Large Synoptic Survey Telescope

Séminaire Technique LPC Clermont
Implication technique de l'IN2P3 dans le projet LSST

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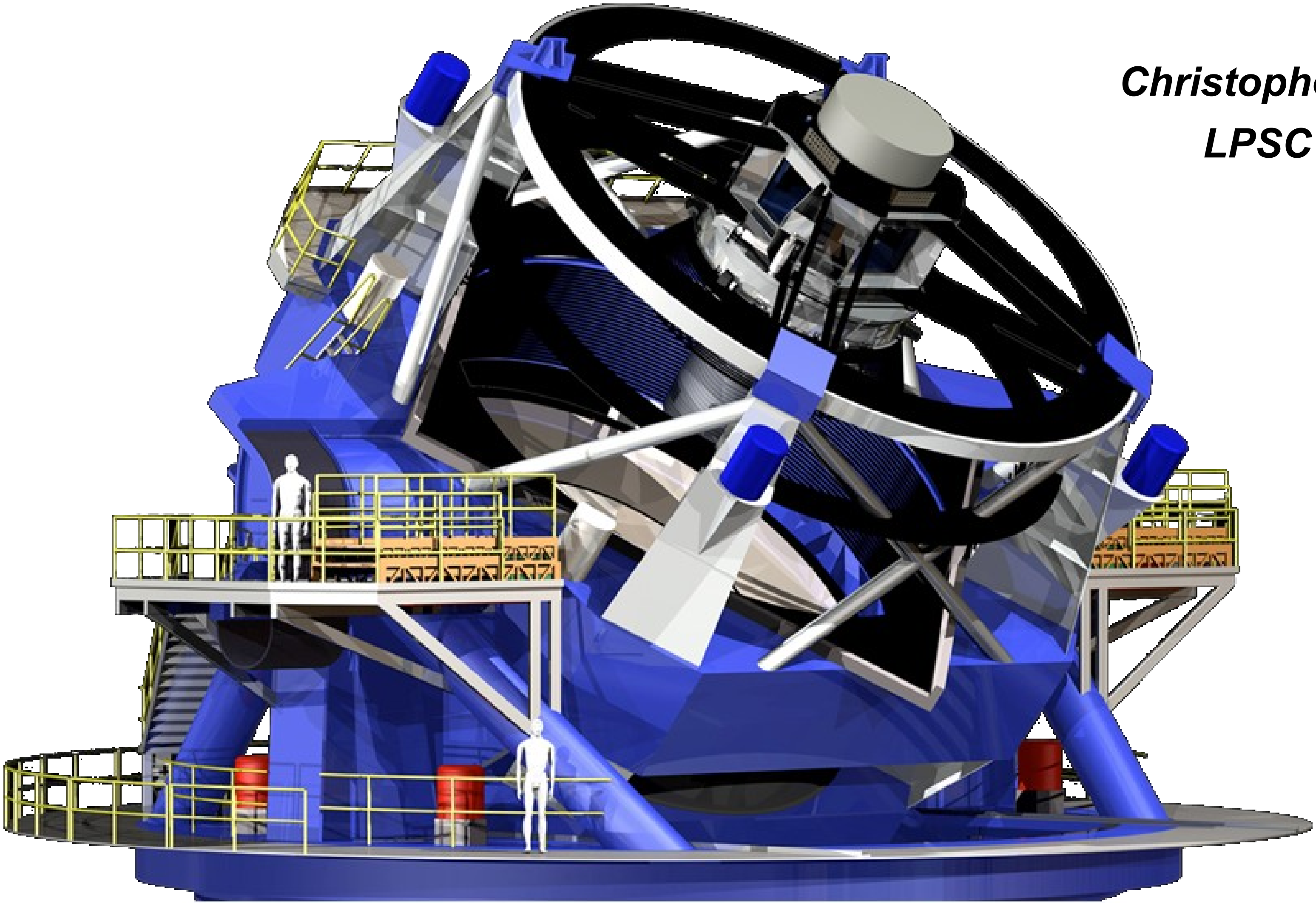


LSST in Brief

Large Synoptic Survey Telescope

- **Telescope**
  - 3 mirror compact design
  - 8 m primary mirror
  - Wide aperture , f/1.2 : 15s exposure time
  - Very large field of view (9.6 square degree)

- **Camera**
  - 64 cm segmented focal plane
  - 189 CCD : 3.2 G.pixels
  - Fast readout : 2s

- **Data Management**
  - Processing : > 100TFLOPS sustained
  - Storage : 60GB/s read, 6GB/s write, 15 PB/Years
  - Communications : 2.5 Gb/s sustained, 10 Gb/s peak

LSST Wide-Fast-Deep Survey

- 6 filter survey of 20,000 deg^2 to ~27 mag co-added depth
- One 6-Gigabyte image every 17 seconds
- 15 Terabytes raw data every night for 10 years
- 100-Petabyte final image data archive anticipated
- 20-Petabyte final database catalog anticipated
- Real-Time Event Mining: ~100,000 events per night, every night, for 10 yrs
- Repeat images of the entire night sky every 3 nights

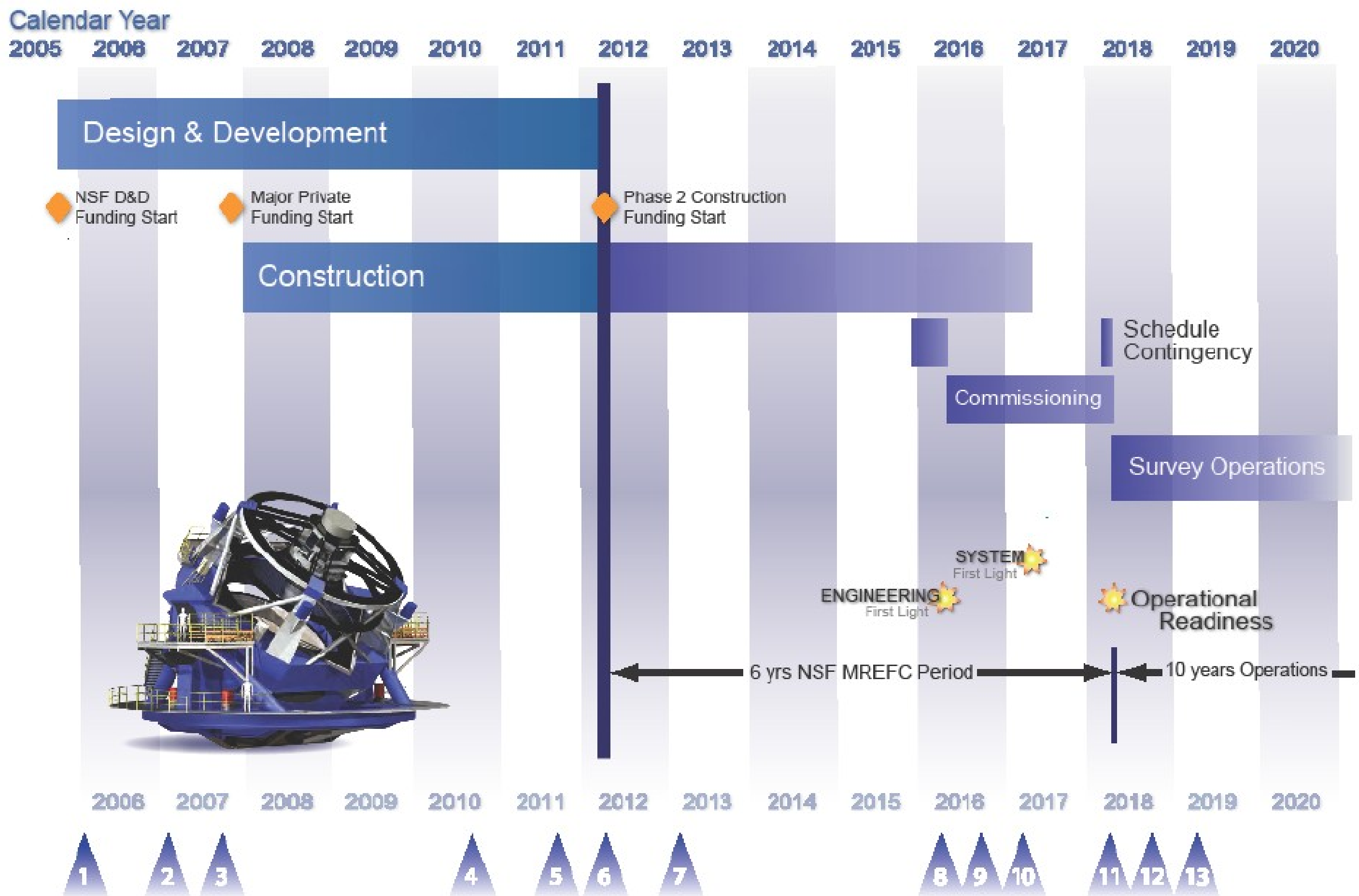
LSST Organisation

- **LSSTC :**
  - Non-profit corporation
  - Private/Public Partnership
  - 34 institutional members
    - US universities and labs
    - Private companies : Google
    - Chile
    - IN2P3
  - Private donors
    - Bill Gates & Charles Simonyi
  - LSST Project divided in 3 main technical WP
    - Data Management (NSF, ~100M$)
    - Camera (DOE HEP, ~ 120M$)
    - Telescope & Site (NSF, ~180M$)

LSST Science

- 4 main science goals
  - Dark Matter and Dark Energy
  - Solar System
  - Transients
  - Galactic Structure
- Science book
  - http://www.lsst.org/lsst/scibook
  - 15 chapters, 600 pages …
- Decadal survey : Astro2010 (August 13th 2010)
  - LSST has been ranked top priority for the next large ground-based astronomical facility by the National Research Council for the National Academy of Sciences.
    - Scientific interest
    - Technical readiness
  - This is the kick-off for construction funding (NSF, DOE)

LSST Schedule



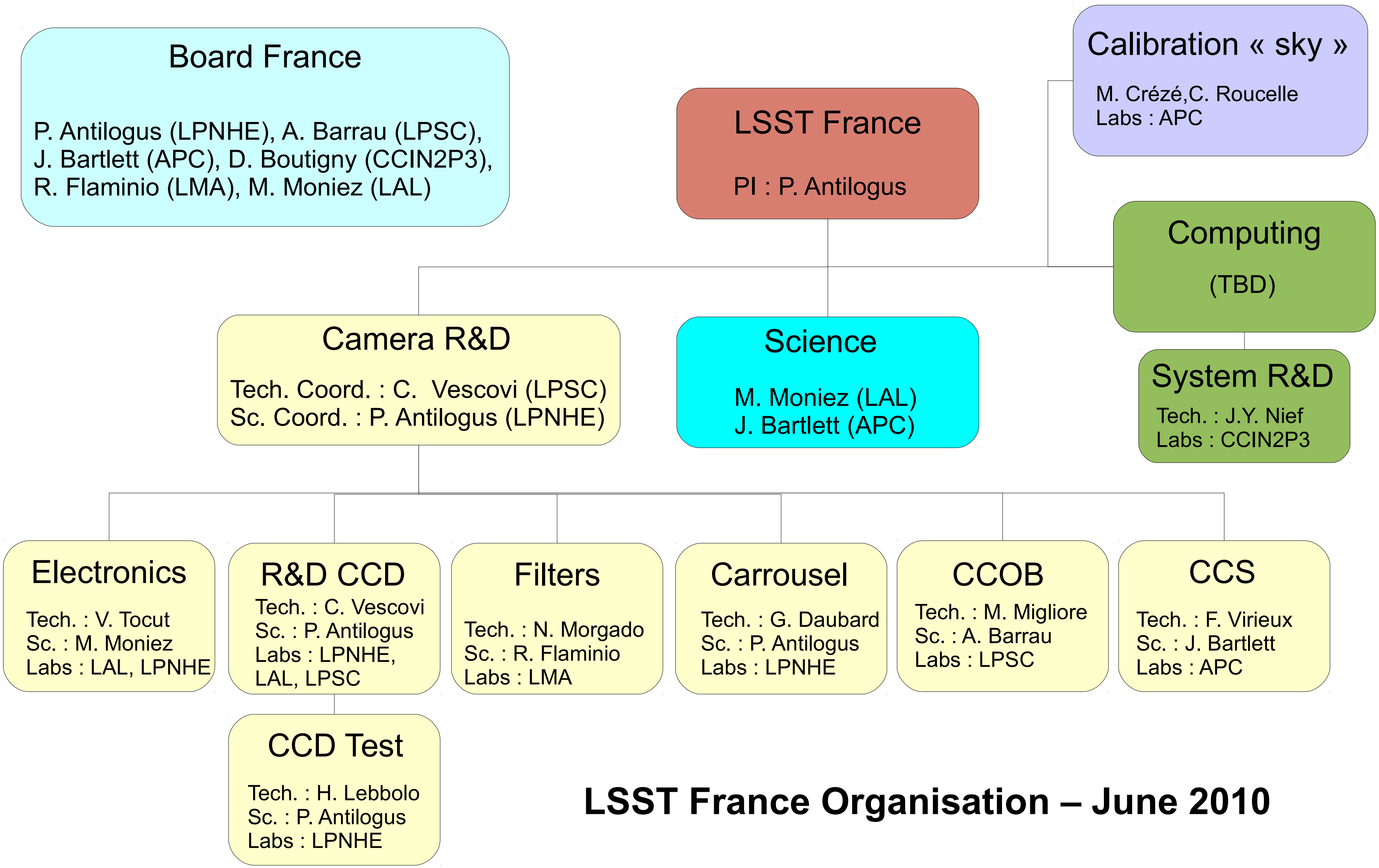
Major Project Milestones:

