Large Synoptic Survey Telescope

CCD Characterization and Measurements Automation

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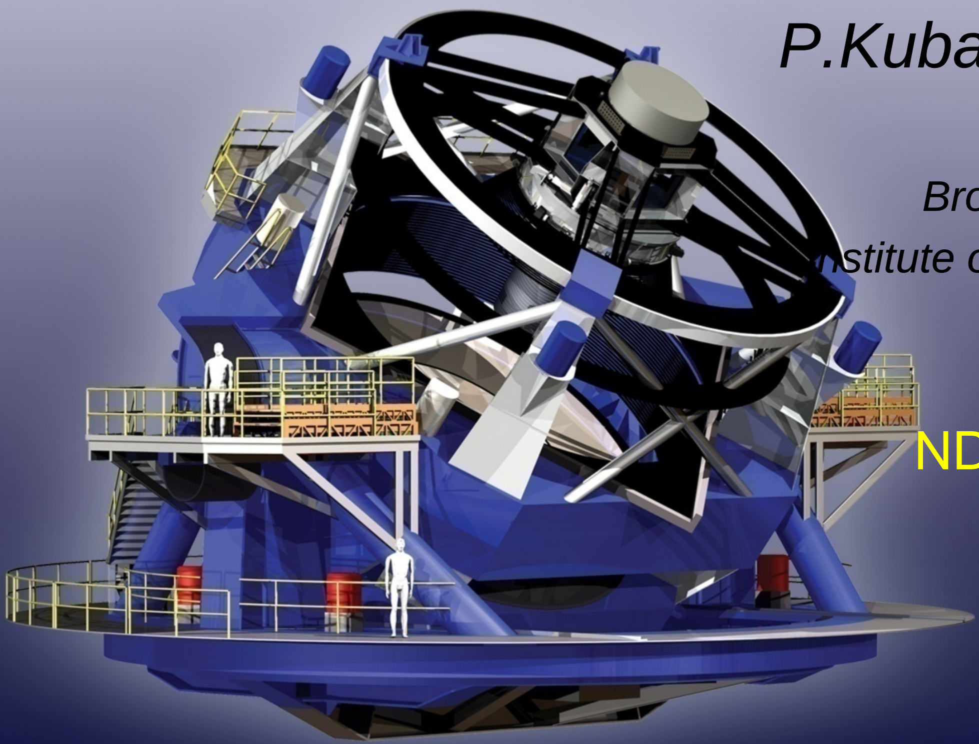


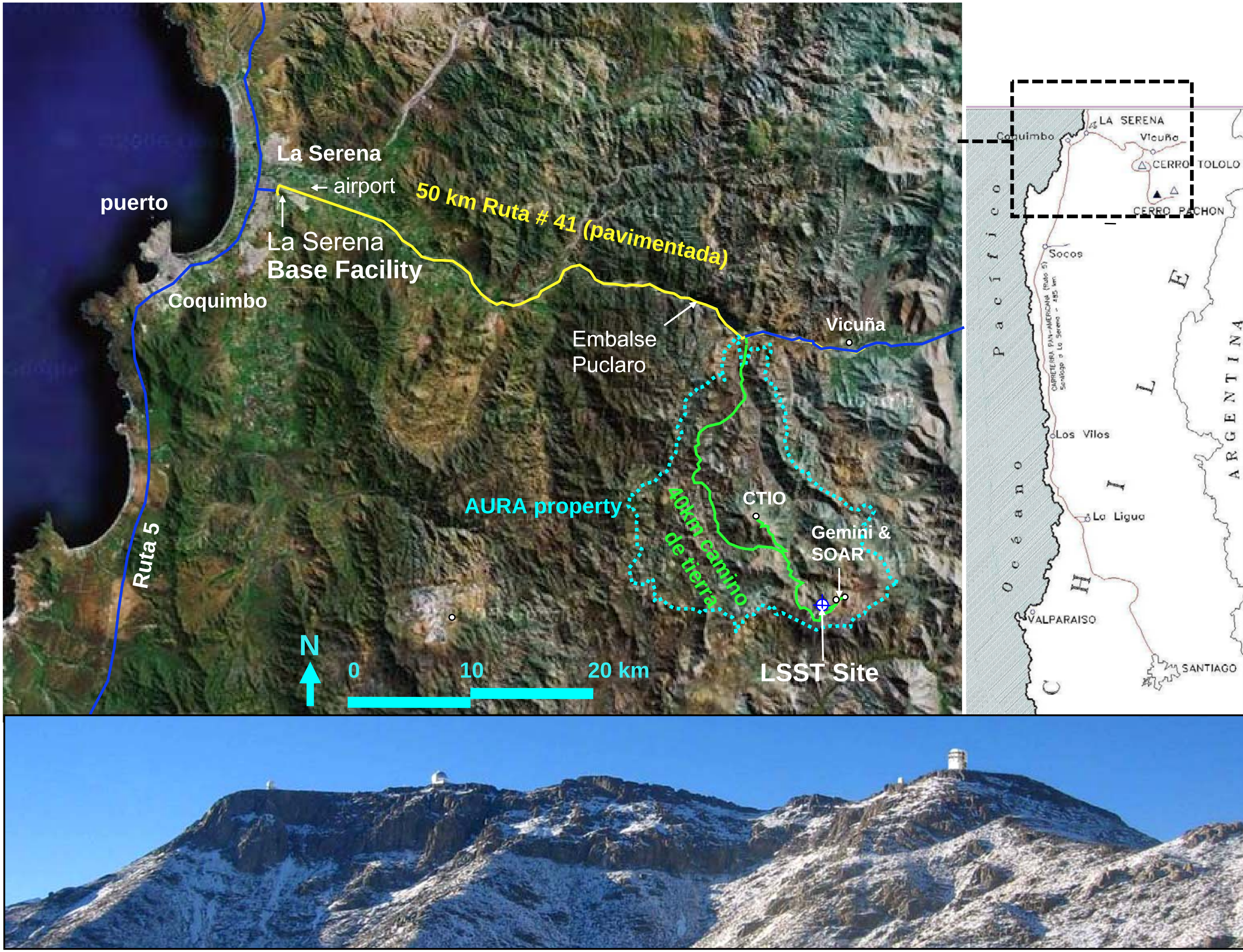
NDIP July 8, 2011 Lyon, France

What is LSST? (Large Synoptic Survey Telescope)

wide-deep-fast survey

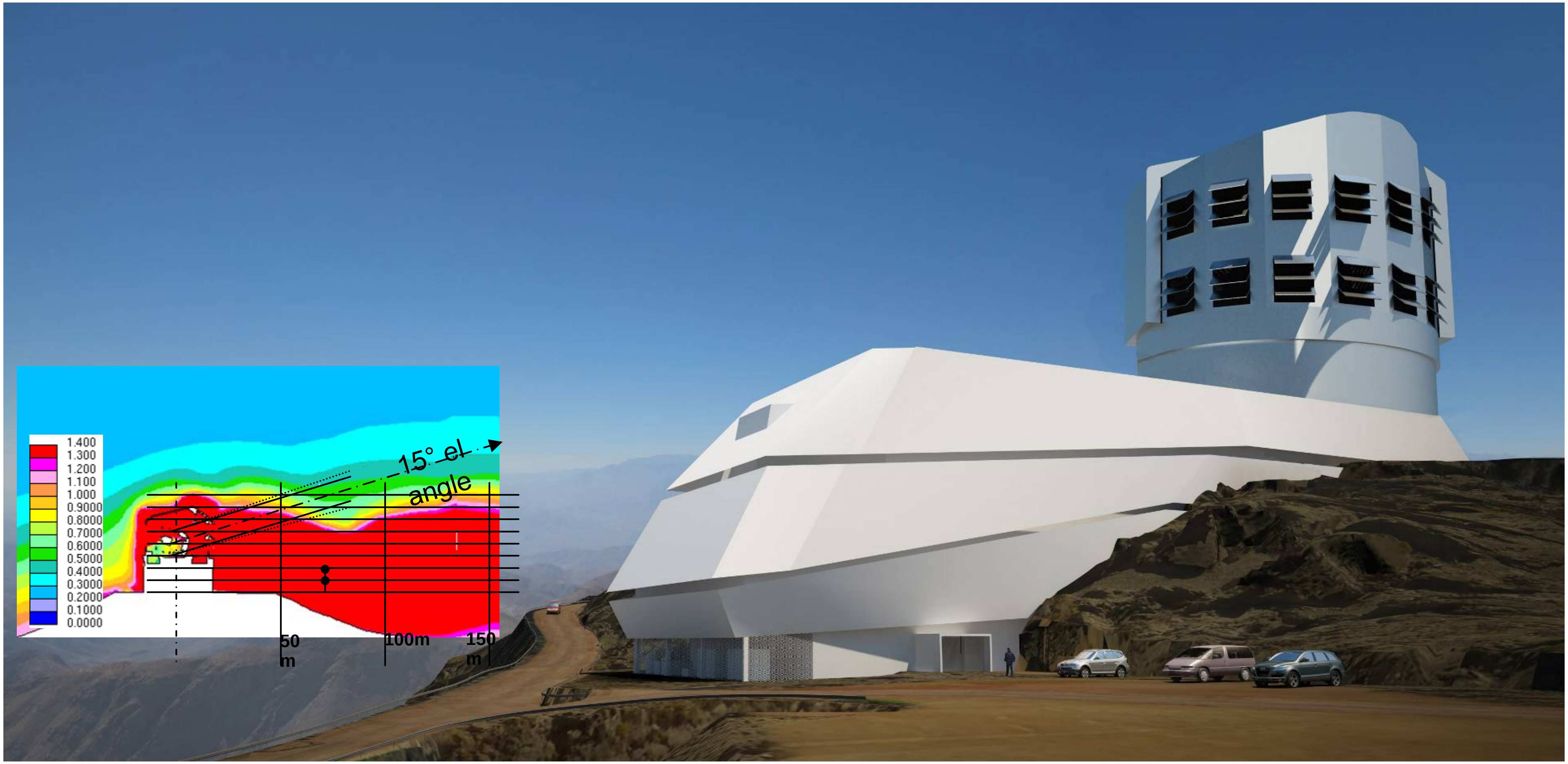
technical characteristics of the LSST survey

