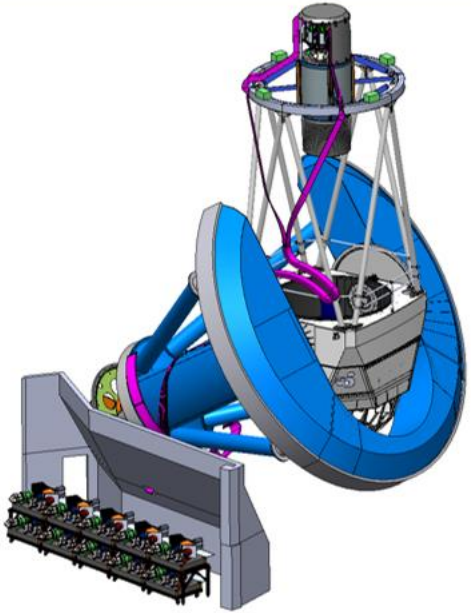
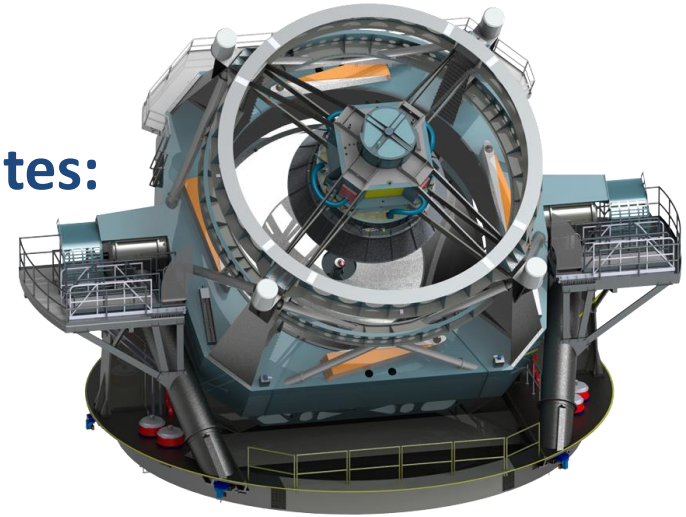
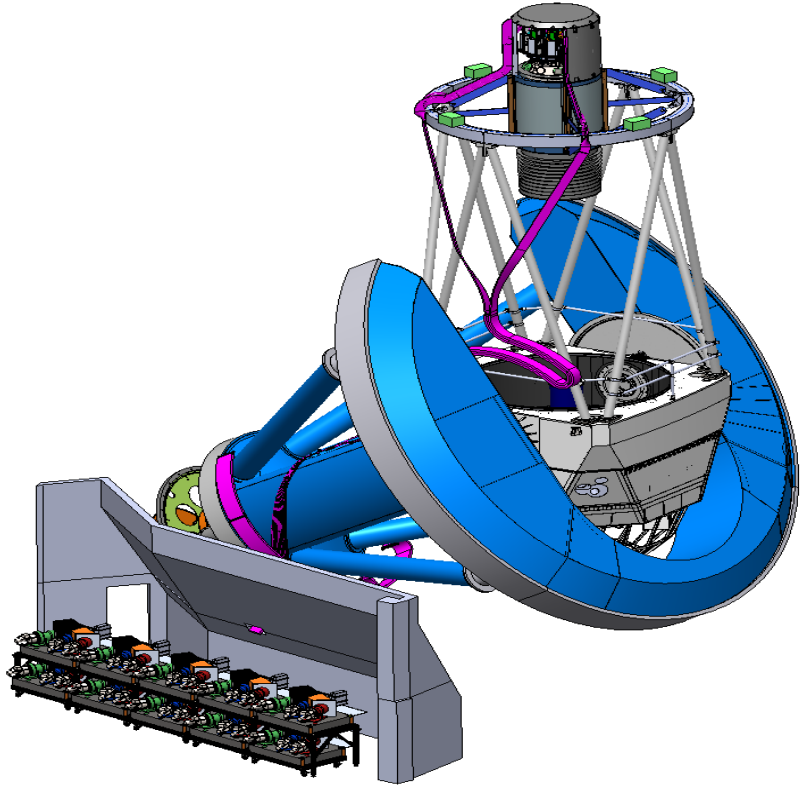


Dark Energy Project Updates: DESI and LSST



Victor L. Krabbendam
LSST Project Manager

(***DESI Inputs by Michael Levi***)