1. Sep 2005 NSF D&D Funding Start
2. Feb 2007 NSF MREFC Proposal Submitted
3. Sep 2007 NSF Conceptual Design Review
4. Oct 2010 NSF Preliminary Design Review
5. Oct 2011 NSF Critical Design Review
6. Apr 2012 Construction Funding Start; DOE Acquisition Funding Start
7. Apr 2013 First Camera Raft Complete
8. Apr 2016 First Engineering Light with Eng Camera System Integration and Test Begins
9. Oct 2016 Archive Center Complete
10. Mar 2017 System First Light with 3.2 GP Camera System Science Validation Begins
11. Apr 2018 Full Science Operations Begins
12. Oct 2018 First LSST Data Release
13. Apr 2019 Second LSST Data Release

IN2P3 and LSST

- **Start of French participation to R&D in 2007**
  - **APC, CCIN2P3, LAL, LMA, LPNHE, LPSC and CPPM in 2010**
  - **Main contributions :**
    - **CCD procurement (25% of the CCDs)**
    - **Filter procurement and measurements**
    - **Filter changer mechanism**
  - **Additional contributions :**
    - **CCD readout ASIC**
    - **Calibration**
    - **Slow Control**
- **IN2P3 official member of LSSTC**
  - **MOU for R&D phase signed in 2009**
  - **MOU for Construction phase to be signed in 2011**

LSST France Organisation



LSST France Organisation – June 2010

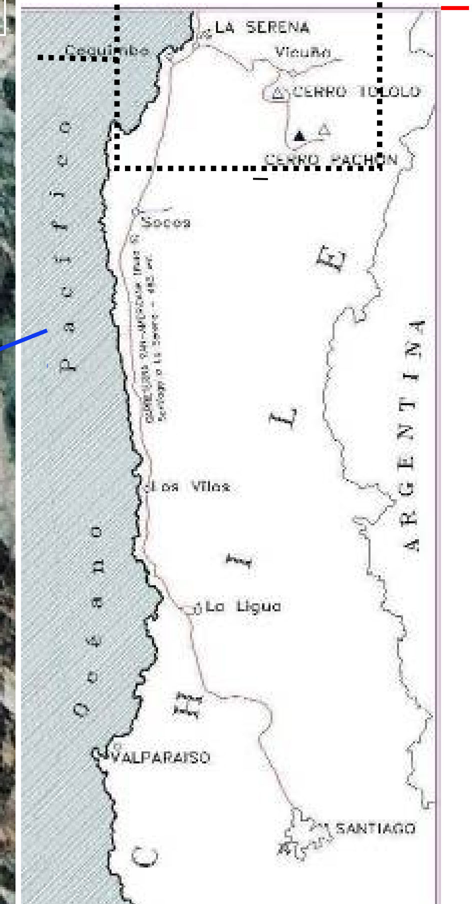
LSST France Manpower & Funds

- Manpower
  - 20 FTE working on the project in 2010
  - This will increase during the construction phase
- TGIR Funding
  - First recurent budget from TGIR in 2010
  - Secured for the R&D phase (up to 2012)
  - Prepared for the construction phase
  - Travel money not covered by TGIR → Other funds needed
- Total 2010-2015
  - TGIR Plan for the project is 6.5M€, 10% is R&D
  - Manpower cost : 15 M€ from 2010 to 2015
  - Other funds : 900 k€ (150k€/year average)
    - IN2P3, P2I, P&U, BQR, University
    - 2008:184k€, 2009:180k€, 2010:90k€

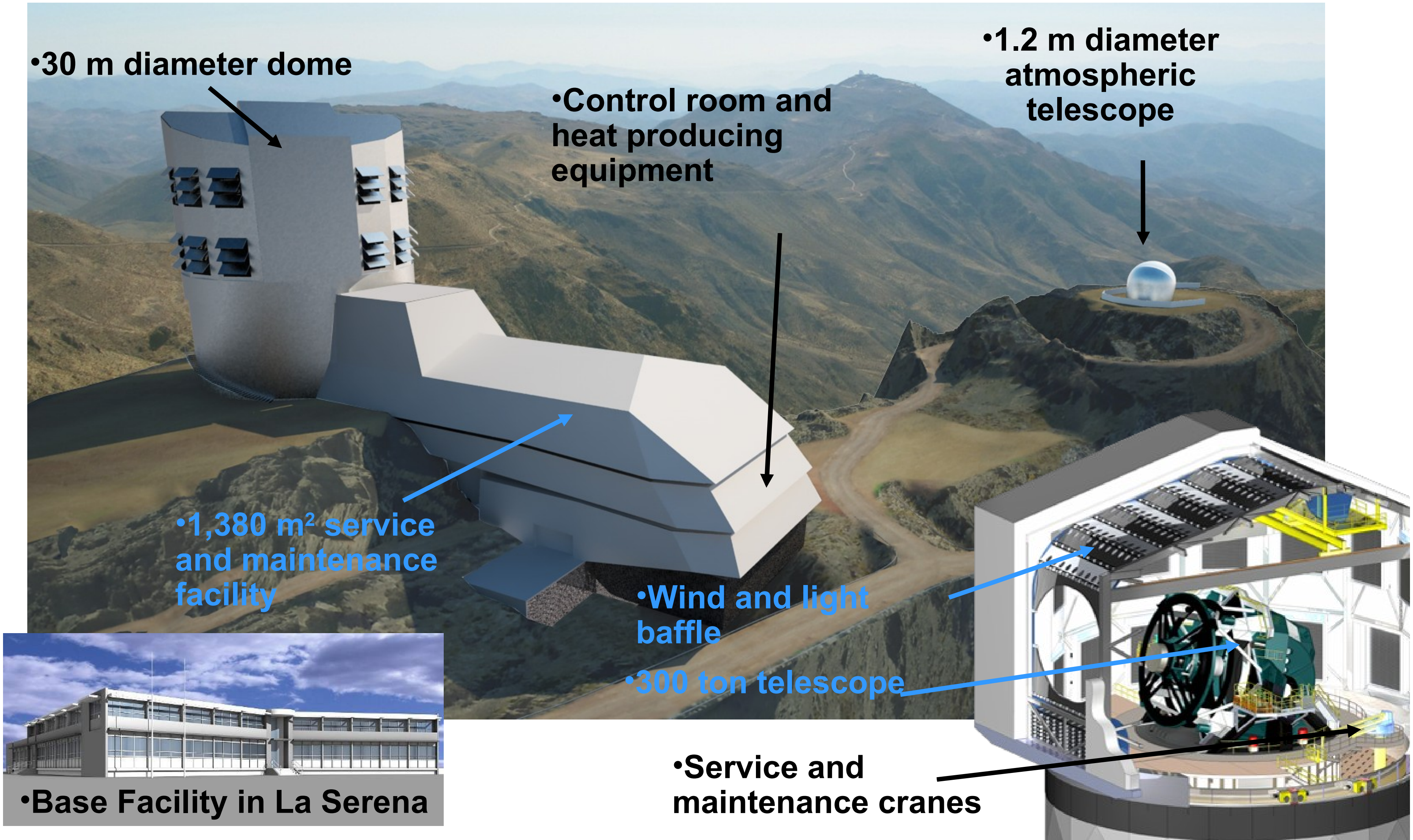
LSST Telescope & Site short description

Large Synoptic Survey Telescope

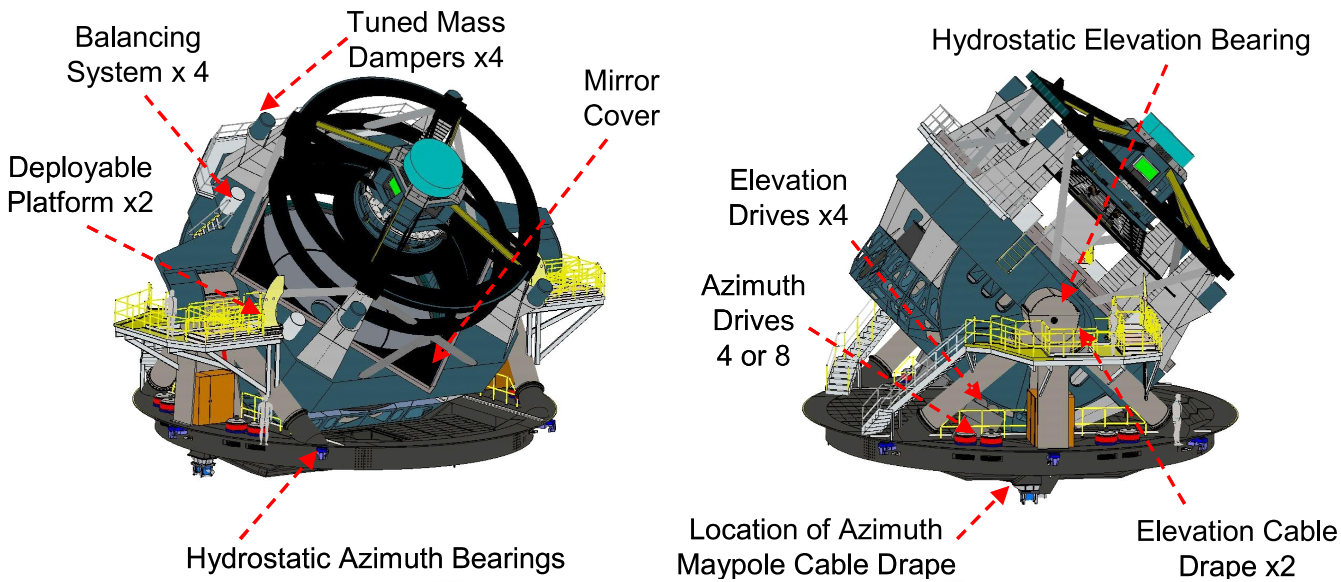
•The site has been chosen on Cerro Pachón, Chile