- 6-band Survey: *ugrizy* 320–1080 nm
- Frequent revisits: 2 x 15 s, 25 AB mag/visit
- Sky area covered: > 20,000 deg^2, 0.2 arcsec / pixel
- Each 9.6 sq.deg FOV revisited ~ 1000 times
- 10-Year Duration: Yields 27.7 AB magnitude @ 5 σ
- Photometric precision: 0.01 mag absolute; 0.005 mag repeatability



La Serena
airport
50 km Ruta # 41 (pavimentada)
puerto
La Serena
Base Facility
Coquimbo
Embalse
Puclaro
Vicuña
AURA property
40km camino
de tierra
CTIO
Gemini &
SOAR
Ruta 5
N
0
10
20 km
LSST Site
LA SERENA
Coquimbo
Vicuña
CERRO TOLOLO
CERRO PACHON
Socos
Los Vilos
La Ligua
VALPARAISO
SANTIAGO
Océano Pacifico
CHILE
ARGENTINA

Summit Facility



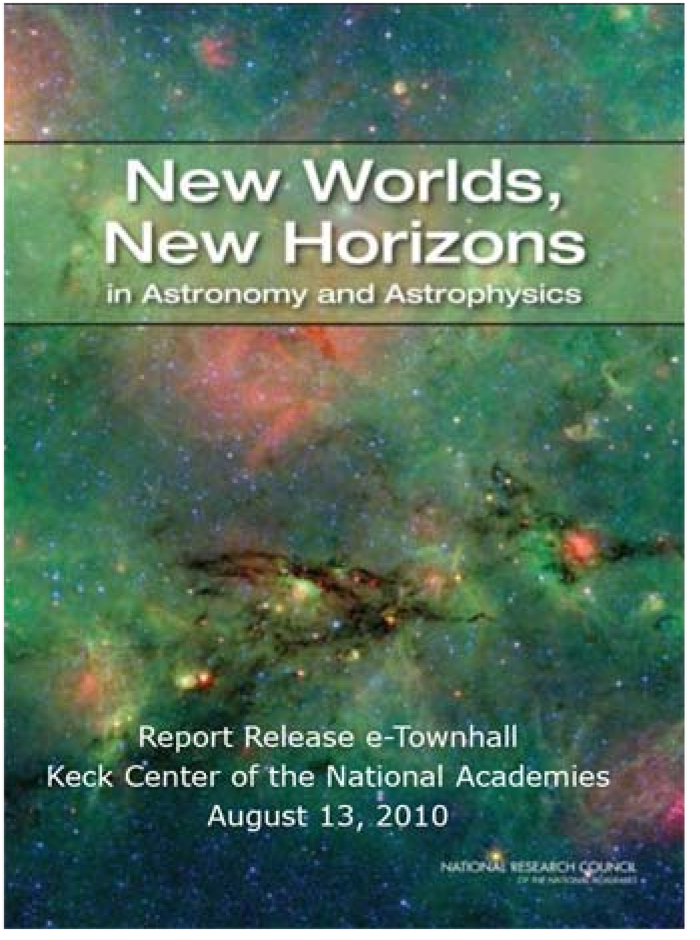
Recent Astro2010 Endorsement

- LSST ranked as the highest priority large ground-based facility for the next decade.

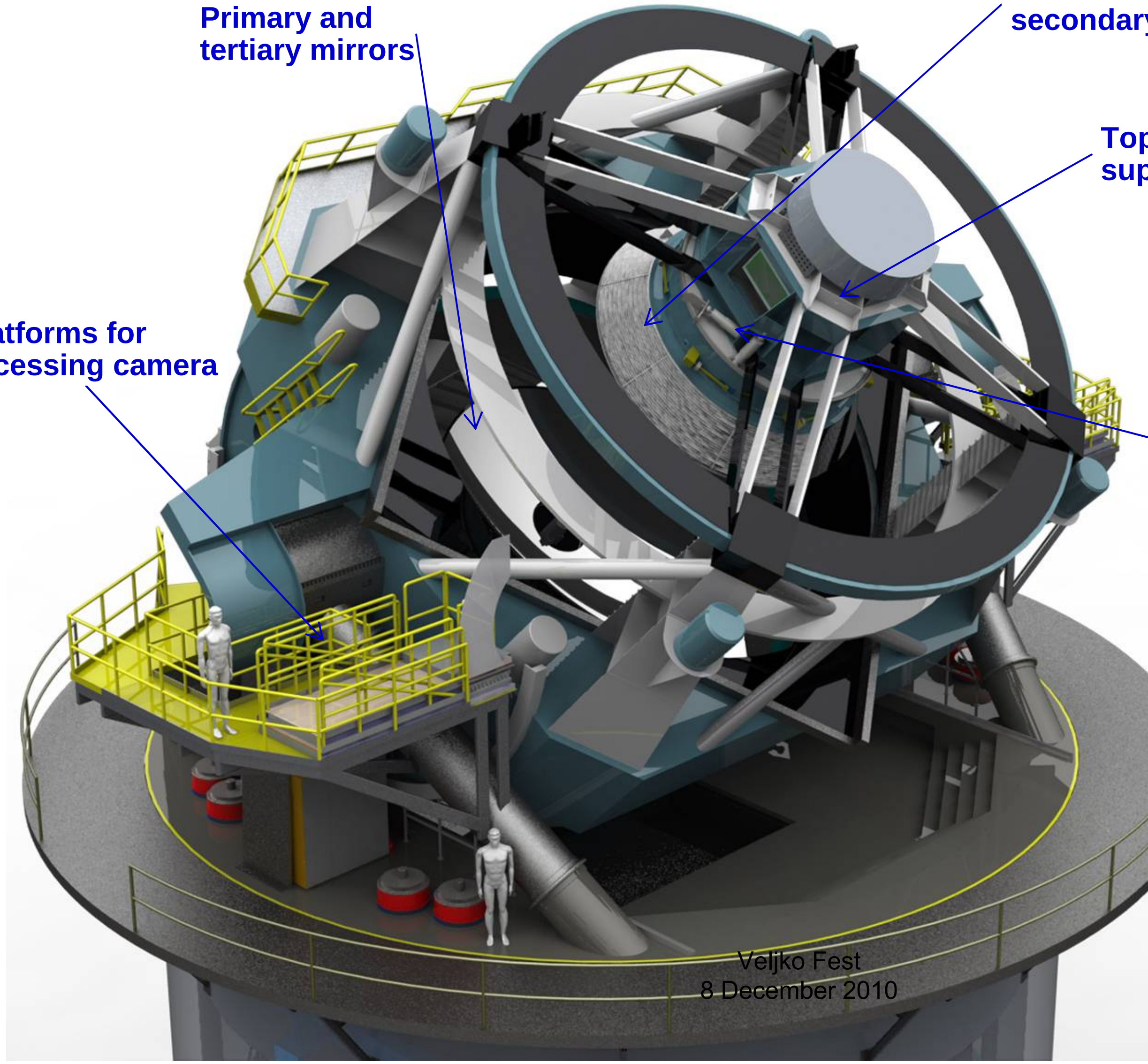
- Top rank accorded on the basis of:

  - Compelling science and very broad range of topics addressed.

  - Technical maturity, and appraised construction and operations costs.