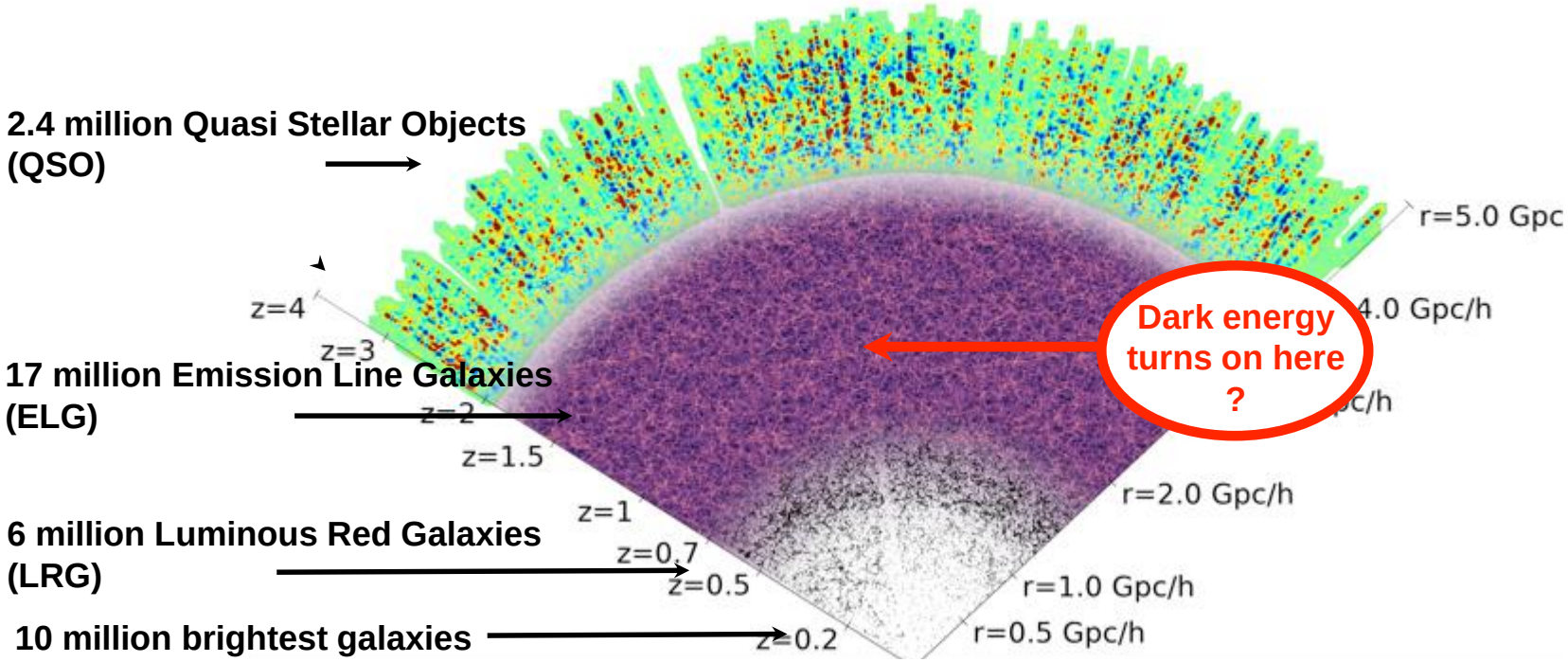
DESI Status

Presentation to HEPAP

November 21, 2019

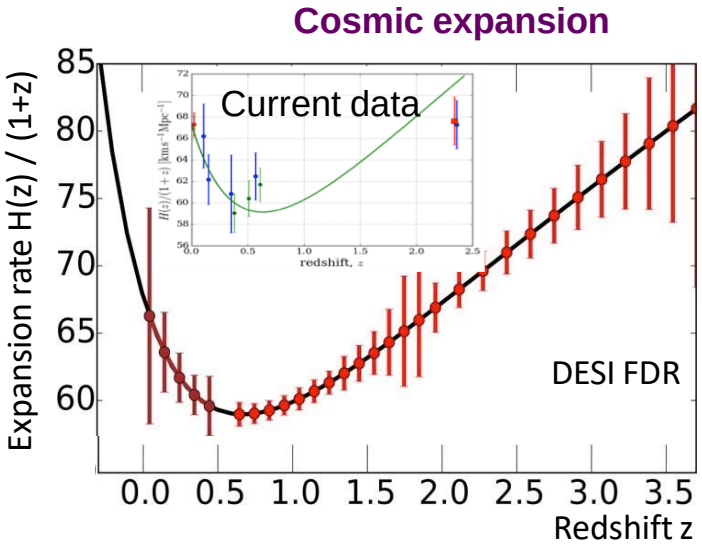
DESI will be the largest spectroscopic survey for dark energy. Each spectrum measures a galaxy redshift.

DESI will explore a x30 larger map over a x10 larger volume than SDSS



DESI Science

- DESI is the first Stage-IV Dark Energy Experiment to go on-sky
- DESI will collect 35 million spectra
  - Will measure dark energy equation of state with Baryon Acoustic Oscillations and growth of structure
  - Additional power from Redshift Space Distortions
  - Sum of neutrino masses to ~32 milli-eV
- DESI will precisely measure the cosmic distance scale:
  - Survey 14,000 deg^2 at nP ~ 1
  - 0.3% precision from $0 < z < 1.1$
  - 0.4% precision from $1.1 < z < 1.9$
  - Hubble parameter to 1% at $1.9 < z < 3.7$
  - Plus, inflation parameters



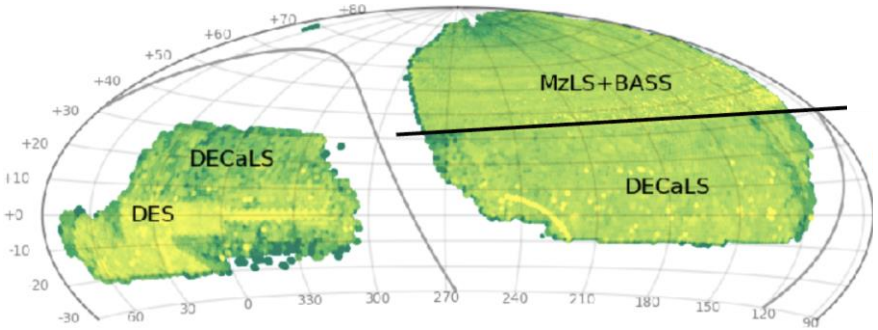
Status on imaging = 14,000 sq deg complete
All data public. See http://legacysurvey.org