The future LSST site

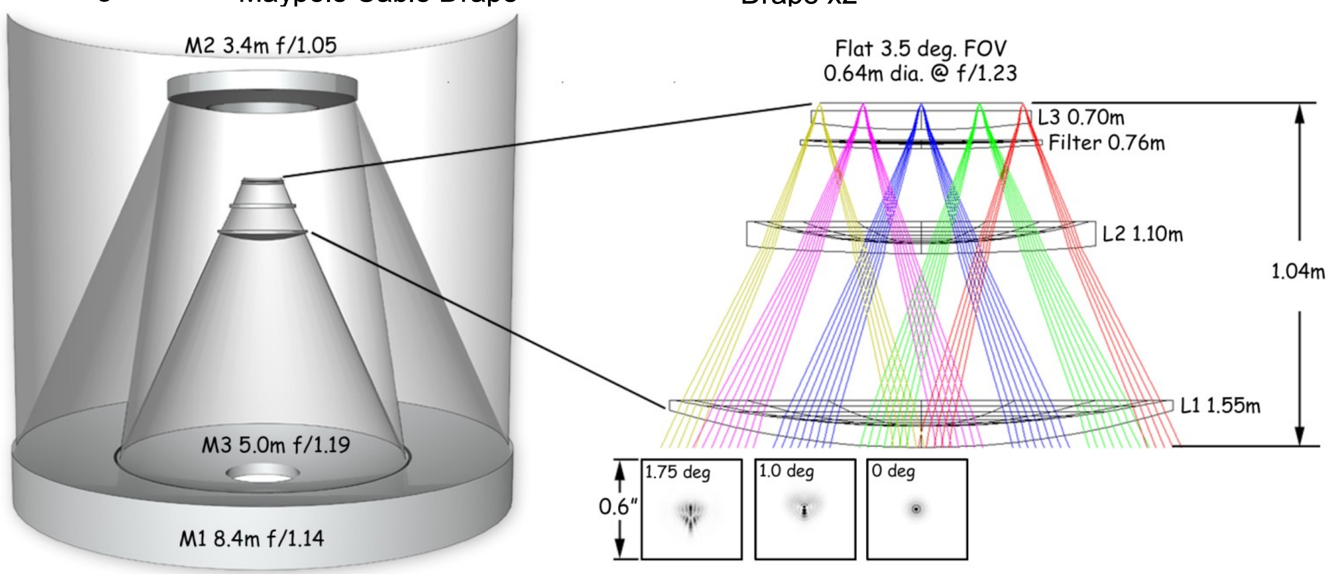


LSST Telescope



- **Moving structure:**

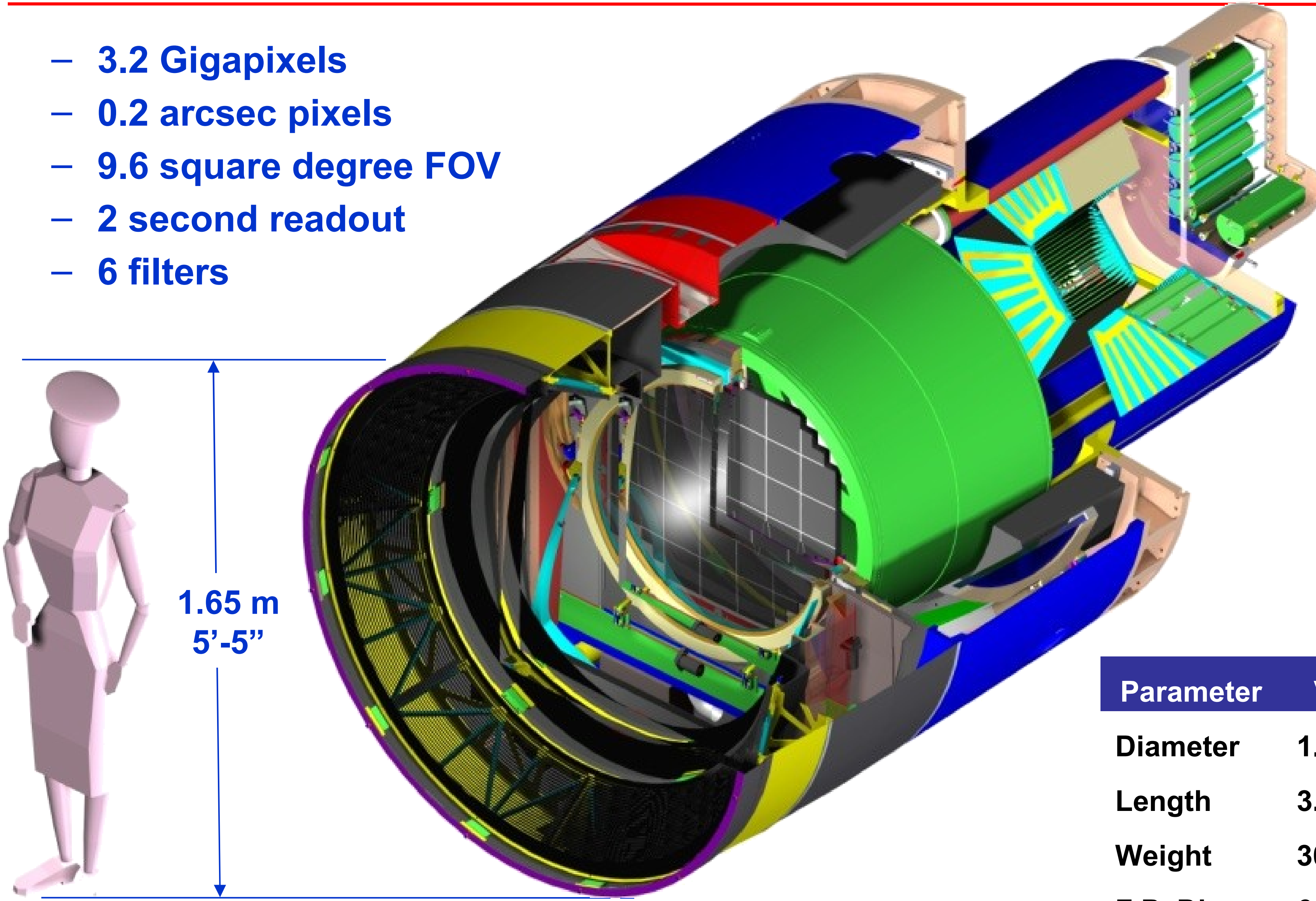
  300 tons
- **Compact 3 mirror design + corrector**



LSST Camera in Detail
(almost ...)

LSST Camera : the largest digital camera for astronomy

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



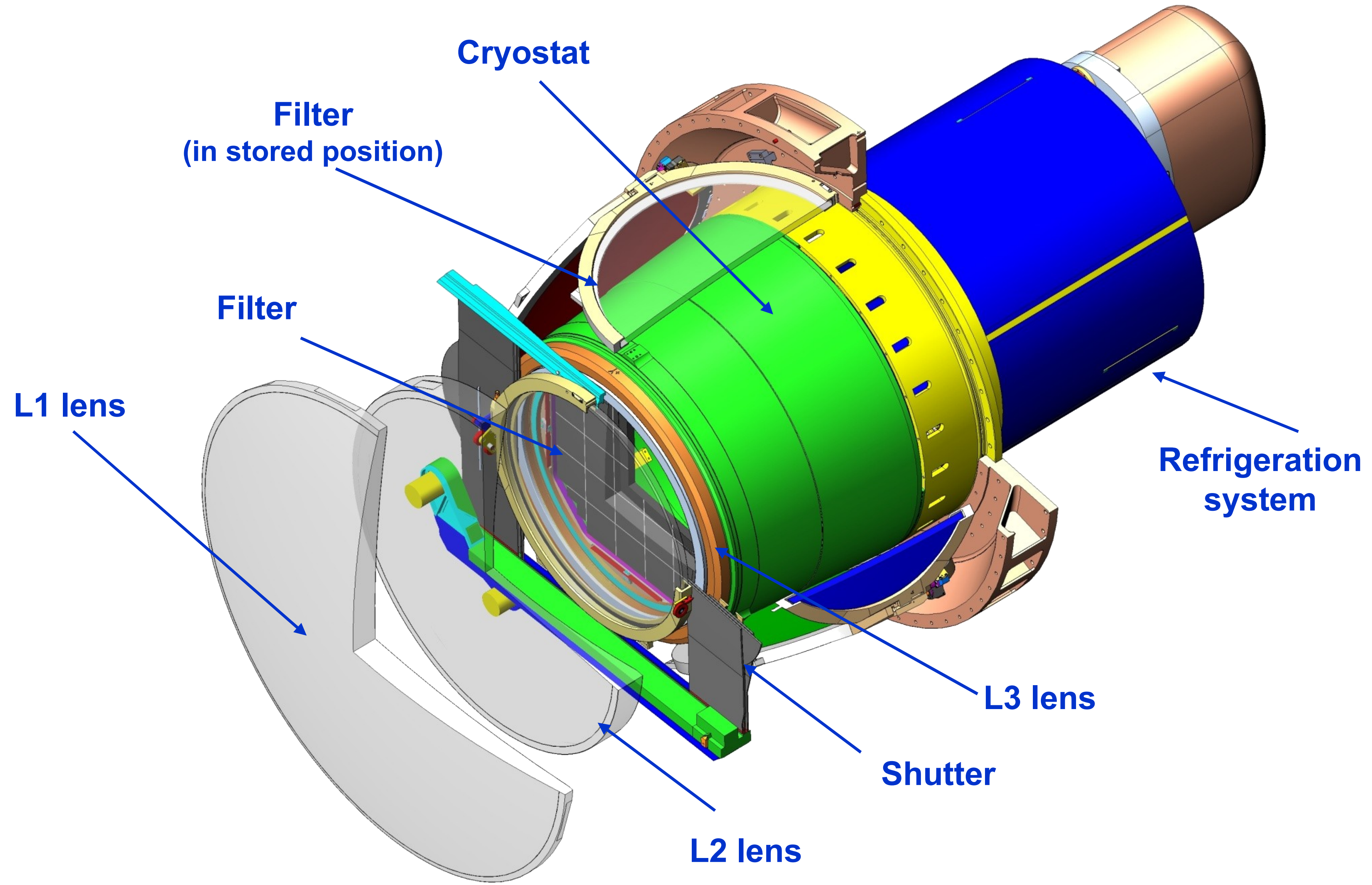
Parameter	Value
Diameter	1.65 m
Length	3.7 m
Weight	3000 kg
F.P. Diam	634 mm

Unique technical challenges drive camera design

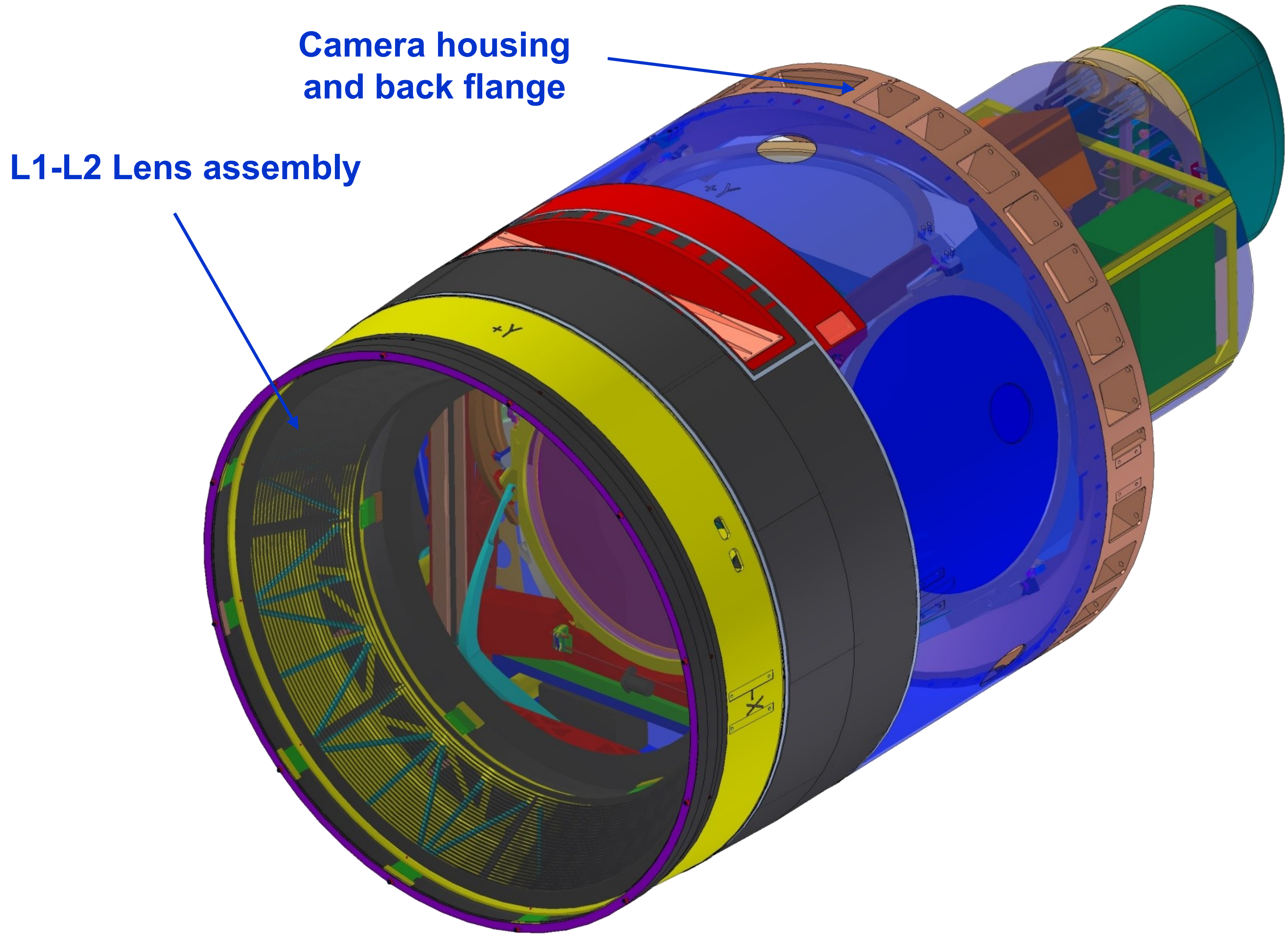
Large Synoptic Survey Telescope

Very large field of view (9.6 square degree FOV) implies a physically large focal plane (64-cm diameter) with small (10µm) pixels	⇒ Mosaicing 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, & dissipation of heat