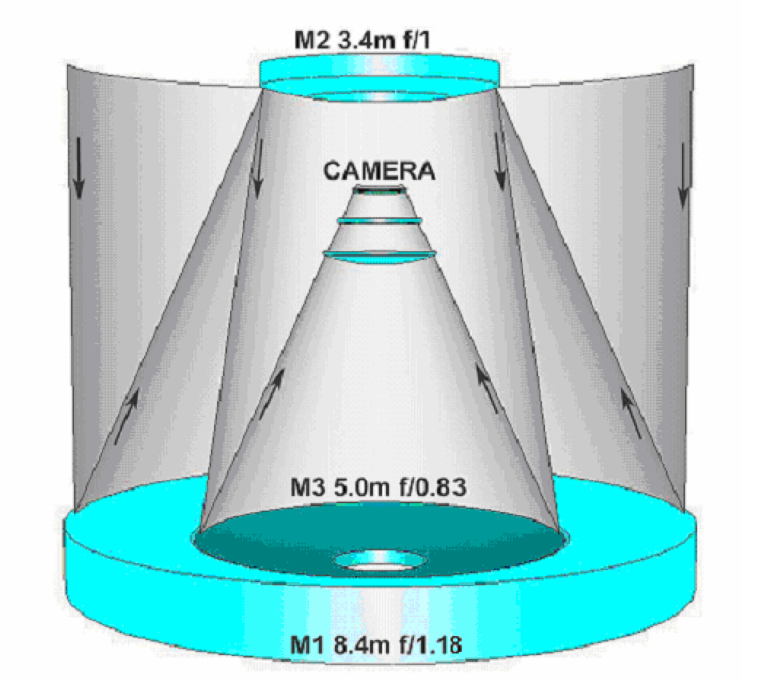
LSST Telescope



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

LSST Optical Design

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

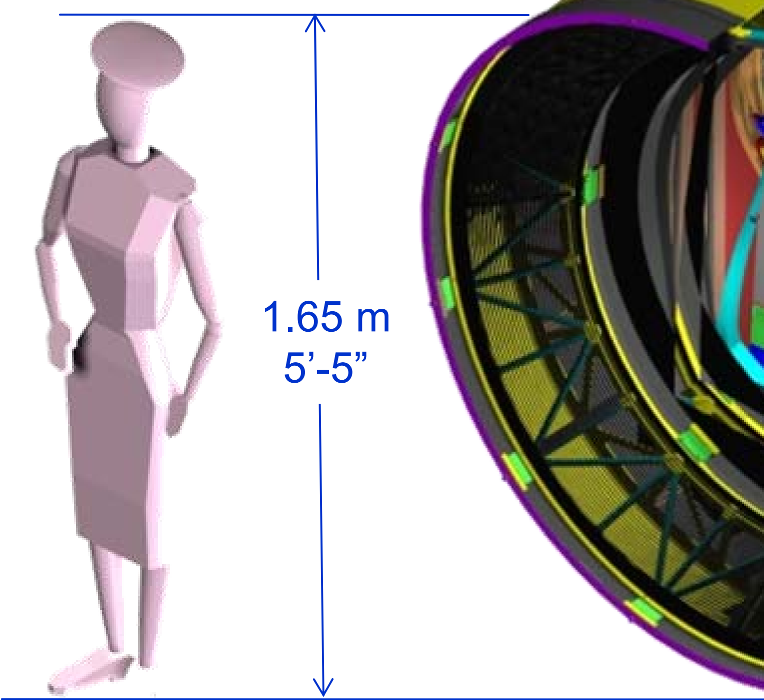


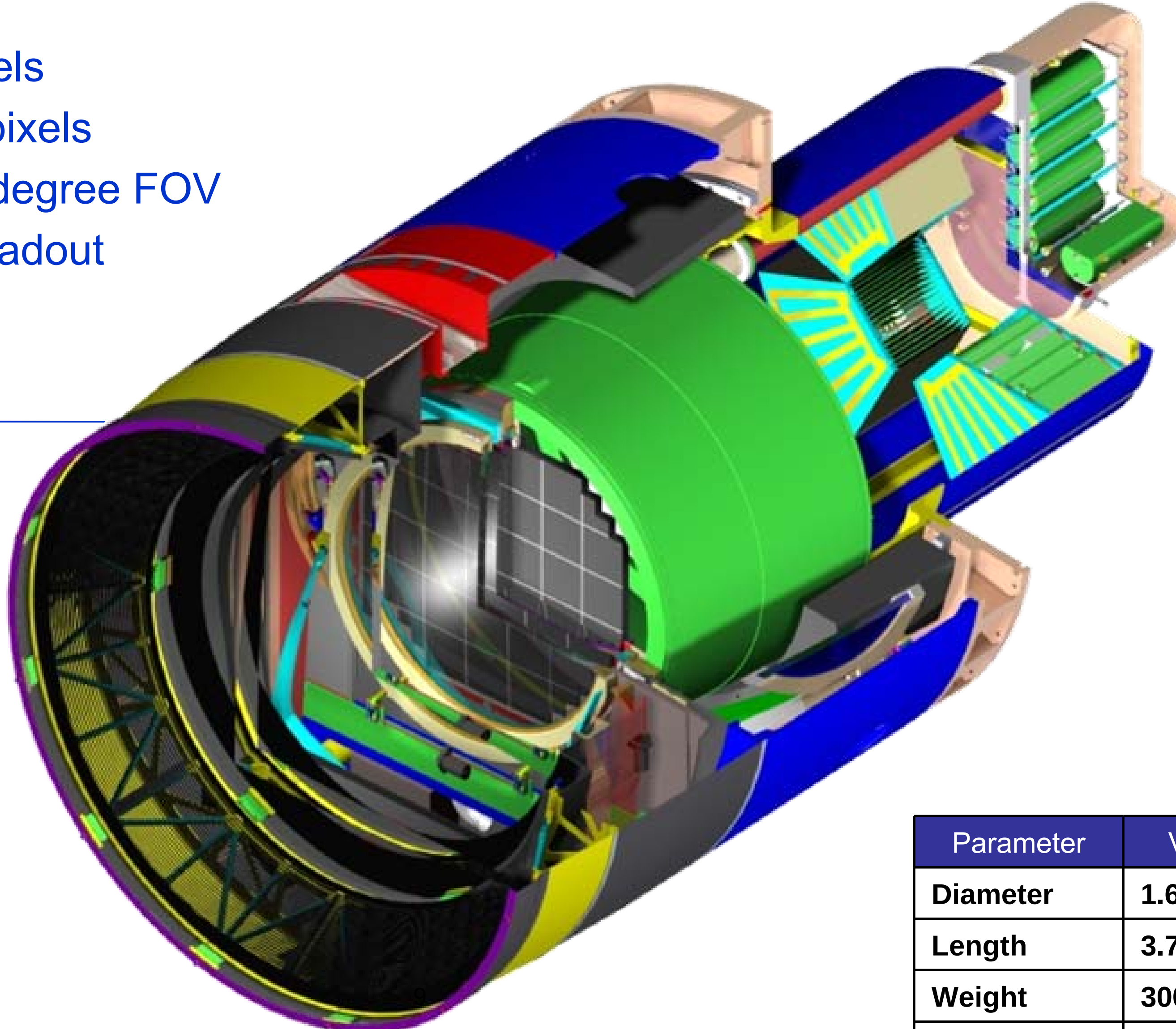
LSST optical layout

Primary/Tertiary in Fabrication

Camera

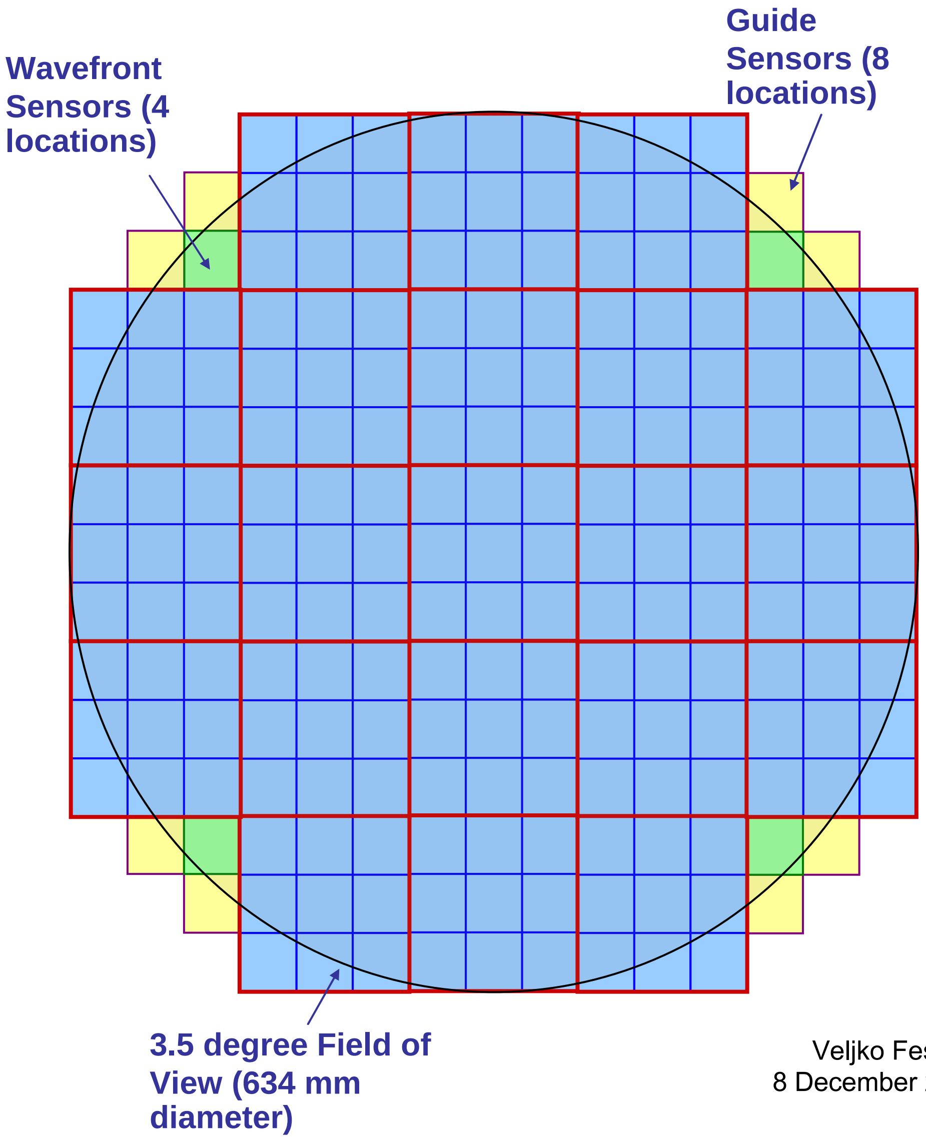
- 3.2 Gigapixels
- 0.2 arcsec pixels
- 9.6 square degree FOV
- 2 second readout
- 6 filters