Three optical surveys completed

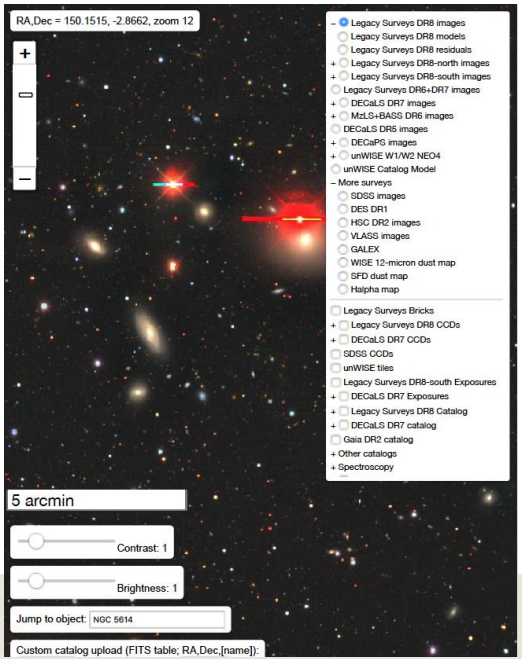
- **North** (*5k deg²*) **BASS** gr-bands **MzLS** z-band
- **South** (*9k deg²*) **DECaLS** grz-bands

One infrared survey completed

- **All Sky WISE** (NASA satellite) W_1 W_2 bands

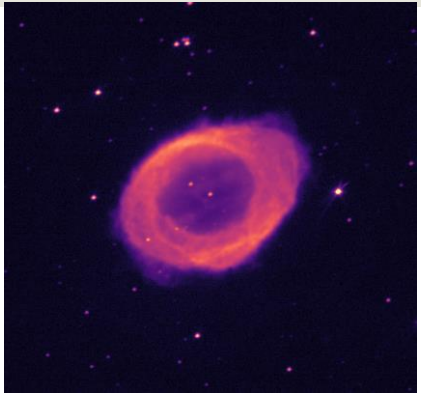


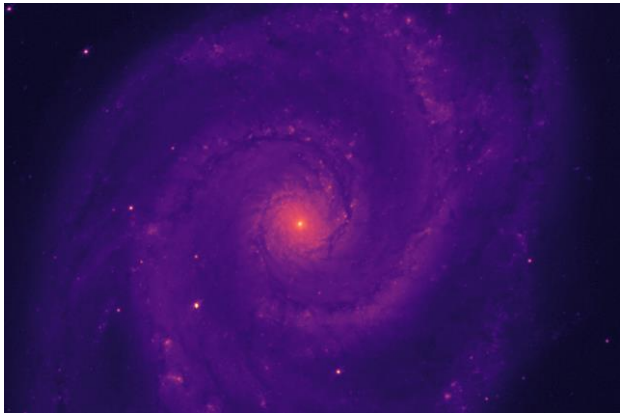
- Images combined using Tractor code
- DR8 published July 2019
- Final data release by Q1 2020
- Viewer and other tools available:



New wide-field optical corrector and focal plane are installed & working at the Mayall Telescope at Kitt Peak

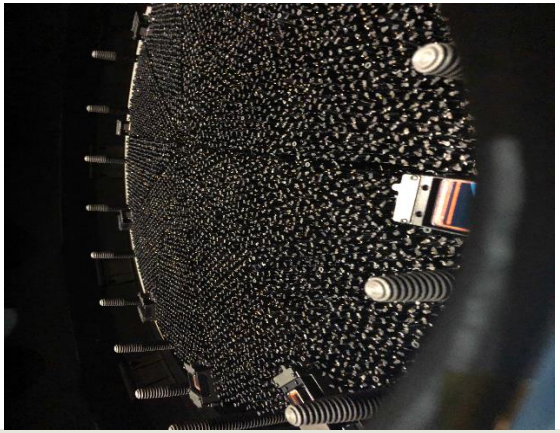
- 6 lenses, largest ~1m in diameter
- First light of corrector images were measured to be 0.7 arcsec
- Ring nebula and whirlpool galaxy:

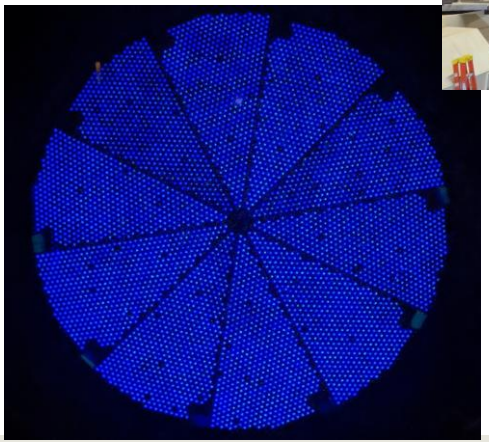




DESI nearing completion. All ten “petals” installed into the focal plane

Installation of the focal plane instrument was completed in August, 2019. The picture shows the fiber ends of the 5,000 robotic positioners on the focal plane, and back-illuminated

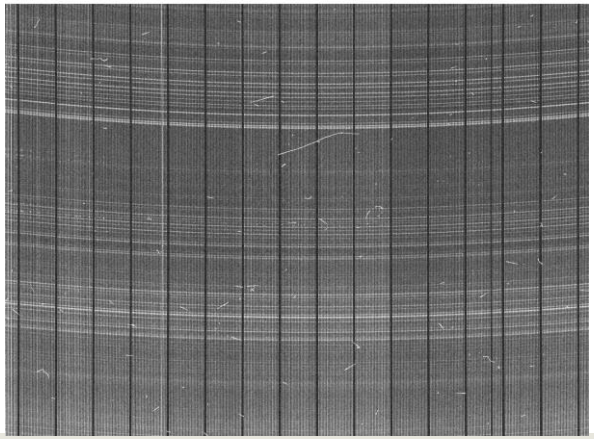




Spectrographs nearing completion

- Nine of ten spectrographs are at Kitt Peak today. Last spectrograph is at vendor ready for shipment.
- We have 500M pixels within the ten 3-arm spectrographs (30 cryostats)
- Spectroscopic pipeline is working well, and the sky background subtraction is working near statistical limit