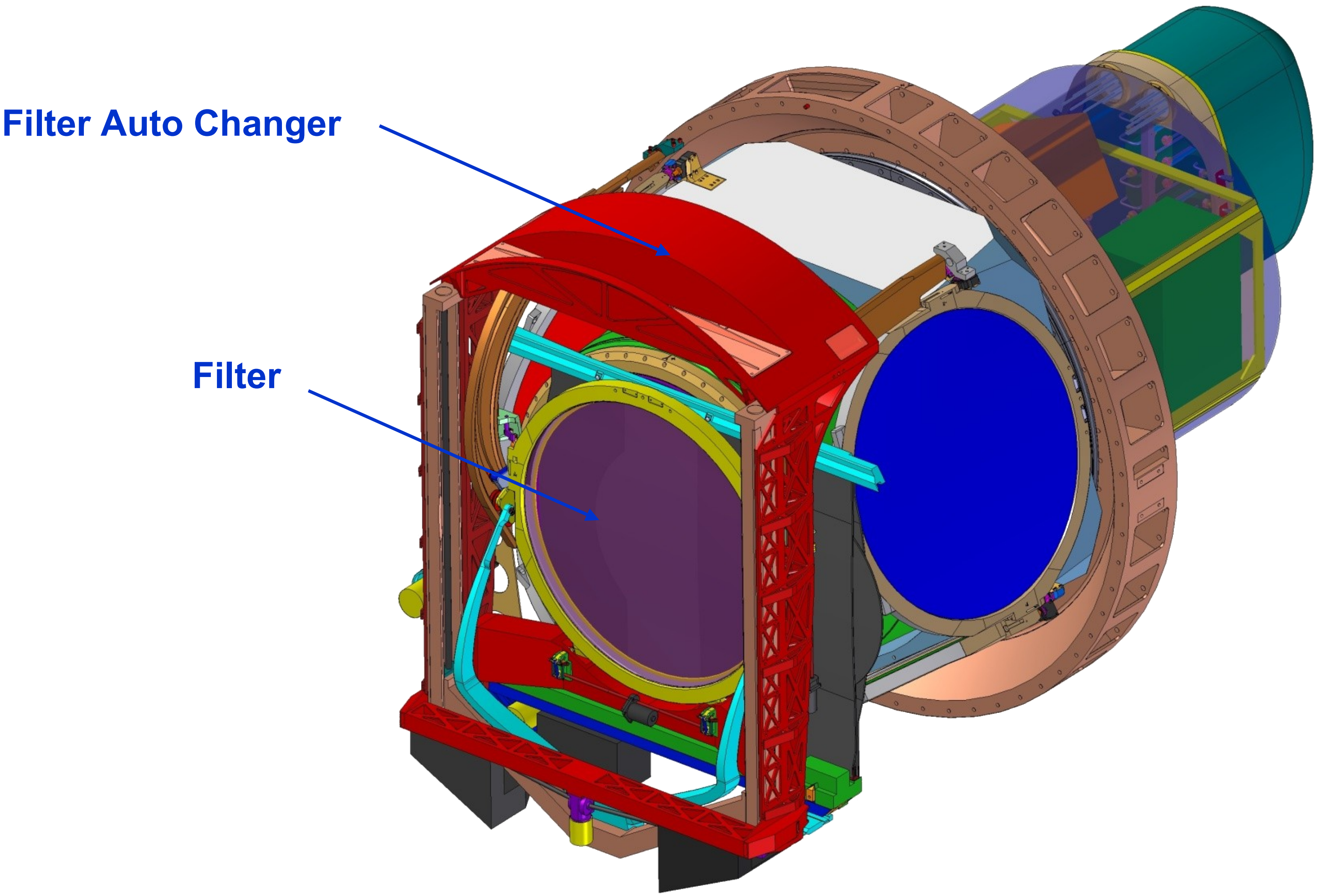
Integrated complex sub-systems tightly packaged within the telescope optical constraints