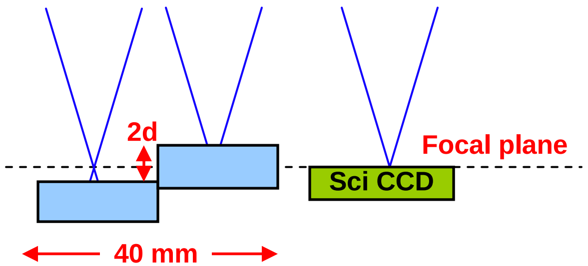


Parameter	Value
Diameter	**1.65 m**
Length	**3.7 m**
Weight	**3000 kg**
F.P. Diam	**634 mm**

The LSST Focal Plane - 64 cm in Diameter



Wavefront Sensor Layout

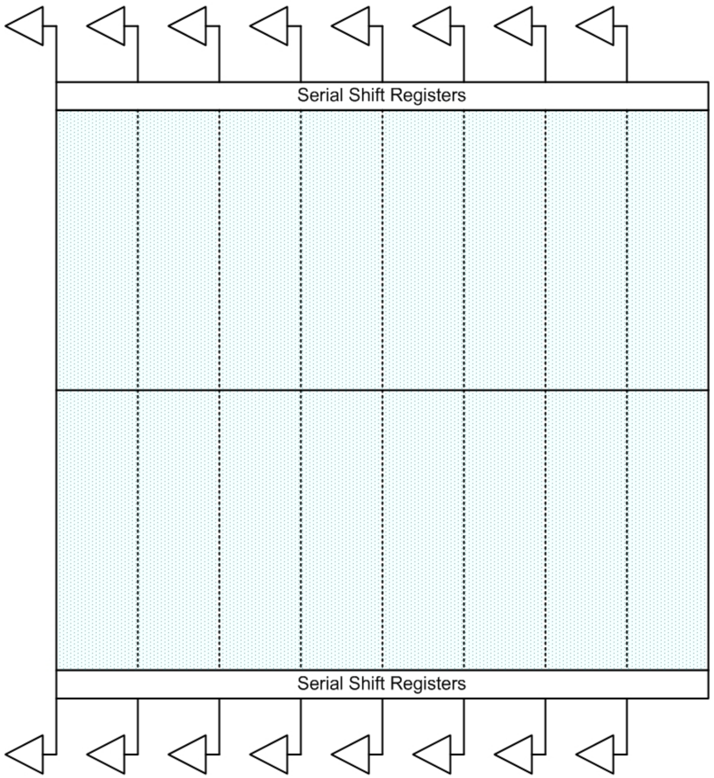


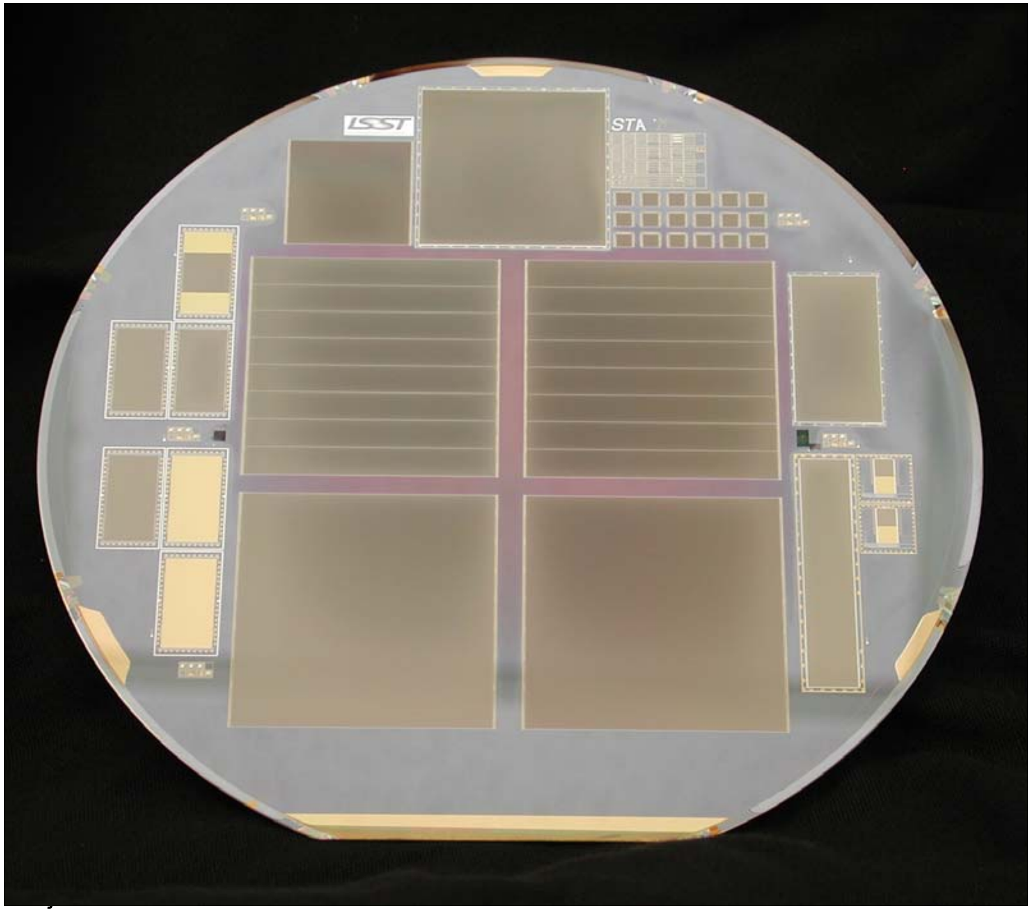
Curvature Sensor Side View Configuration

Veljko Fest
8 December 2010

The LSST CCD Sensor

16 segments/CCD
200 CCDs total
3200 Total Outputs





Introduction: what CCD tests are required ?