Raw Data of one chip (of 30):

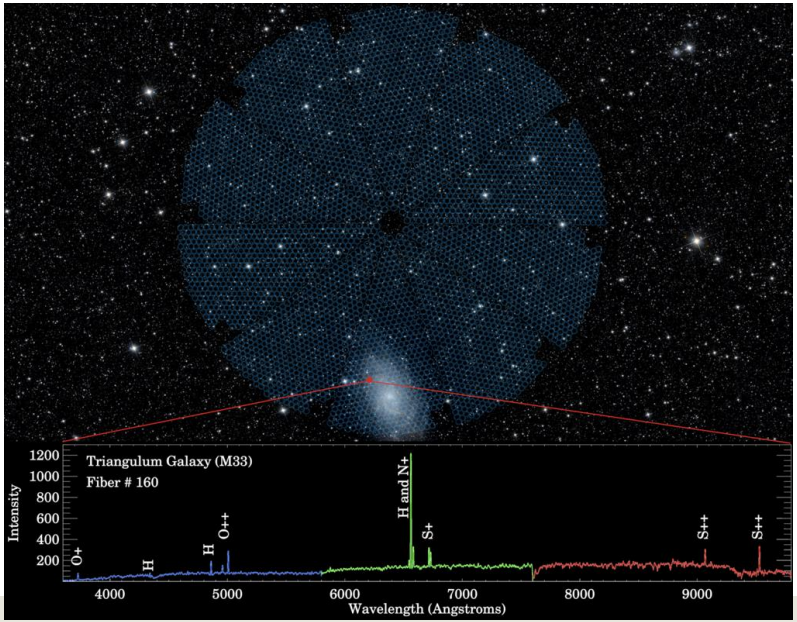


DESI First Spectroscopic Light

- First Light achieved on Oct 22, 2019, on the first day of the start of commissioning. The spectrum shown was collected by one fiber from a small section of the Triangulum Galaxy. The blue circles represent the sky footprint of the 5000 fiber positioners on the DESI focal plane.

- Commissioning started Oct. 22. Expected to last for 5 months, ending in March 2020

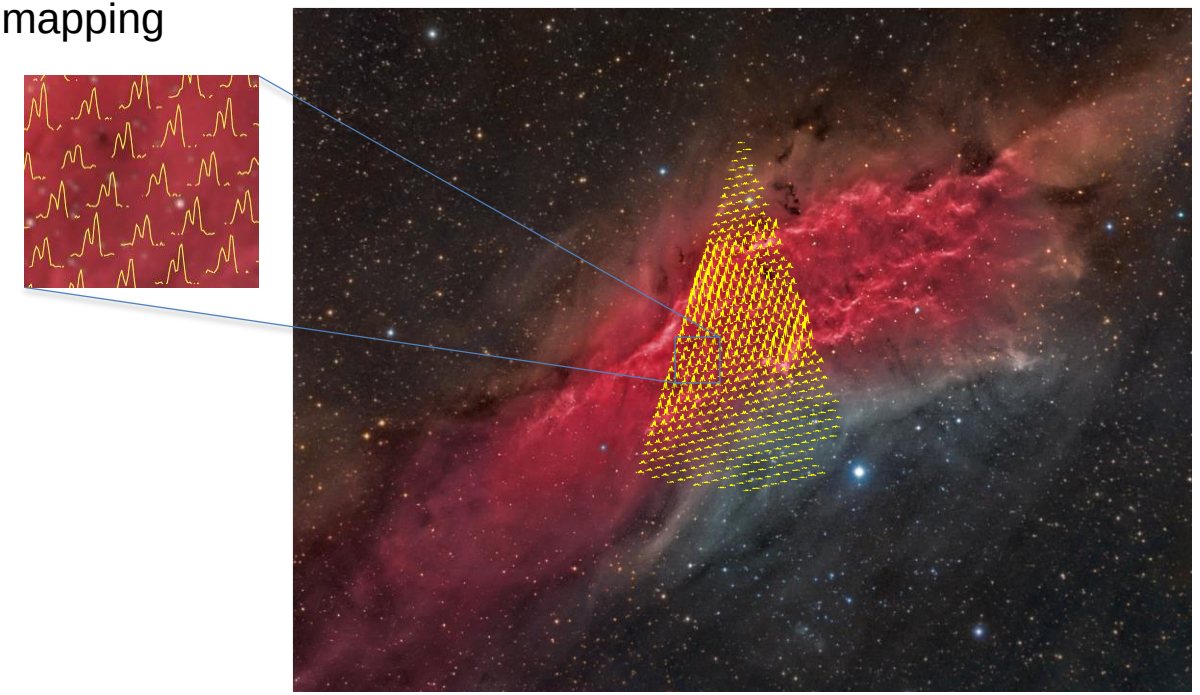
- Measured instrument performance so far surpasses requirements and expectations!