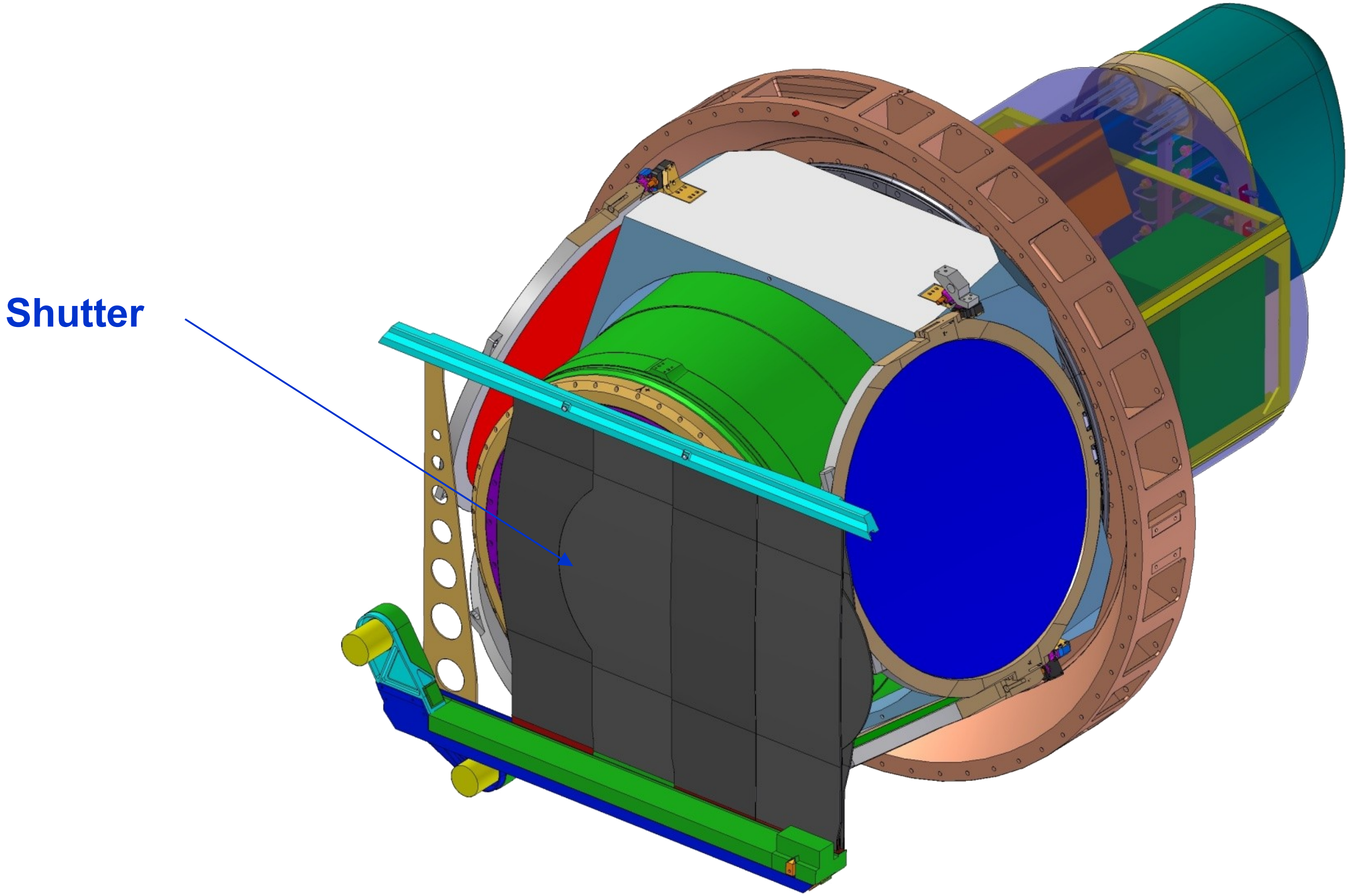
Walk-through 1: Overall view



Walkthrough 2: Camera partial assembly showing Auto Changer

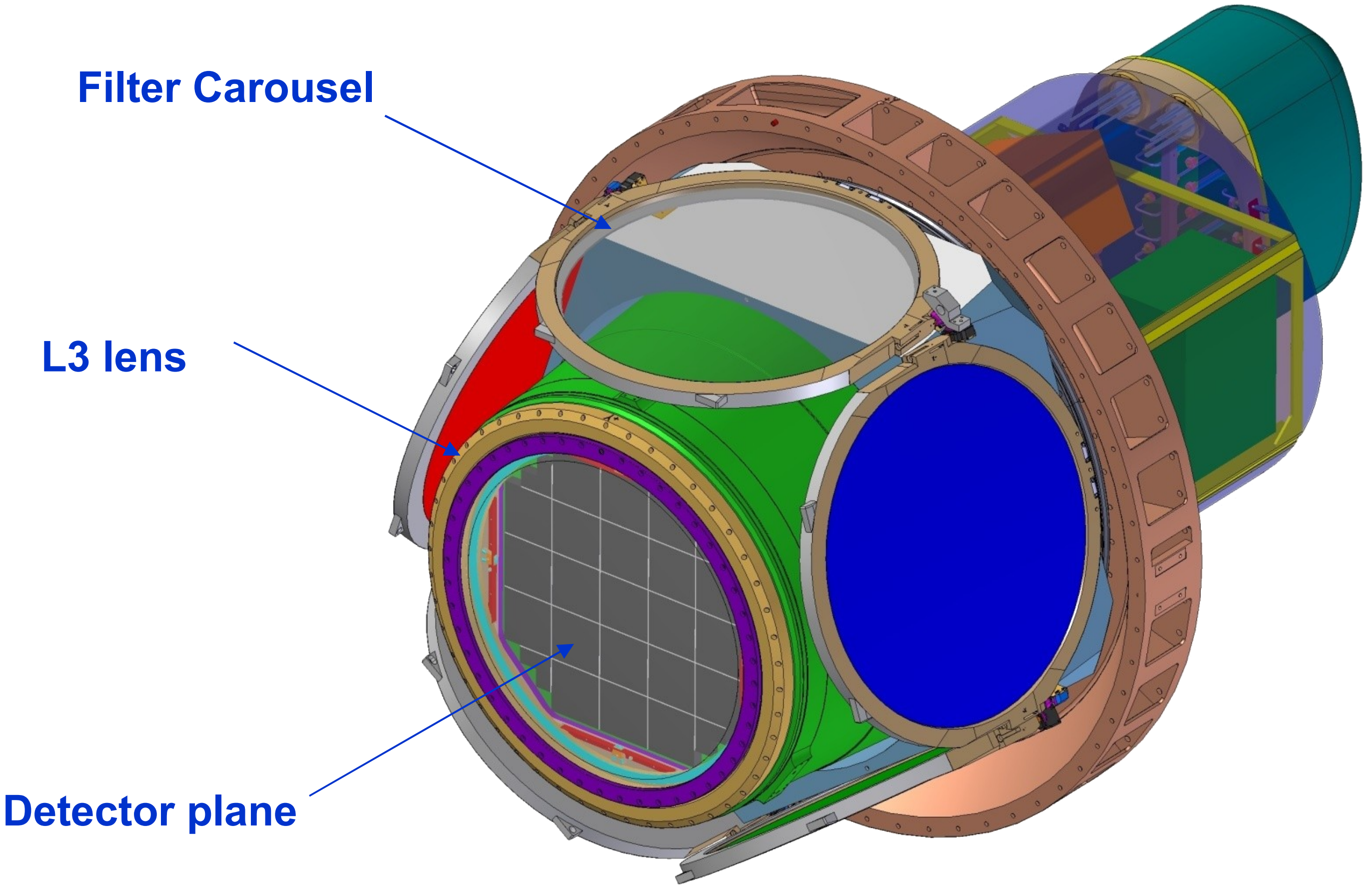


Walkthrough 3: Camera partial assembly showing Shutter

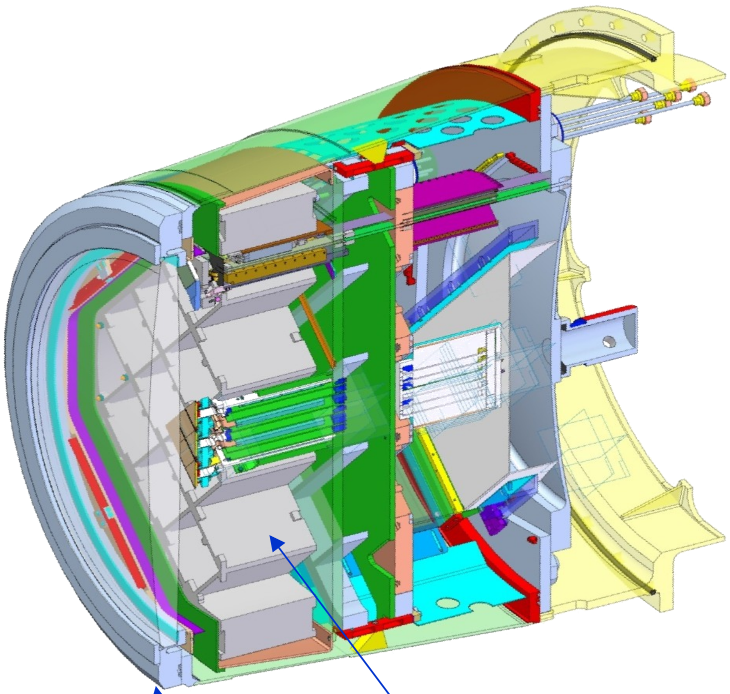


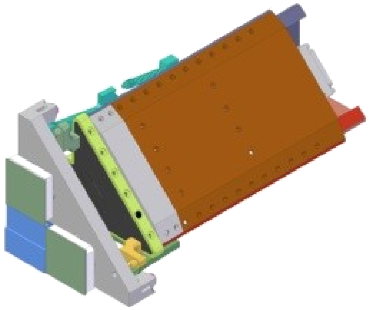
Walkthrough 4: Camera partial assembly showing Carousel, Cryostat, and detector plane past L3 lens

Large Synoptic Survey Telescope



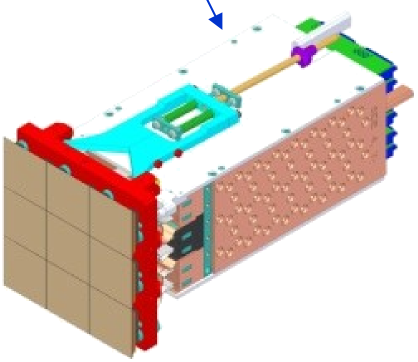
Walkthrough 5: Cryostat section showing detectors, structure and thermal control elements





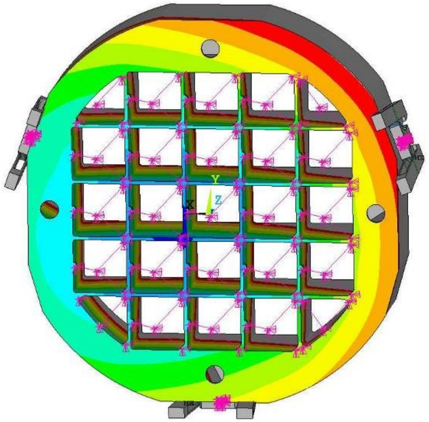
Corner Raft Tower
2 guide sensors
1 wavefront sensor
Front end electronics

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



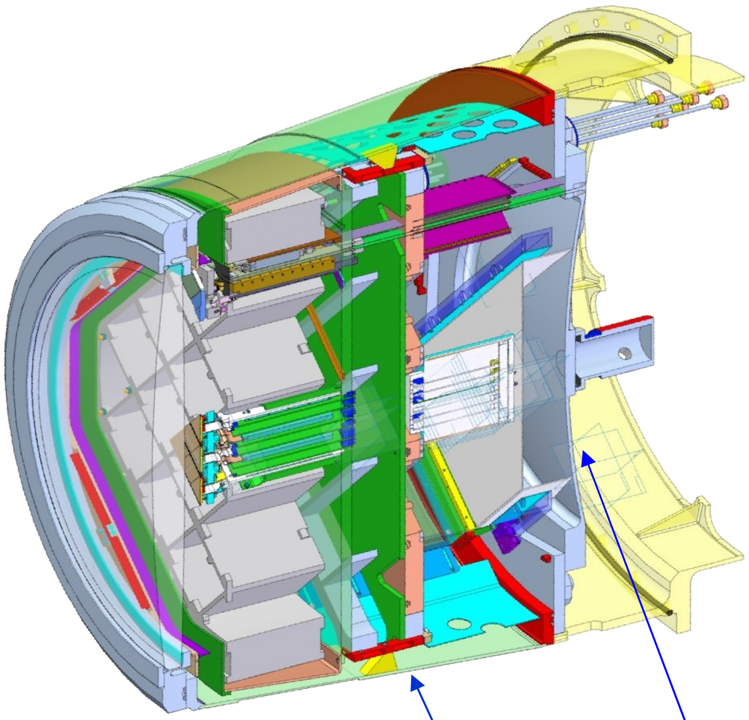
L3 lens assembly

Grid assembly
Cesic ®



Cryostat environmental systems maintain clean vacuum and thermally stable focal plane region

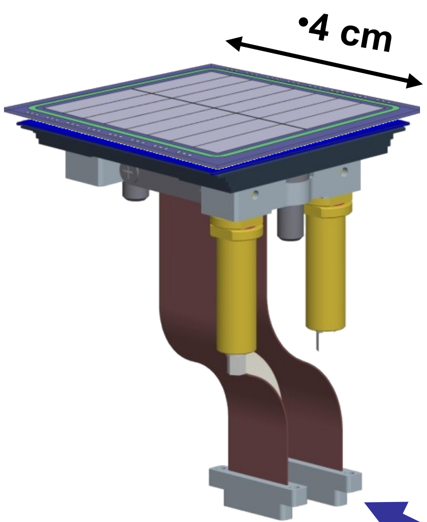
- **Design features**
  - Mixed refrigerant cryogenic cooling system with room temperature gas transfer lines
    - 600 W capacity at -130ºC
  - Two isolated vacuum regions to reduce contamination risk
  - Getter pump near focal plane
- **Key development activities**
  - Prototype mixed refrigeration system for thermal performance
    - Demonstrate control functionality
    - Fabricate & test full-scale prototype
  - Cesic® single bay prototype for manufacturing, flexure prototype & structural and metrology studies underway.



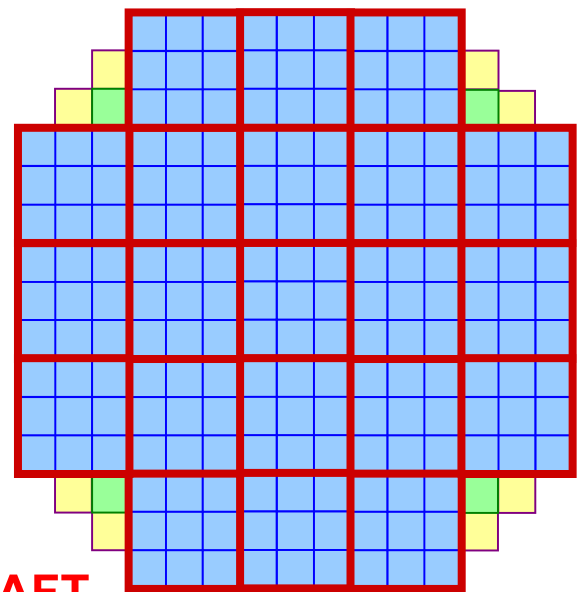
The Sensors subsystem consists of the 21 “science rafts” that make up the 3.2Gpix focal plane

4K x 4K CCD

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

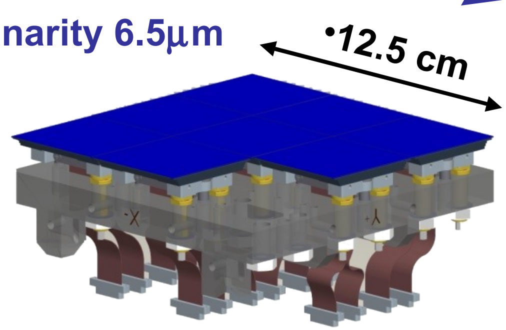


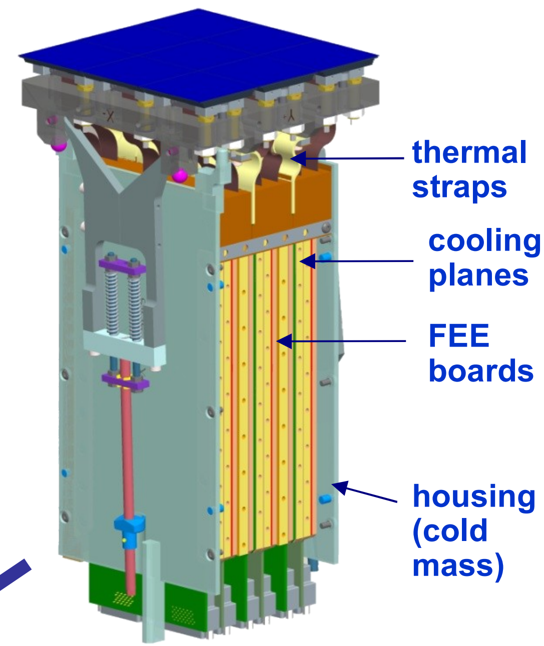
FOCAL PLANE WITH 21 SCIENCE RAFTS



RAFT

- 9 CCDs
- coplanarity 6.5μm





TOWER

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

Unique science goals drive sensor design

Large Synoptic Survey Telescope

Driving Requirements	Design Features	Details
Large field of view implies physically large focal plane (64cm)	Modular mosaic focal plane construction	21 rafts × 9 CCDs/raft
Broadband, high spectral sensitivity	Thick silicon sensor, back illuminated, AR coat	100 micron thickness for IR sensitivity
Seeing-limited image quality	Internal electric field to minimize diffusion	High resistivity, biased silicon (> 3 kΩ-cm, -50V)
Fast f/1.2 beam, shallow depth of focus	Small pixels, tight alignment and flatness tolerance, stable	Pixel: 10μm Flatness: 5μm Alignment (z axis): 10μm
Fast readout (2s)	Highly parallel readout	16 amplifiers/4K CCD
High fill factor (>90%)	Close-butting of chips and rafts	Chip-chip: 250μm Raft-raft: 500μm
Large # of signal lines, large cryostat in beam	Low-power electronics in cryostat vacuum	ASIC-based, <200mW/channel

Brookhaven and Paris are the primary sites for sensor testing

BNL Cleanroom

IN2P3 Cleanroom

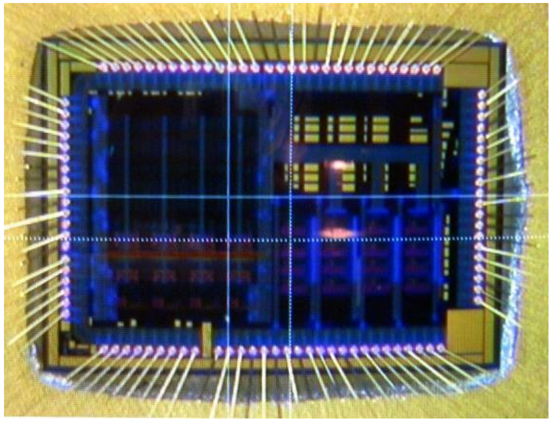
Common Controller Electronics and Software

CCD electronics must achieve 2 second readout with low noise, low cross-talk and low power dissipation

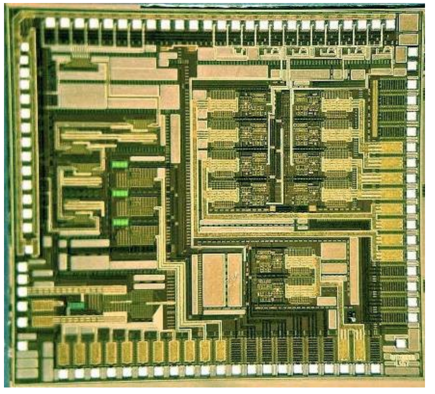
Large Synoptic Survey Telescope

- **Design Features**
  - Front end electronics support functions to control and read out CCDs.
    - Video processing with custom ASIC for compact size and reduced power
    - Clock/bias buffering electronics
  - Raft control crate (RCC) functions,
    - Video digitizing,
    - Clock sequencing,
    - Bias generation,
    - Temperature sensing, and
    - Interfacing to the control and DAQ systems.
- **Key development activities**
  - Testing 2nd & 3rd generation ASICs and 2nd generation boards
  - Prototyped all other components
  - Vertical slice test for integration and to characterize noise and cross-talk