- test flavors
  - to check sensor performance against specifications
  - to study specific sensor parameters at more detailed level
- tests include:
  - system gain, noise and cross talk
  - linearity and full well capacity
  - dark current and defects
  - QE in wavelength range 300 - 1100 nm
  - charge transfer efficiency (CTE)
  - charge diffusion sigma (sensor contribution to PSF)
  - persistence artifacts
  - etc…
- these tests are typical for CCD sensors
- the test suite have been developed

Introduction, the need of automation

- development phase
  – thorough sensor characterization is important to check sensor prototypes performance against LSST specs
- production phase
  – sensor has to be fully characterized before it can be placed in the LSST mosaic
- commonality of both phases
  – **large volume of testing** → high throughput is required, and this can not be achieved without automation

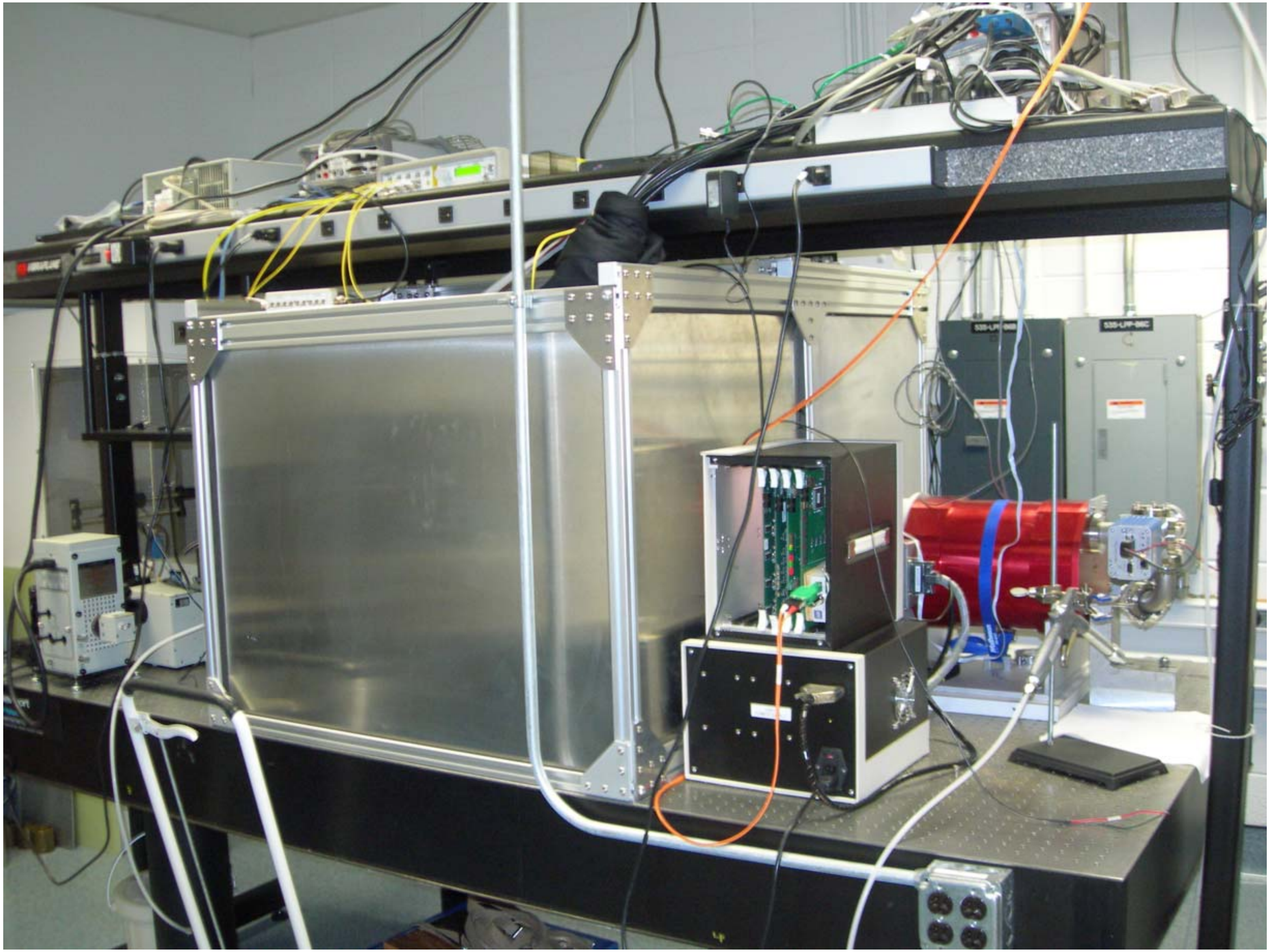
- automate tests from the very beginning

- CCD test facility was set up at Brookhaven National Laboratory Instrumentation Division

Introduction, automation components

- computer controlled instruments
- control software + bash scripting
- data base for measurement metadata
- express analysis

Introduction, testing lab



Software → rts2 + bash scripts

- Remote Telescope System 2nd version (RTS2) software package
  - open source package for remote observatory control under the Linux operating system
  - supports a large variety of instruments with different interfaces
  - a framework to develop new RTS2 instrument drivers
  - synchronize all devices in the laboratory
  - monitoring capabilities
  - conform to FITS standard
  - scripting capabilities
- A combination of both Linux and RTS2 scripting allows for execution of a complete set of measurements and running express analysis as soon as data are available

Measurement metadata logging & browsing

- Information about environment conditions and instrument settings for measurements of interest is stored in FITS headers but
  - search and data retrieve is slow (files need to be open, read etc)
  - there is no mechanism to narrow down the search (what files to search - all?)
  - something more flexible and convenient is needed

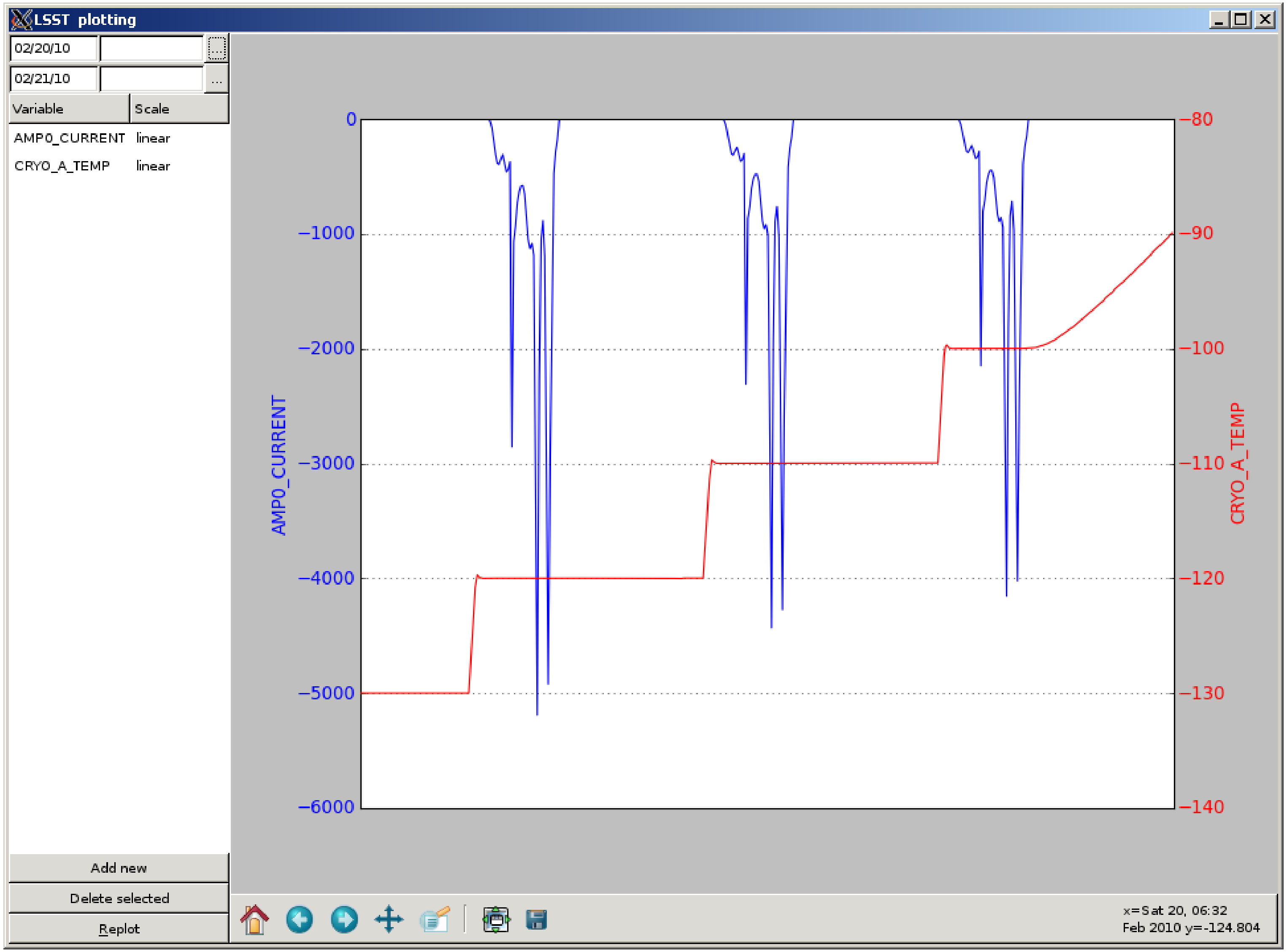
- Fast, flexible and convenient access to metadata can be achieved using a database (DB). The ease of access allows one
  - keep track of performed measurements
  - search and compare
  - plot essential measurements parameters