Background: Legacy Surveys image viewer

OII map of the California Nebula from 1st light

The OII emission-line doublet is a “signature” line that we will be using for most of our DESI redshift mapping



Background: Antonis Farmakopoulos

Career Development

Claire Poppett (Lead Observer), Stéphanie Juneau (NOAO) & Suk Sien Tie (OSU)

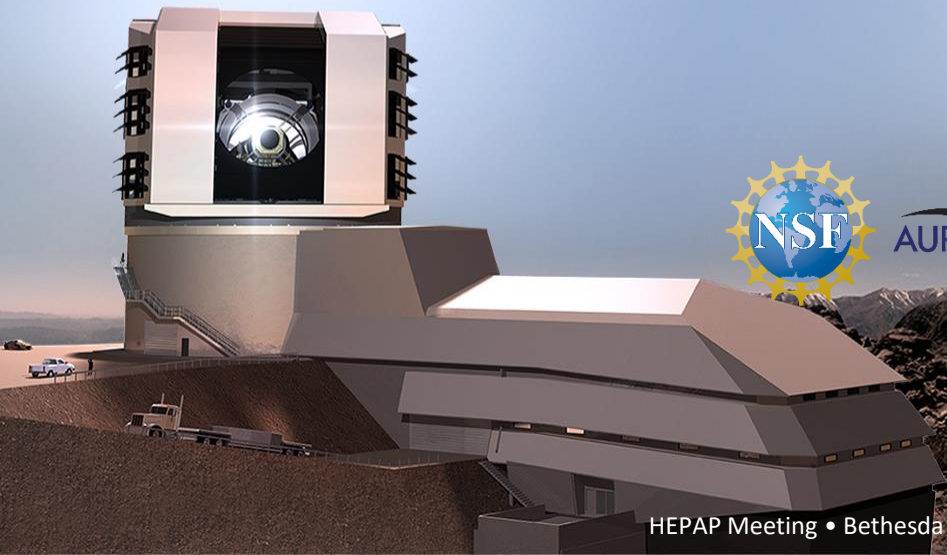
- 70+ institutions, 500 scientists, including 140 graduate students!
  - US Collaboration is: LBNL (lead), with: FNAL, SLAC, ANL, BNL, LLNL plus 21 US Universities
- Robust university-laboratory partnership with numerous important instrumentation subsystems developed and built at universities. Key examples are the fiber positioners built at the Univ. Michigan, the instrument control system, commissioning camera, & sky monitor built at the Ohio State Univ., the fiber view camera built at Yale University, and petal-bodies machined at Boston Univ, among others.
- Code-of-conduct policy, Meeting code-of-conduct policy
- Diversity
  - DESI is 24% women scientists. LBL technical staff on DESI 15 men:15 women
  - Fraction is higher at early career
- Diversity is improved by promoting Early Career Scientists
  - Subsidized travel to DESI meetings
  - DESI is a small expt. which allowed us to give significant responsibility to early career scientists (*eg*. L2 managers)

Project Metrics: On track for early finish. Looking forward to operations & an exciting scientific program.

- Funding sources: $56M DOE, $19M non-federal (Gordon & Betty Moore Foundation, Heising-Simons Foundation, Science and Technology Facilities Council of the UK, the French Alternative Energies and Atomic Energy Commission (CEA), the National Council of Science and Technology of Mexico, and member institutions)
- Installation complete (with exception of last spectrograph)
- On budget, on schedule
  - CD-0 2012, CD-1 2015, CD-2 2015, CD-3 2016
  - CD-4 expected March 2020
  - 95% complete, SPI=0.98 (schedule), CPI=0.98 (cost) as of end-October
  - Remaining contingency $1.9M on costs to go of $2.5M
  - 549 days of schedule float
- 4 months of Survey Validation to start in March 2020
- 5 year survey to start Summer 2020
- Looking forward to operations, robust research and operations funding will be critical to scientific success!

LSST Status

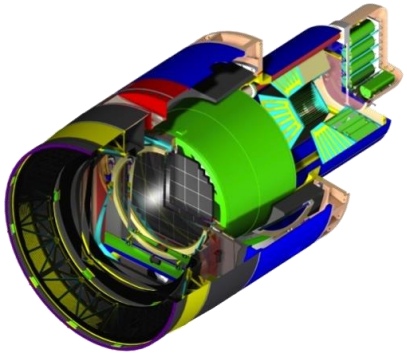
Presentation to HEPAP
November 21, 2019



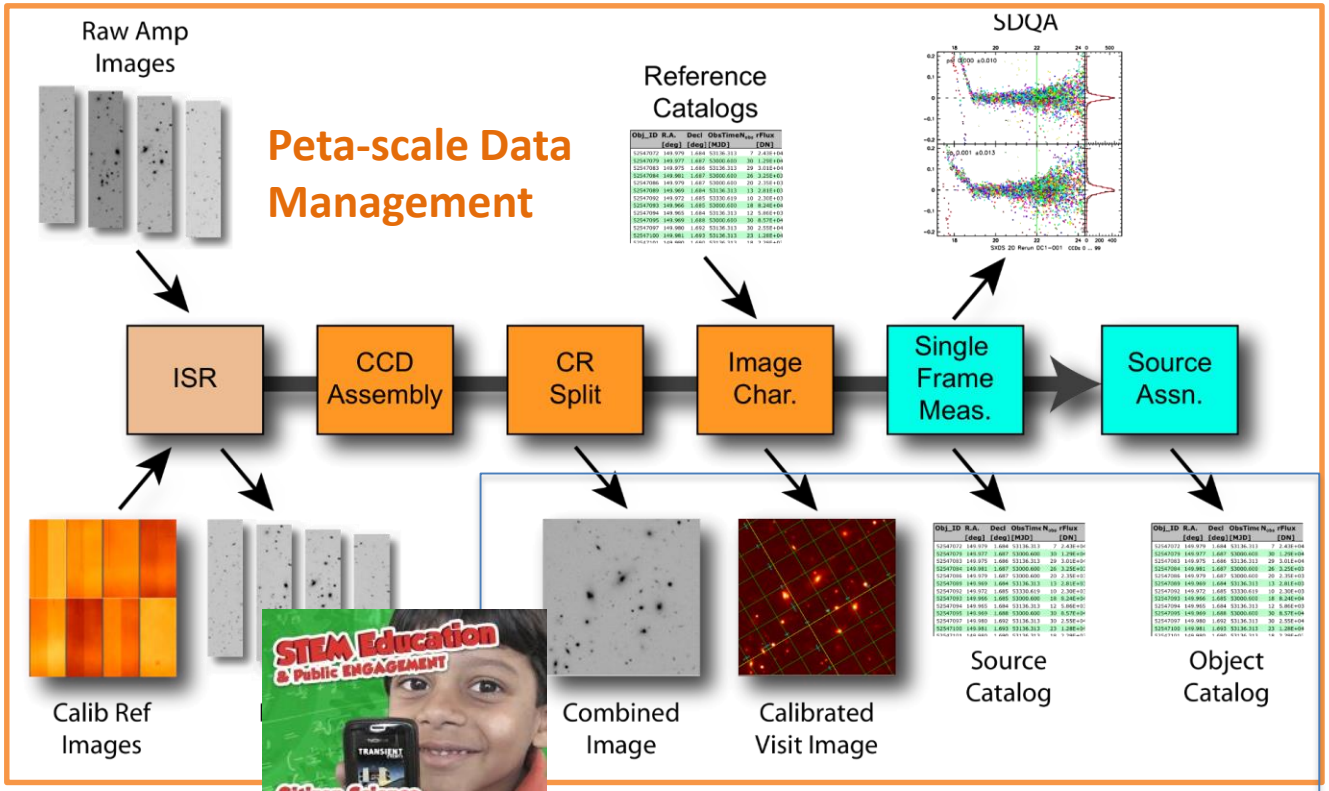
To build an observing facility, conduct 10-year survey, process, archive, and serve images and data products