ASPIC *(video processing)*



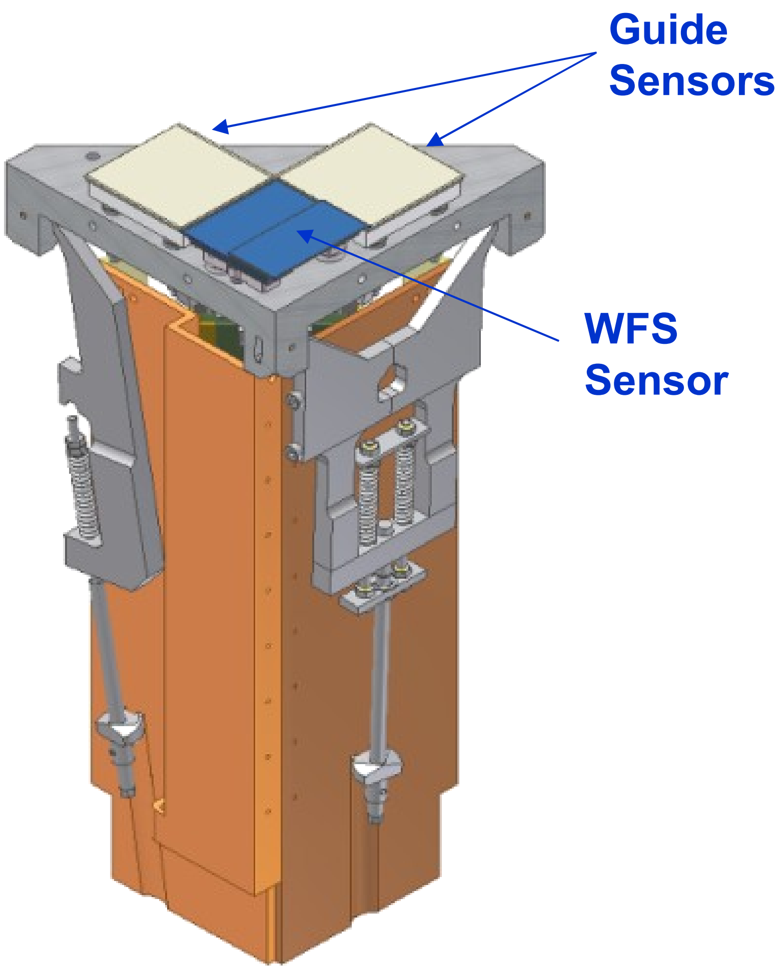
SCC *(clock/bias generation)*



Corner Raft System preliminary design is mature

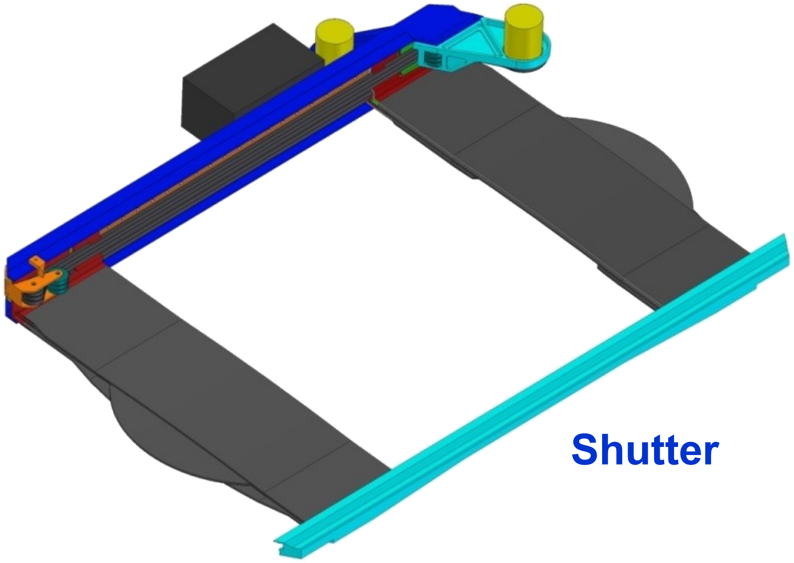
- **Design Features**
  - Curvature wavefront sensing using split science sensor
  - Guide sensor uses hybrid CMOS technology for fast windowed readout

- **Key development activities**
  - Construct rapid prototype to evaluate assembly tooling and procedures
  - Laboratory prototyping to validate hybrid CMOS algorithms and performance
  - Finalize WFS and Guide sensor packaging, electronics, and cabling schemes

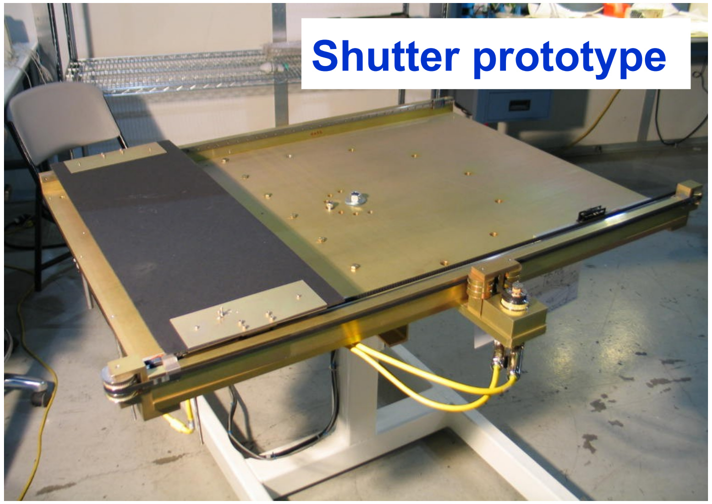


Shutter design builds on established technologies

- Design features
  - Stacked blade accommodates large aperture in tight volume
  - Double-blade design with servo feedback ensures repeatability, exposure time uniformity
  - Hall switch motion monitor mounted along the track avoiding moving cables and is light free

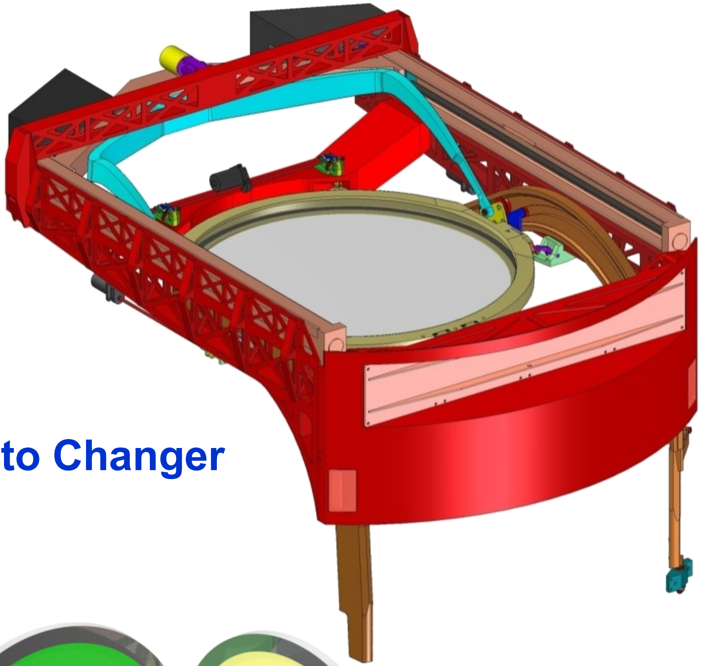


- Key development activities
  - Complete motion and control system prototype testing
  - Life-test drive-train components to spec wear and maintenance
  - Build & test full Shutter prototype

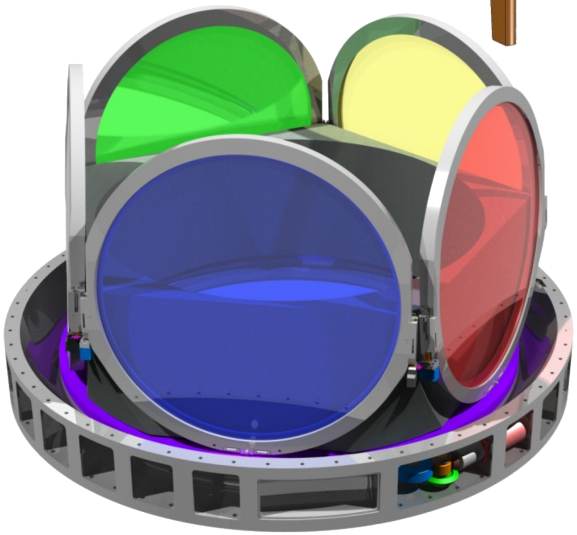


Filter Exchange System prototyping underway

- **Design features**
  - Industry standard motion control processes and products
  - Carousel safely stores 5 filters in clean environment
  - 2 minute exchange time
- **Key development activities**
  - Load and life-test Carousel components
  - Fabricate and load-test CFC Carousel support structure
  - Prototype Auto Changer mechanisms
  - Demonstrate control of particulate generation



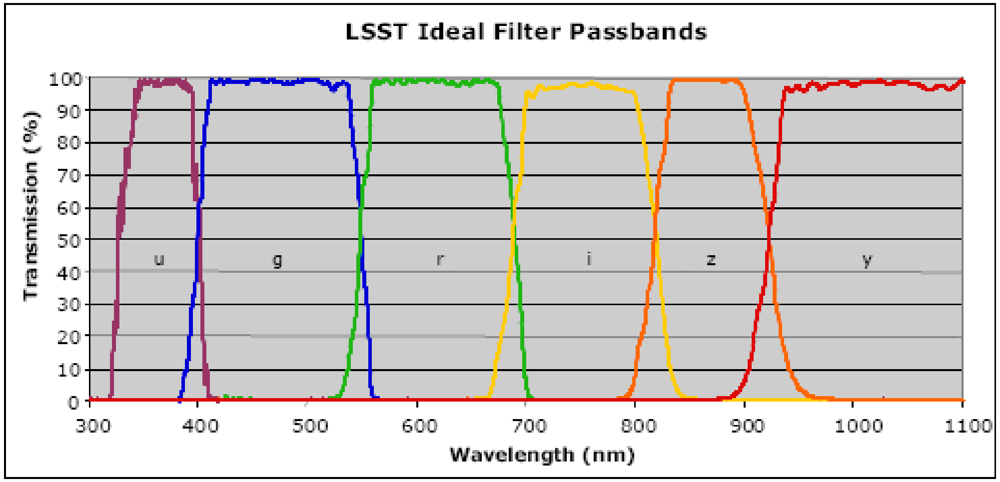
Auto Changer



Carousel

Filter vendor engineering design contract underway

- **Design features**
  - Unique interference coatings for defined bandpasses
  - Curved substrate to maintain normal incidence to incoming beam



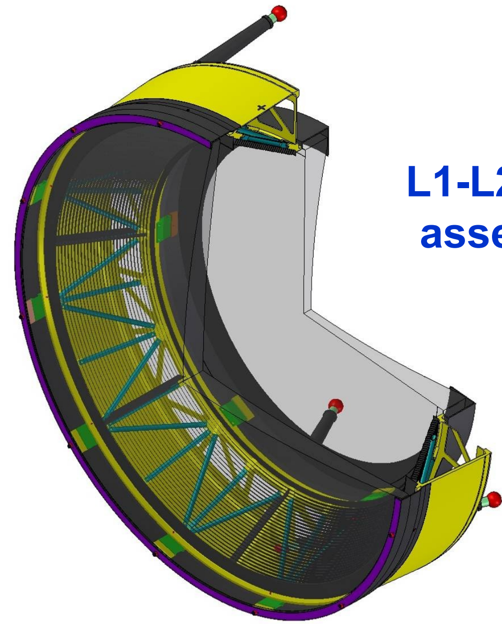
- **Key development activities**
  - Two vendors (JDSU, Sagem) to complete full engineering design
    - Analysis of coating prescription
    - Validation of manufacturing techniques to meet requirements
  - Full scale prototype coating to demonstrate uniformity
    - Finalize manufacturing processes