- MySQL
  - open source product
  - multi platform capability
  - performance and reliability
  - user familiarity and wide knowledge base

- The metadata logging is performed by running the executable from a measurement script when a set of measurements is completed
  - the executable is built from C/C++ code
  - table altering is supported
  - tables are defined in the code header file
    - change the table layout easily
    - keep track of the changes

- visualization GUI was developed in Python using PyGTK open source package

DB GUI example

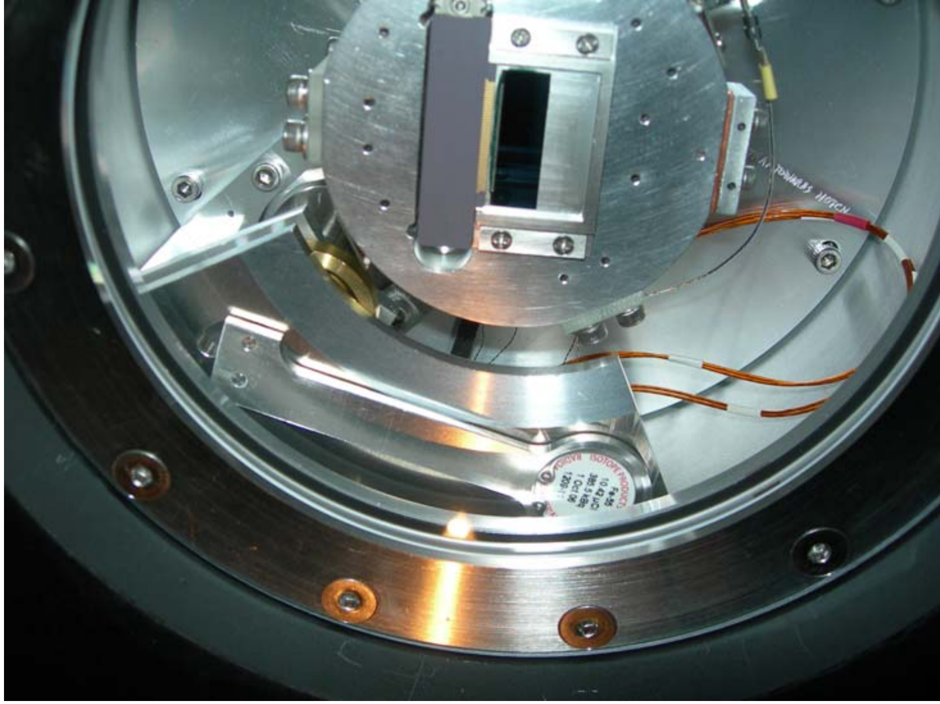


horizontal axis – time of observation

Express analysis of ^{55}Fe data (1)

- standard input signal ($K_\alpha \rightarrow$ 1620 e-)
- provide absolute calibration of the entire electronics chain in a very straightforward way
- what CCD parameters can be measured:
  - system gain
  - system noise
  - CTE
  - PSF

^{55}Fe data



- ^{55}Fe data are obtained by multiple CCD exposures to a 10 µCi source
  - source swings over CCD surface on a motorized arm mounted inside the cryostat
  - swing time is minimized to 6 sec to reduce the pile up of X-ray clusters
- arm motion is synchronized with the CCD exposure
- the simplest form of the rts2 command is

```
rts2-scriptexec -d C0 -s ’for 100 { E 6 FEARM.!CURPOS+=8000 }’
```

- measurements and analysis are automated

\+ series of bias exposures (6s darks)

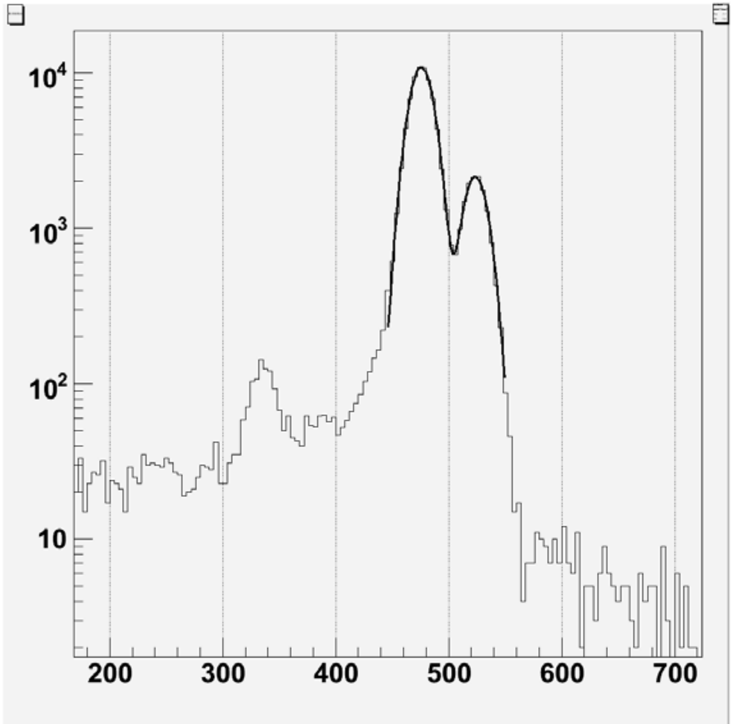
^{55}Fe data analysis outline

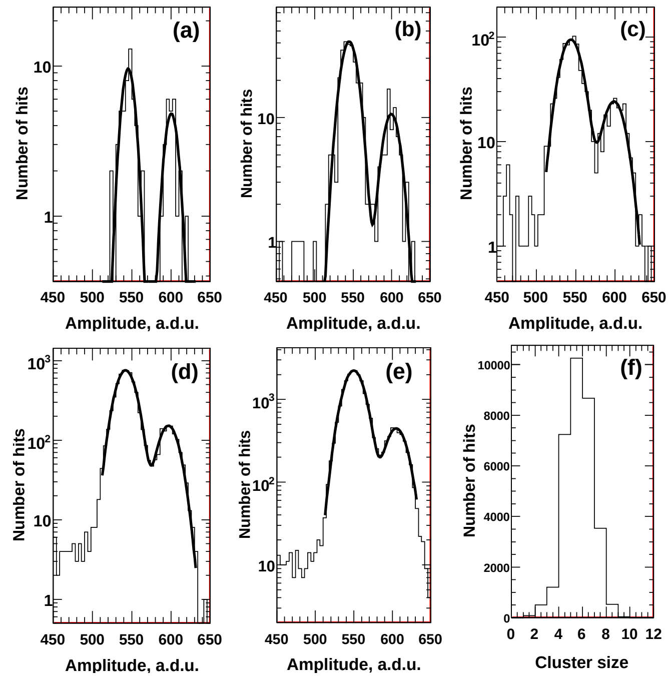
1. base line subtraction (IEEE Transactions on Nuclear Science, Vol.57, p. 2200-2204, August 2010, DOI: 10.1109/TNS.2010.2049660)
   - bias exposures
   - evaluated from the ^{55}Fe image itself
- ➢ read-out noise noise in a.d.u.

- cluster finding algorithm to find X-ray hits
  - cluster seeds = pixels with amplitude above 5σ noise
  - seeds are ordered automatically in amplitude decrease order
  - n × n pixels zone around a seed is analyzed (usually n = 3)
  - n × n zone is cleared

- statistical analysis of X-ray clusters
  - gain determination
  - charge transfer efficiency
  - etc..

^{55}Fe express analysis: gain





The conversion gain is determined from fitting $K_{\alpha,\beta}$ lines in cluster total amplitude distribution.