8.4m Telescope

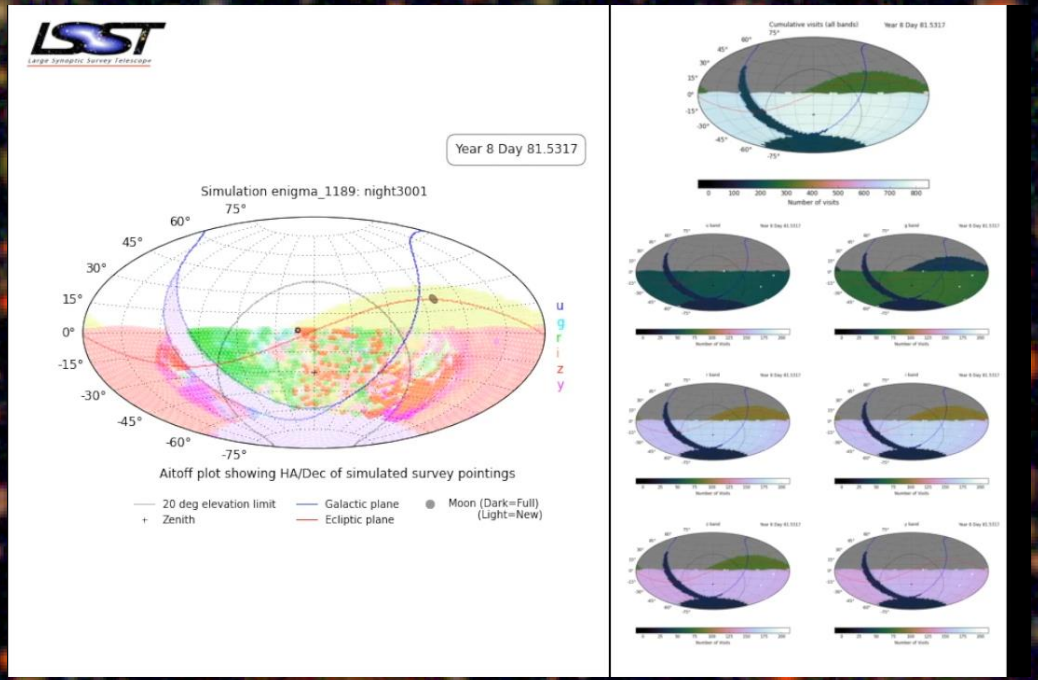
+



3.2Gpix Camera



A integrated 10-yr optical survey of the night sky



Prompt Data Products
Real Time Difference Image Analysis (DIA)

Data Release Data Products
Reduced single-epoch & deep co-added images, catalogs, reprocessed DIA products

User Generated Data Products
User-produced derived, added-value data products

- 5 million images
- Tens of billions of time-domain events
- Catalogs of over 37 billion objects and 7 trillion sources.

Four Science Goals used to Define Requirements

Dark Matter, Dark Energy

- Weak Lensing
- Baryon acoustic oscillations
- Supernovae, Quasars

Cataloging the Solar System

- Potentially Hazardous Asteroids
- Near Earth Objects
- Object inventory of the Solar System