L1-L2 integrated as single assembly; L3 is entrance window to cryostat

Large Synoptic Survey Telescope

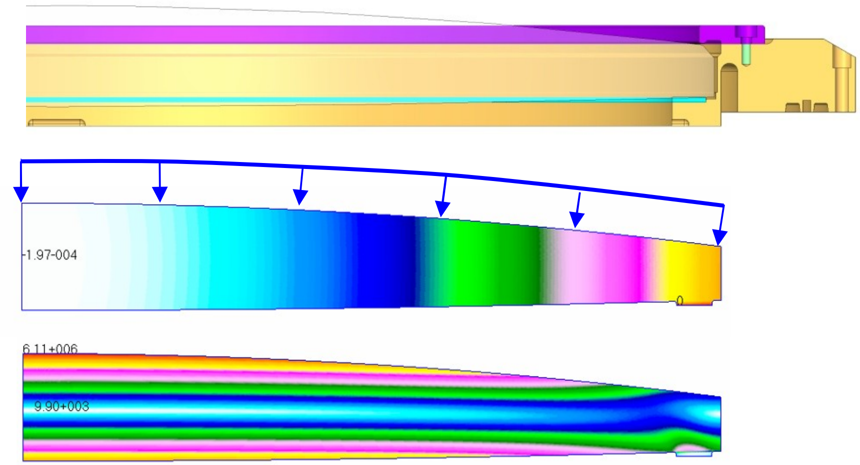
- **Design features**
  - Baffling, traps, and aperture rings minimize light scattering
  - Efficient structural design of L1-L2 ring reduces sagging and stress on glass
  - L3 flange reduces stress and temp gradients in lens

- **Key development activities**
  - Proof and destructive test L3 prototype lens and flange
  - Test stiffness and strength of L1-L2 assembly struts and flexures



L1-L2 lens assembly

Deflection and stress in L3 lens

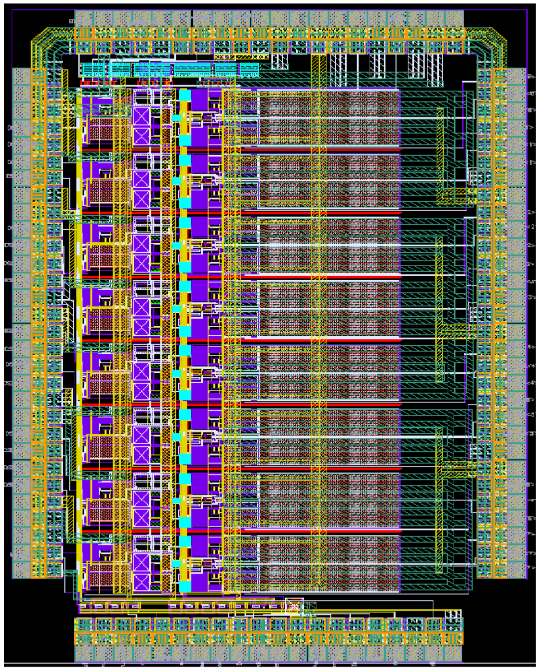


What have been done at IN2P3 ?

ASIC for CCD readout : ASPIC

Large Synoptic Survey Telescope

- **People involved in LAL and LPNHE**
  - **ASPIC design : V. Tocut, H. Lebbolo, R. Sefri**
  - **ASPIC tests : P. Antilogus, S. Bailey, J. Jeglot, C. Juramy, D. Martin, F. Wicek**
- **Last years activities**
  - **2 ASIC made for LSST**
    - ASPIC I : submitted july 2007, fully characterised by june 2008
    - ASPIC II : submitted november 2008, characterised and accepted by LSST collaboration



ASPIC II

8 DSI channels

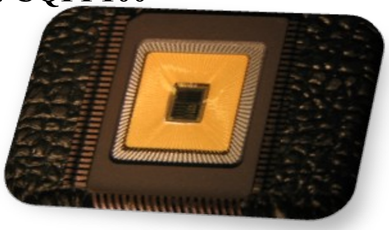
ASPIC I

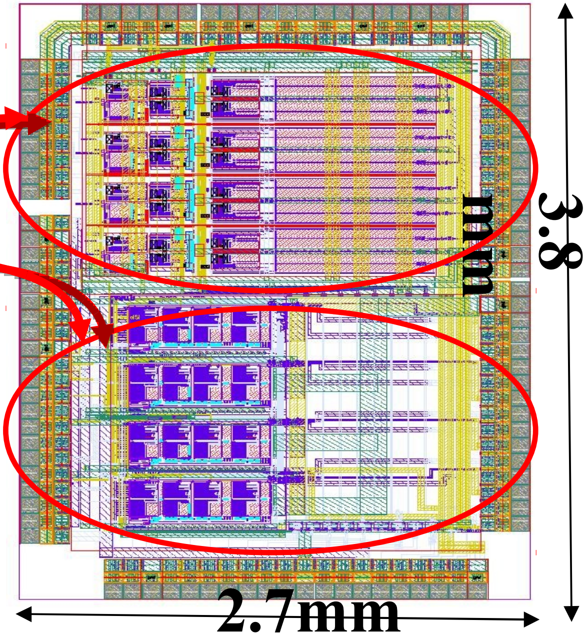
4 DSI channels
4 C&S channels

Techno : CMOS 0.35µ 5V

Vendor : AMS

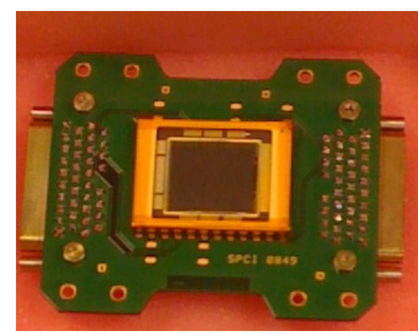
Package : CQFP100





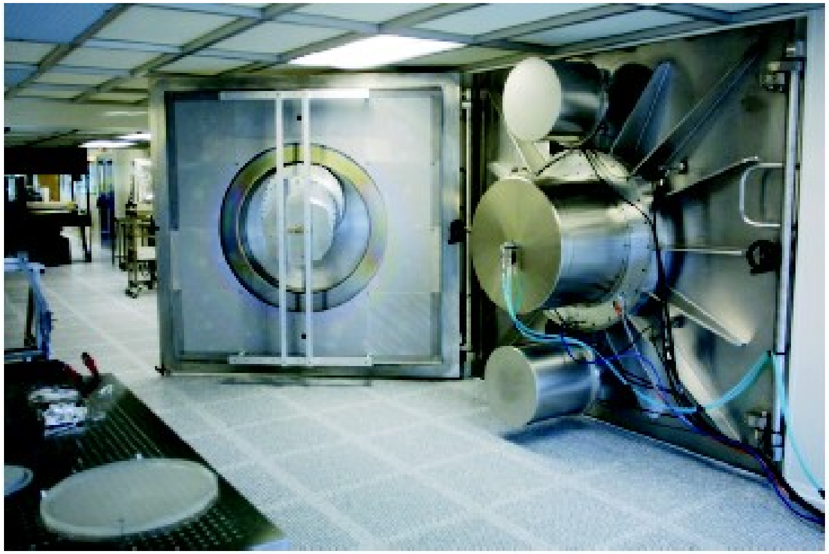
CCD

- People involved
  - CCD test bench @ LPNHE : P. Antilogus, S. Bailey, W. Bertolli, E. Hornero, C. Juramy, H. Lebbolo, D. Martin, R. Sefri, D. Vincent
  - CCD R&D (E2V) : P. Antilogus (LPNHE), C. Vescovi (LPSC)
- Last years activities
  - CCD test bench operational
  - MOU to use French funds (50k€) to extend e2v contract
  - Participation to e2v R&D

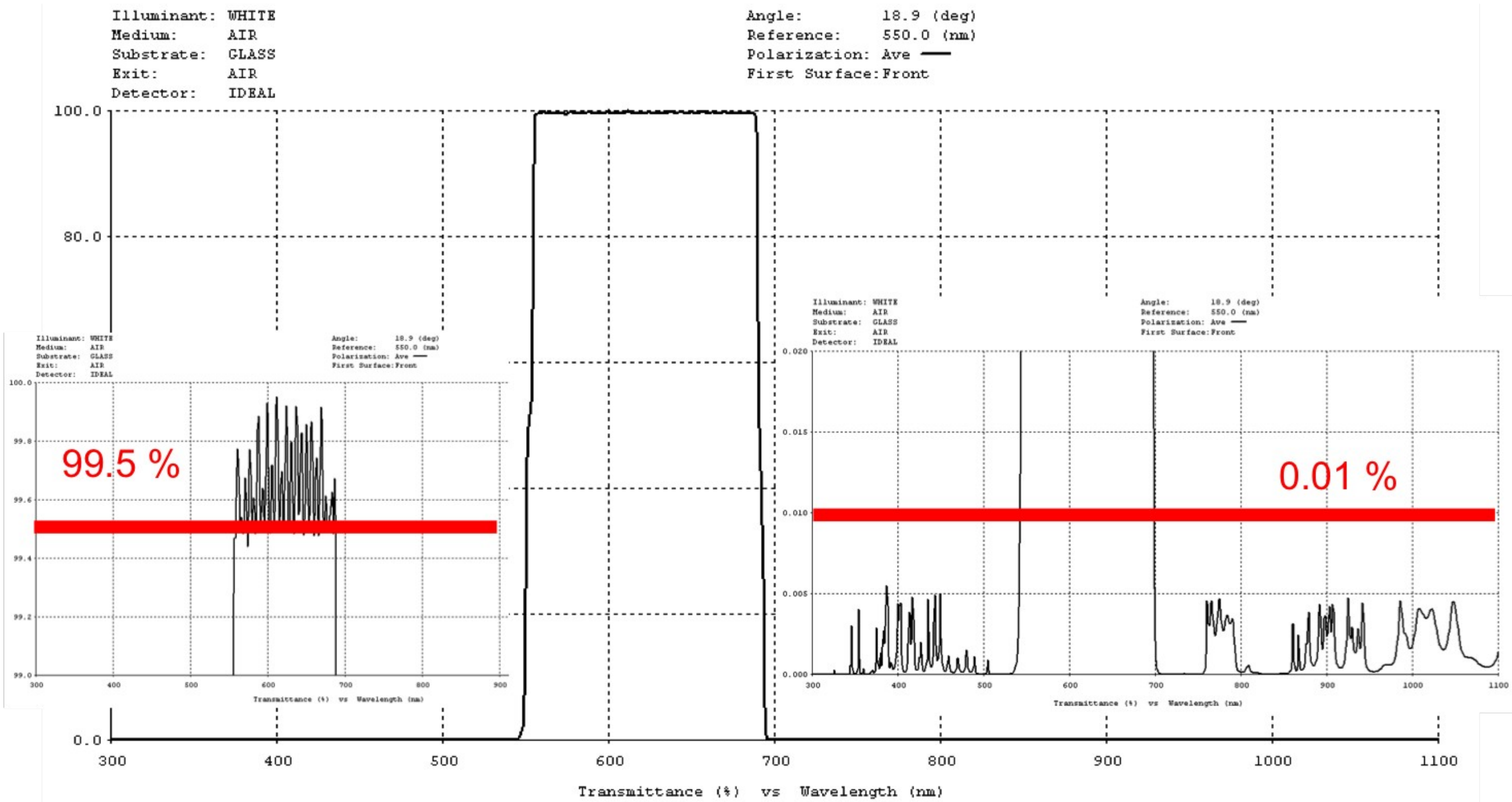


Filters

- People involved
  - LMA : R. Flaminio, C. Michel, J.L. Montario, N. Morgado, B. Sassolas
- Last years activities
  - Layer design for R and U filters
  - Metrology test bench for transmission measurement built and validated
  - Low-pass side of small (1") LSST R Filter have been done
  - Study of the upgrade for the large coating chamber
  - Study of absorption in the U band