- fit function is the sum of two Gaussians
- line width = read-out noise + natural line width
- initial parameter estimates and appropriate range are crucial for fit robustness
- initial estimate of the K_α peak position is done by finding the bin with the maximum content in the X-ray amplitude distribution

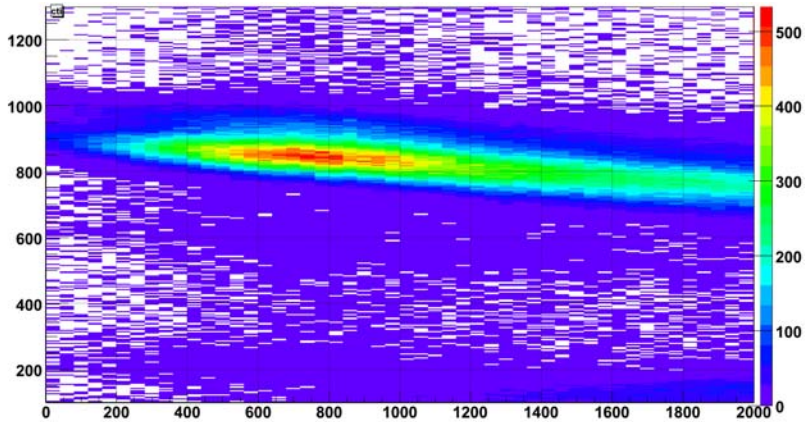
^{55}Fe express analysis: CTE

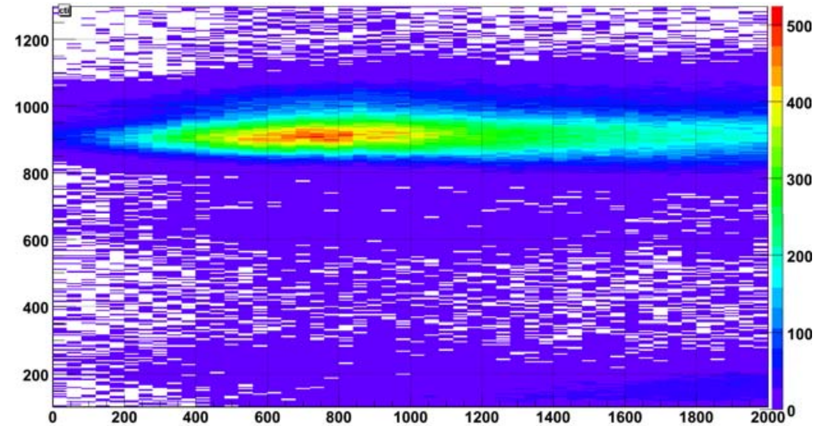
device 106-07, T=-140C

initial distribution

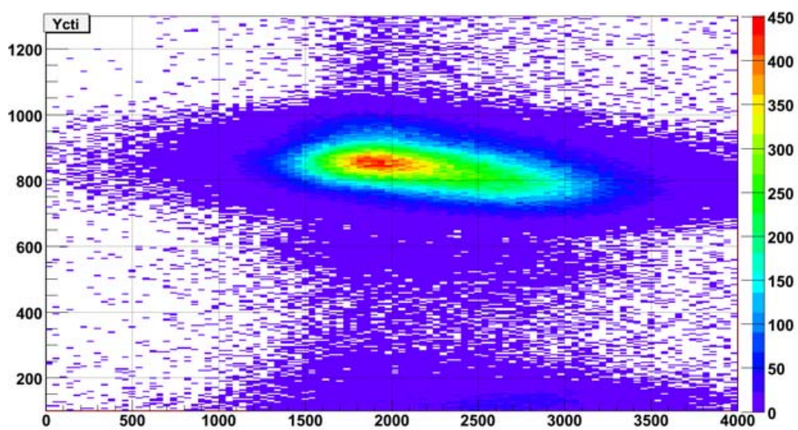
after correction

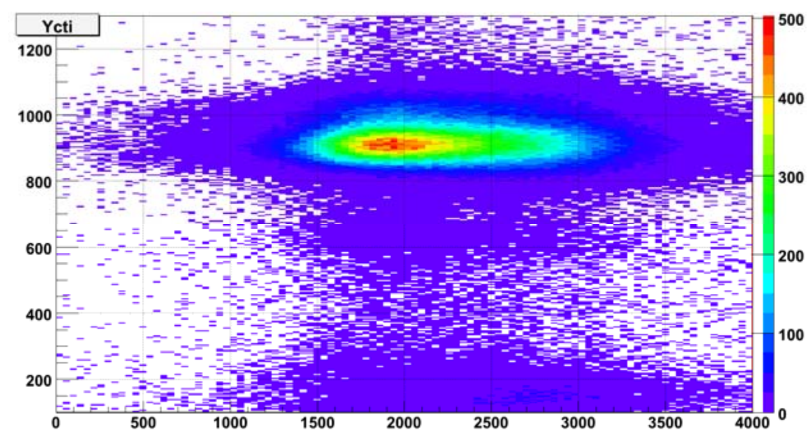
X direction, serial transfer CTE=0.999911





Y direction, parallel transfer CTE=0.999996

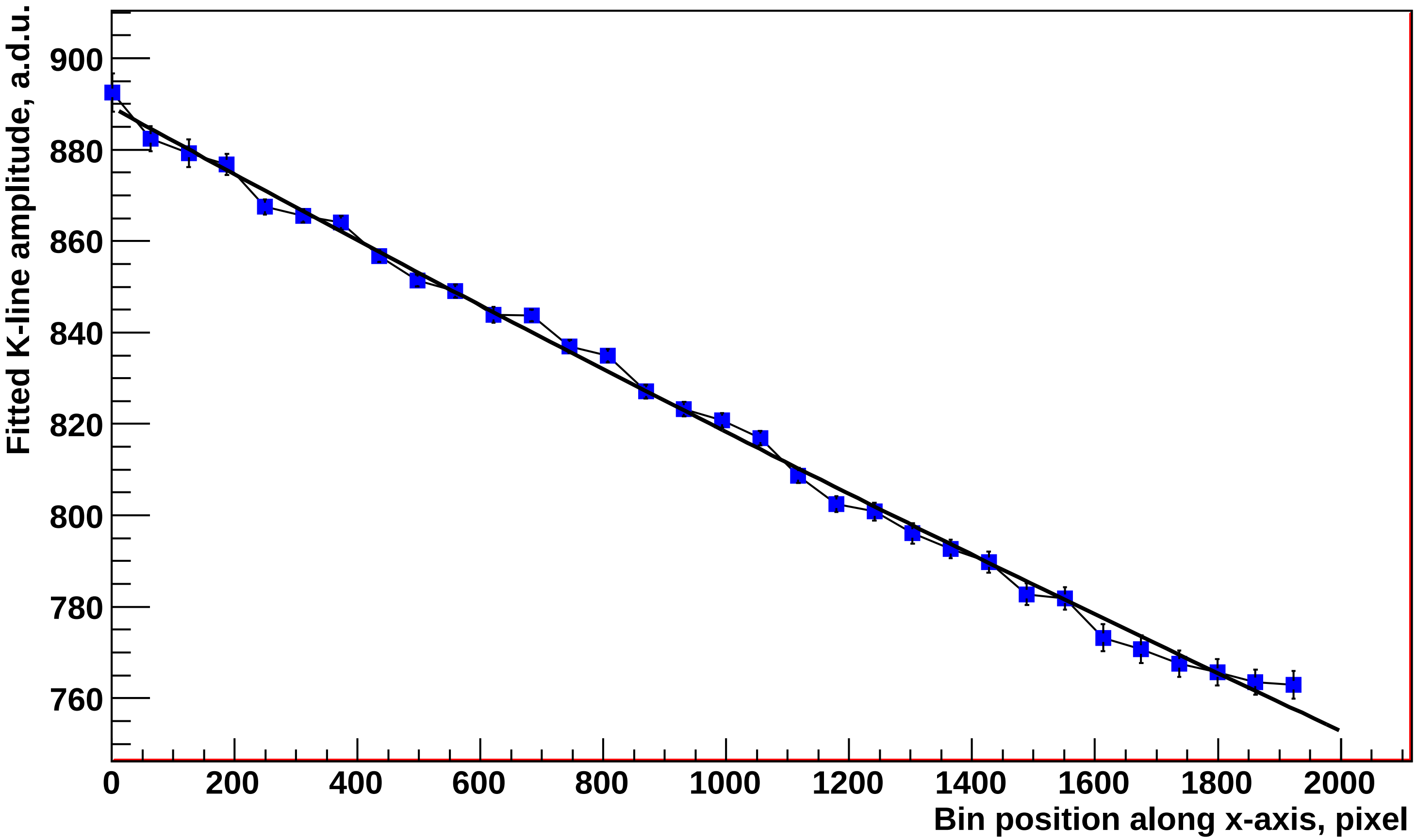




^{55}Fe express analysis: CTE

device 106-07, T=-140C

X direction, serial transfer CTE=0.999911



CTE is calculated using least square regression method assuming exponential amplitude dependence on coordinate.