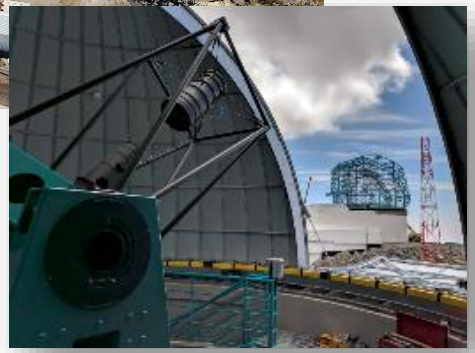
Milky Way Structure & Formation

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo

Exploring the Transient sky

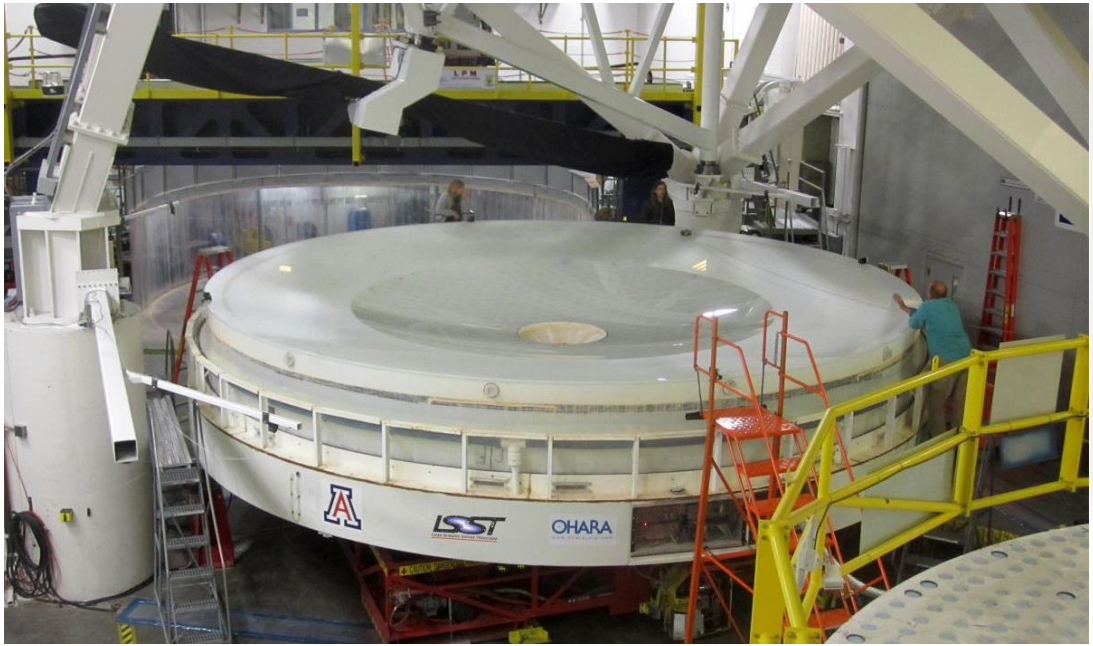
- Variable stars, Supernovae
- Fill in variability phase-space
- Discovery of new classes of transients