Filter Design example

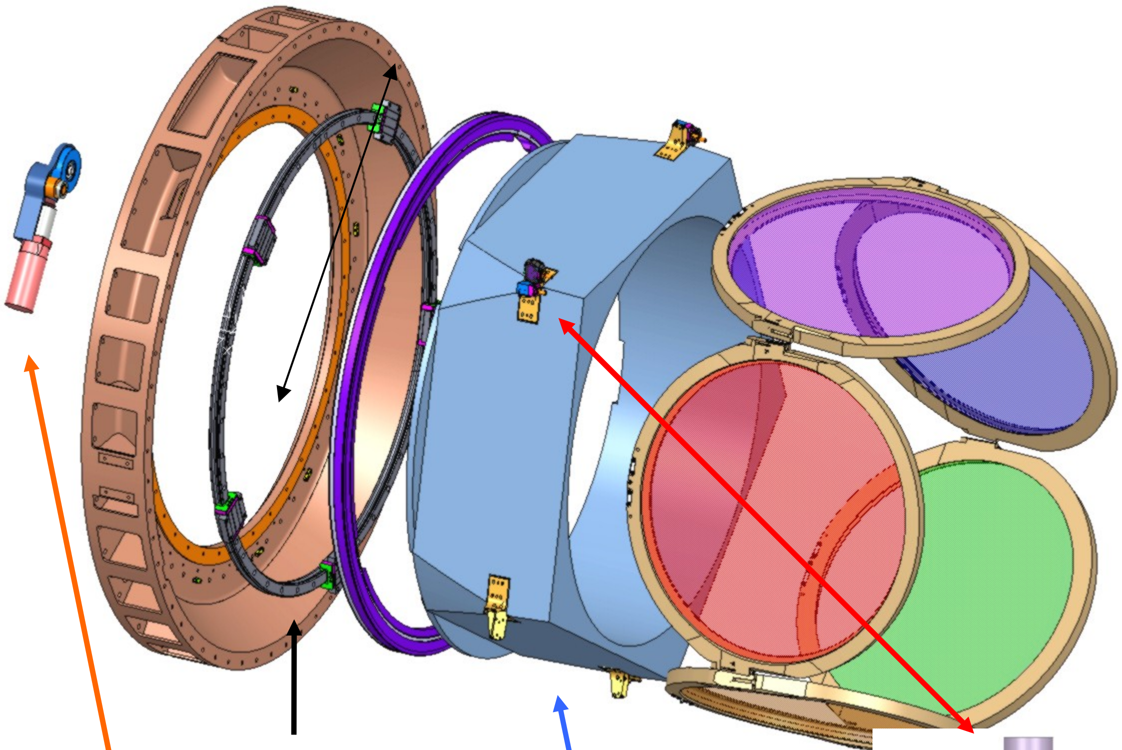


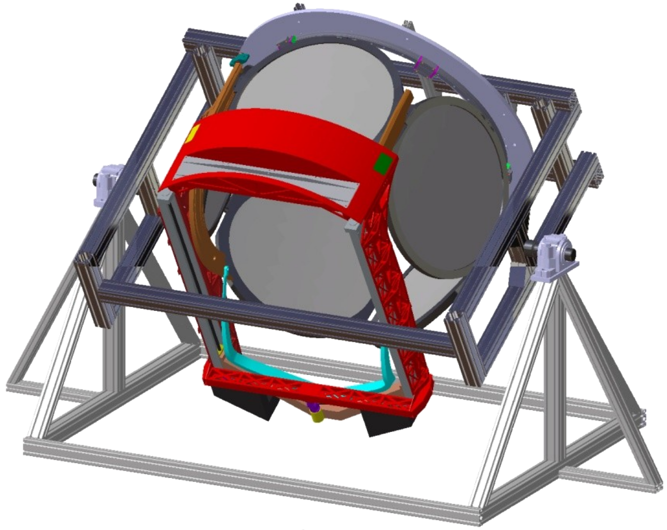
R&D Carousel

- **People involved :**
  - **LPNHE : W. Bertoli, G. Daubard, C. Evrard, Y, Orain, D. Vincent**
- **Achieved :**
  - **Overall realistic design of the carousel**
  - **Full design of the filter clamp**
  - **Filter clamp test bench**
  - **Design of the carousel transmission (gear, motor)**
- **To be done**
  - **Complete clamp tests**
  - **Design carousel composite structure**
  - **Full scale prototype**

Carousel Design

Large Synoptic Survey Telescope





Carousel test facility

(study for the fake fl1ange completed)

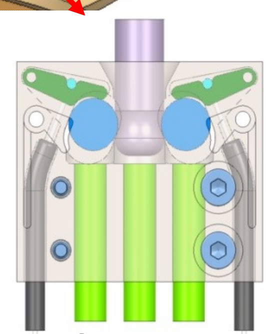
Rail THK

(bought end 2008)

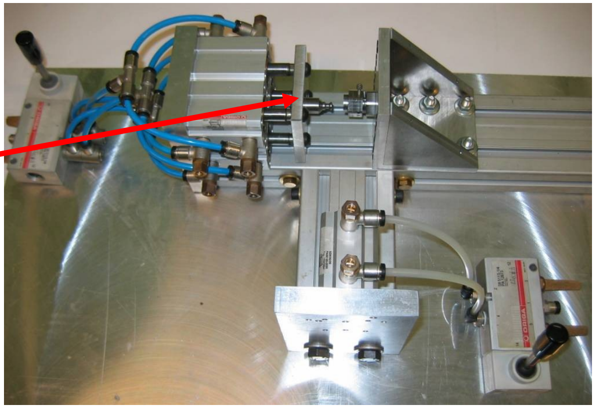
Motorisation

Carbon Structure

(detailed study to be done)



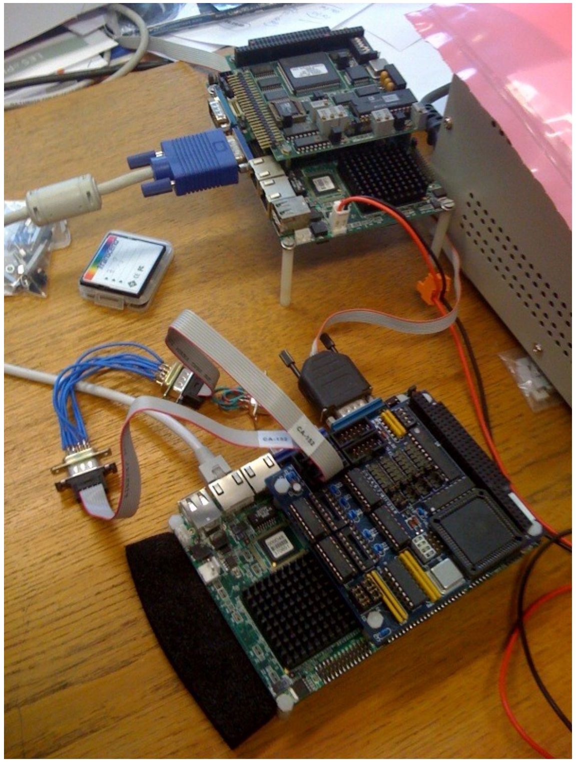
Clamp



Clamp test facility

CCS (Camera Control System)

- **People involved :**
  - APC : F. Virieux, E. Aubourg, L. Guglielmi, J.M. Colley
- **Last years activities**
  - Demonstrator using 2 PC 104 (Java/Linux)
  - Definition of the architecture/communication framework
  - Carousel simulator
  - APC now full part of the CCS team



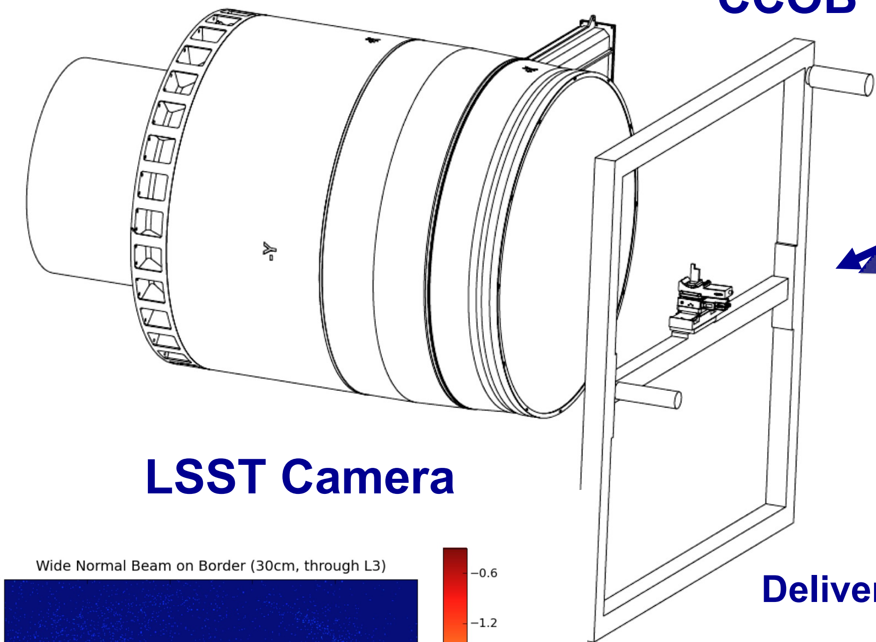
CCOB : Camera Calibration Optical Bench

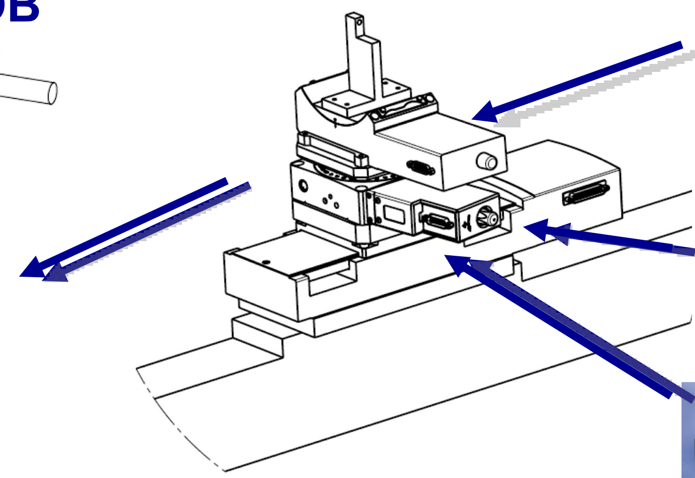
Large Synoptic Survey Telescope

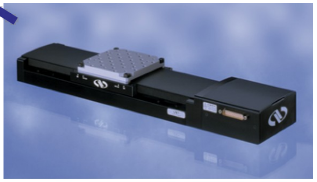
- **People Involved :**
  - **LPSC : A. Barrau, S. Beaumont, M. Migliore, A. Gorecki, E. Perbet, C. Vescovi**
- **Function :**
  - **The role of the CCOB is to provide first light to the camera, to perform a global commissioning of the camera and to calibrate the response of the focal plane array and the refractive optics when the camera is dismounted from the telescope**
  - **Two main coniguerations :**
    - Large beam : FPA relative response
    - Thin beam : ghost related measurements
- **Last years activities :**
  - **Optical test bench for preliminary design**
  - **Zemax simulations of the scattering light in the camera (ghost)**
  - **Beam forming and measurements**

CCOB Design

CCOB



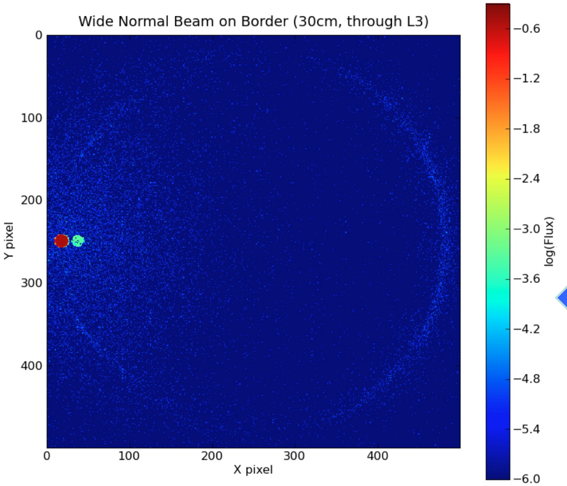




LSST Camera

CCOB moving head

Deliver and monitor the beam to the camera , with controlled position and angle



Full FPA (Focal Plain Array) simulated image with a wide beam from the CCOB:

The visible ghost (5 10^{-4}) is from one reflection on the CCD + reflection(s) on the lens

What's new for 2010

- CPPM join the project
  - Technical implication in the filter changer mechanism
  - IN2P3 responsible for a coherent/complete mechanical system
  - Still need to be validated by the Camera Management (October 2010)
  - French organization is changing
- New needs appear
  - Filter Exchange System prototype/test bench
    - Complexity of the prototype increased → LAL proposed to inject manpower and to take responsibility
  - Filter loader
    - Filter insertion into Camera
    - Share interfaces with Carousel/Changer
    - LPSC proposed to take Filter Loader responsibility
  - LPNHE is missing manpower
    - Composite carousel structure study is compromise → Al design option
    - No other options for the moment ...