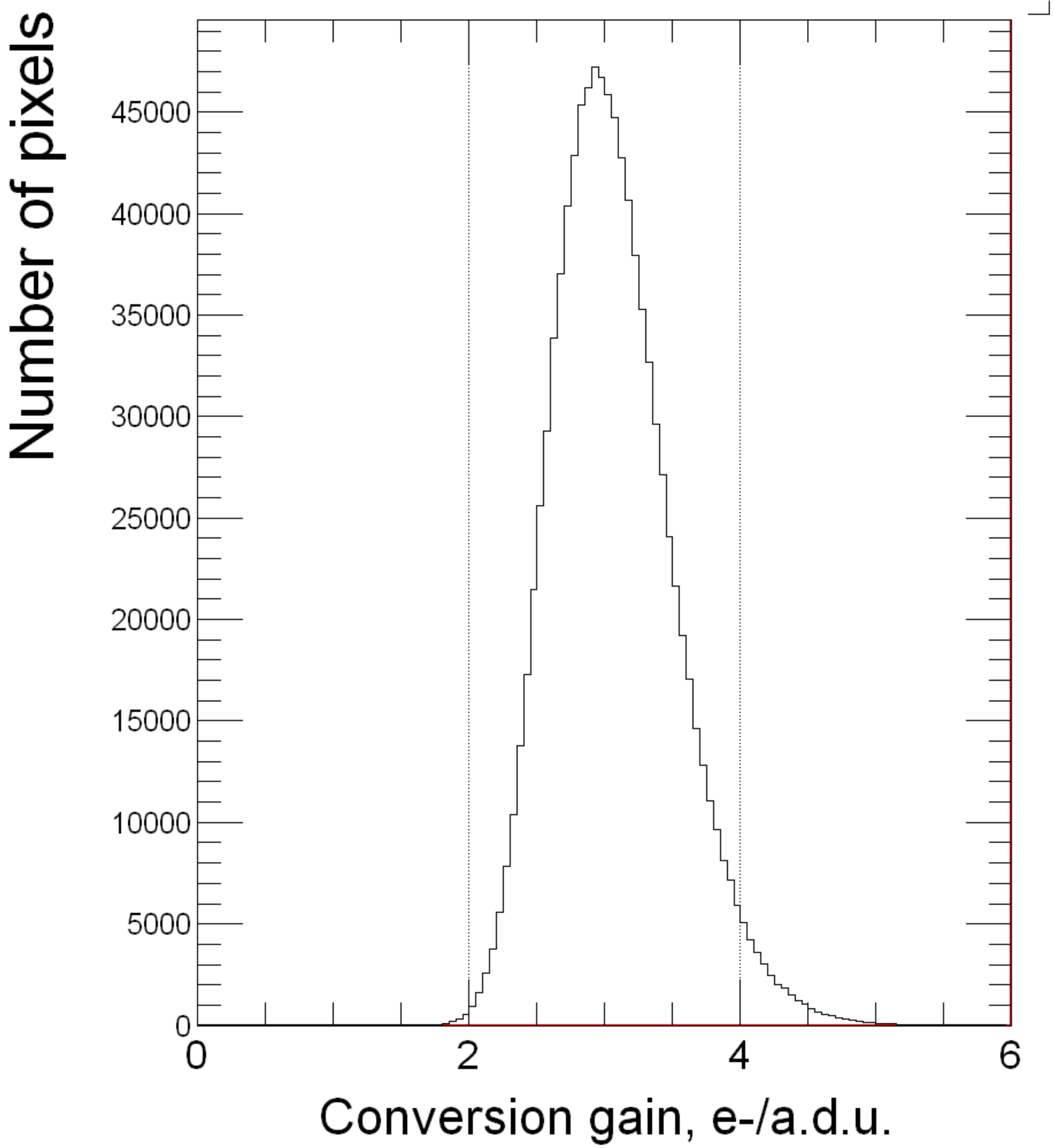
Gain determination using Poisson statistics properties

- number of electrons registered in a pixel, n_e follows Poisson statistics
  - $\mu = \sigma^2$
- amplitude recorded in the pixel
  - $A = n_e \times g$ → $g = \sigma_A / \langle A \rangle$
- usual approach → flat field image
  - variations in photon flux and pixel responses across the image lead to apparent gain dependence on the mean number of registered electrons
- new approach → multiple flat field exposures
  - gain is measured for each pixel
  - statistical sample for each pixel is number of exposures, N
  - stat error in a single pixel measurement is

$$\Delta_g / g = \sqrt{\frac{2}{N-1}\left(1+\frac{1}{2\mu_e}\right)}$$

Gain determination using Poisson statistics properties (2)

- Agreement between ^{55}Fe measurements and Poisson stat method is within 1%
- better accuracy can be achieved



Conclusions

- The suit of automated tests is developed for CCD characterization
- This allows us to run the full characterization sequence in fully automated mode
- The integral parts of our automation approach are:
  - bash + rts2 scripts
  - database use for test metadata access
  - the express analysis of test results
- The automation strategy was developed during study contract sensor testing
- Analysis algorithms, code and scripts were tested and are currently in use for sensors detailed studies

Unique Technical Challenges Have Driven the Camera Design

- Very large field of view implies a physically large focal plane (64-cm diameter) with small (10 micron) pixels.
- Fast f/1.2 beam leads to short depth-of-field.
- Camera located in the telescope beam.
- Broad spectral coverage.
- Fast readout (3 Gigapixels in 2 seconds).
- Large number of signal lines and large cryostat

➢ Mosaicing a large number (189) of sensors with narrow interchip gaps (100 microns).

➢ Tight alignment and flatness tolerances (10 micron p-to-v) on the sensor array.

➢ Tight constraints on envelope, mass, and dissipation of heat to ambient.

➢ Deep, fully depleted CCDs, but with minimal charge spreading.

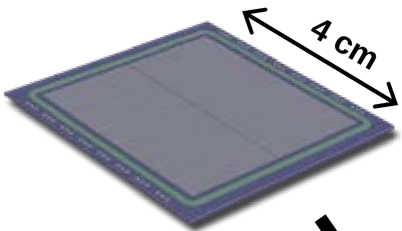
➢ Sensors must be highly segmented (16 readout ports).

➢ Electronics must be implemented in the cryostat.

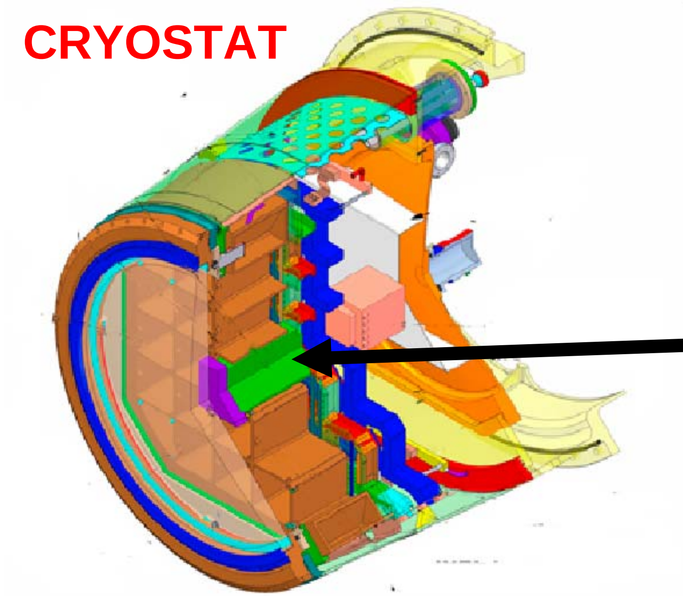
Development of the CCD Sensors is the Pacing Item.

4K x 4K CCD

- 10 micron pixels = 0.2”
- extended red response
- 2 second readout
- 16 outputs

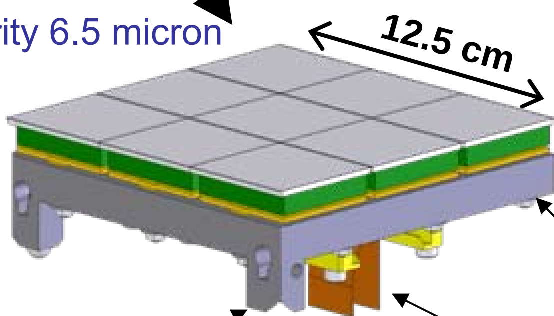


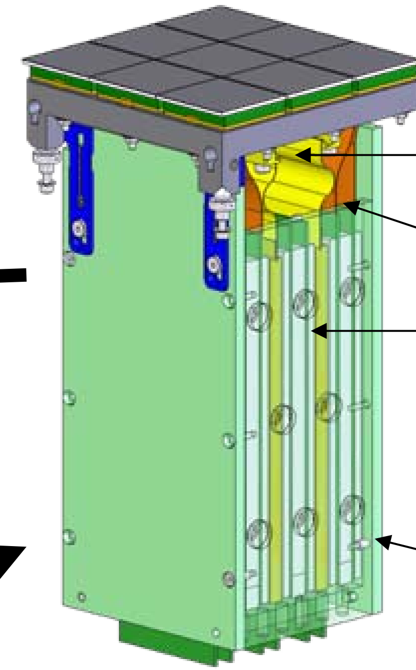
CRYOSTAT



RAFT

- 9 CCDs
- coplanarity 6.5 micron





TOWER

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