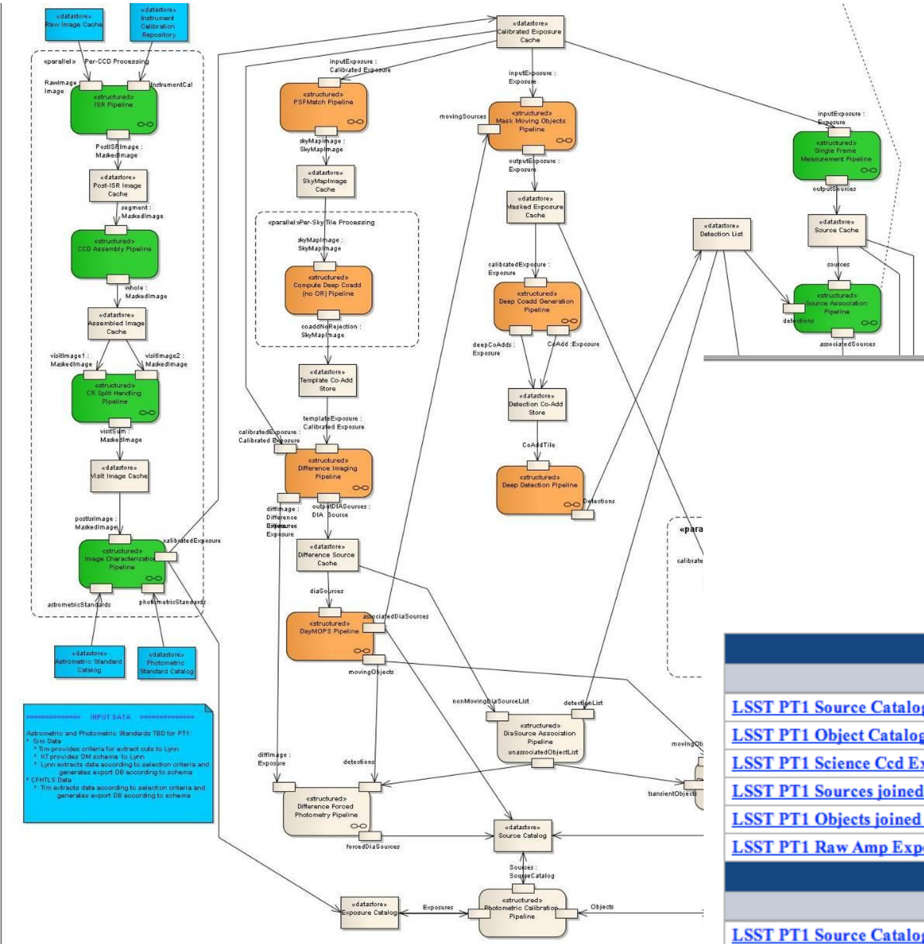
Calyspo has an LSST test camera installed with phase 1 prototype sensor

- LSST's 1.2 meter diameter Telescope on Kitt Peak
- Observing Operations conducted regularly
- LSST U, Y3, and Y4 as well as Sloan filter set on telescope

ITL/STA 1920A at Calypso

M1 (R band, 4Kx4K)

Data Management III



LSST Data Archive

Quick Guide | Tutorial | Catalog List | Process Monitor

LSST PT1 Catalogs for CFHTLS D2 Abe production run			
Descriptions	**# Columns**	**# Rows**	**Information**
LSST PT1 Source Catalog for CFHTLS D2 Abe production run	30	14632721	i
LSST PT1 Object Catalog for CFHTLS D2 Abe production run	48	324905	i
LSST PT1 Science Ccd Exposure Metadata for CFHTLS D2 Abe production run	272	11697	i
LSST PT1 Sources joined with Science Ccd Exposure Metadata for CFHTLS D2 Abe production run	68	14632721	i
LSST PT1 Objects joined with Sources and Science Ccd Exposure Metadata for CFHTLS D2 Abe production run	109	14632721	i
LSST PT1 Raw Amp Exposure Metadata for CFHTLS D2 Abe production run	211	110448	i

LSST PT1 Catalogs for ImSim SLAC production run			
Descriptions	**# Columns**	**# Rows**	**Information**
LSST PT1 Source Catalog for ImSim SLAC production run	30	8488763	i
LSST PT1 Object Catalog for ImSim SLAC production run	84	2757402	i
LSST PT1 Science Ccd Exposure Metadata for ImSim SLAC production run	400	19234	i
LSST PT1 Sources joined with Science Ccd Exposure Metadata for ImSim SLAC production run	68	8488763	i
LSST PT1 Objects joined with Sources and Science Ccd Exposure Metadata for ImSim SLAC production run	109	8488763	i
LSST PT1 Raw Amp Exposure Metadata for ImSim SLAC production run	310	64208	i