Summit Facility and Site Infrastructure Completed – Dome is in Progress



AuxTel under computer control

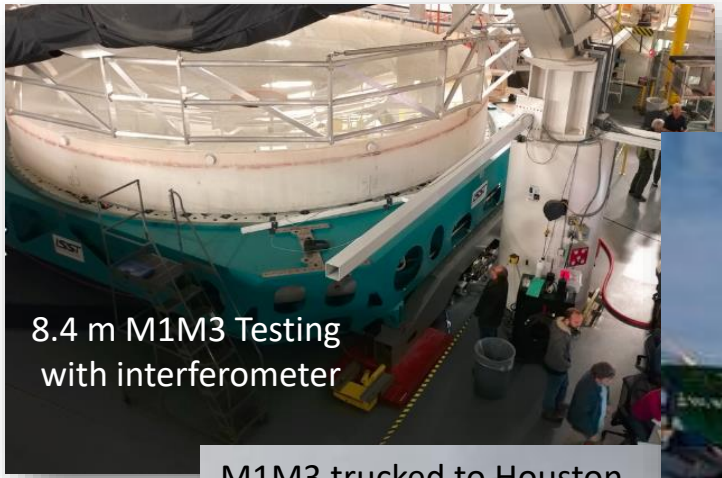
Telescope Optics are fabricated



8.4m diam Primary with 5m diam Tertiary surfaces completed

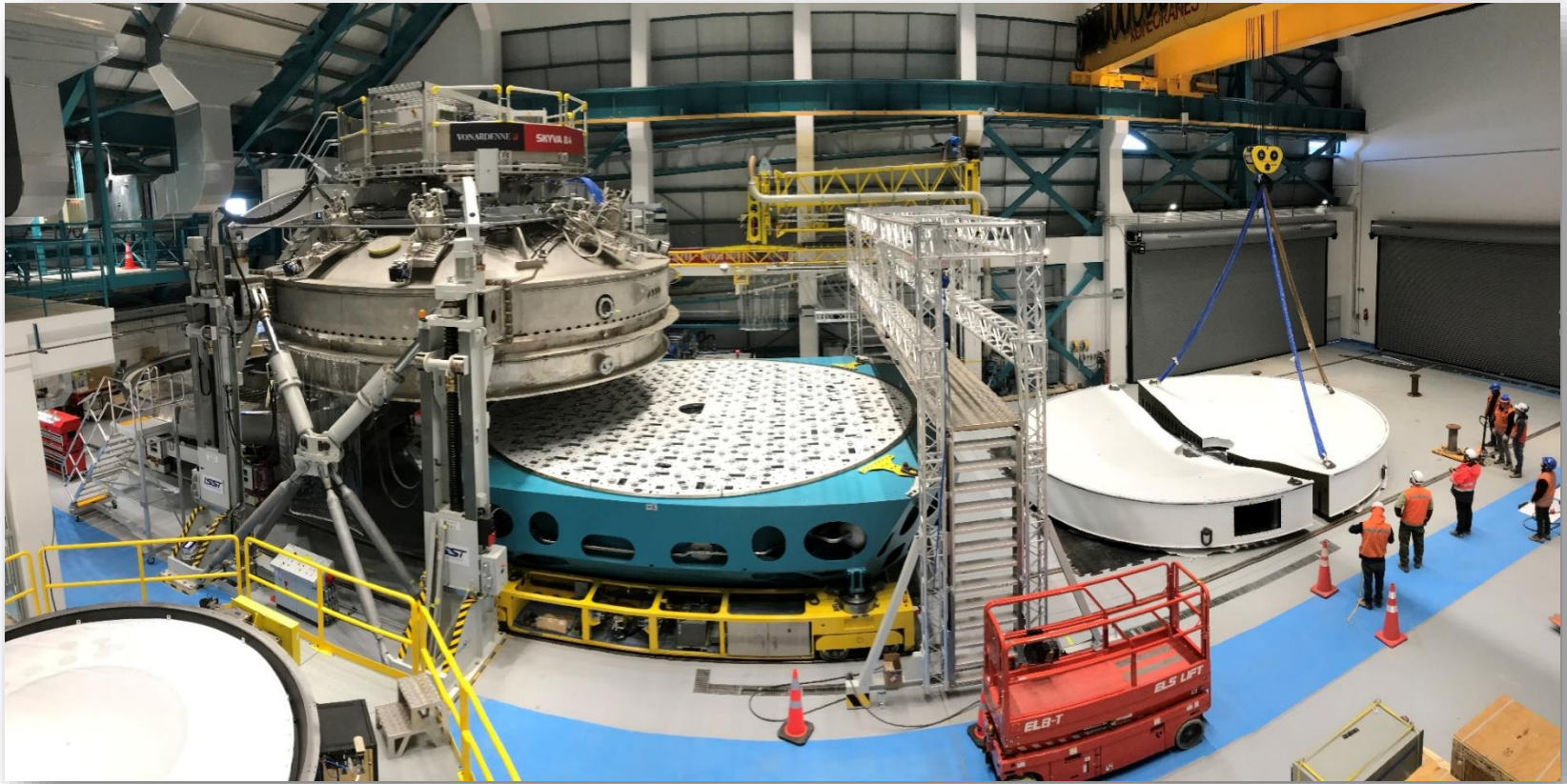
3.5m diam secondary mirror completed

M1M3 system Tested and transported to site



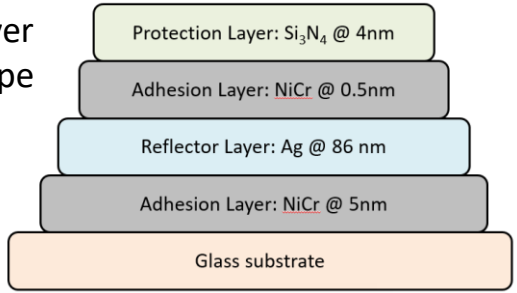
Ocean Cargo to Chile

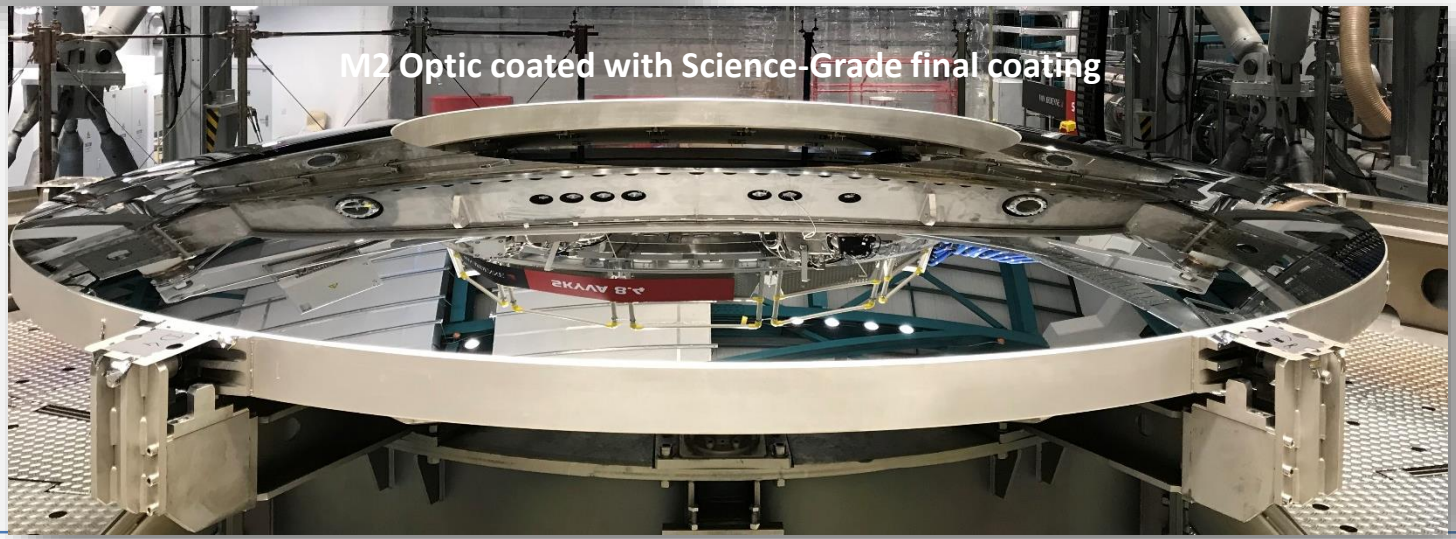
Coating facility completed (left) – M1M3 integration in-progress



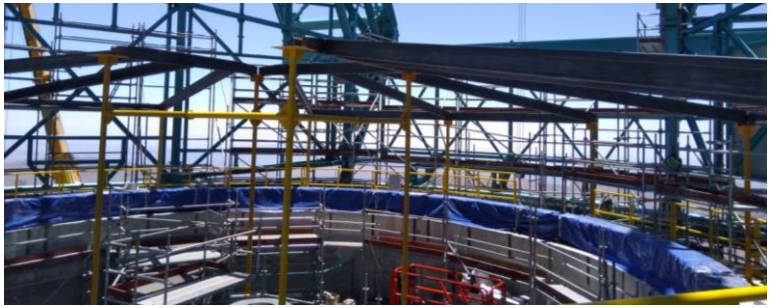
M2 Coating – 16 July 2019

M2 Protected Silver Recipe

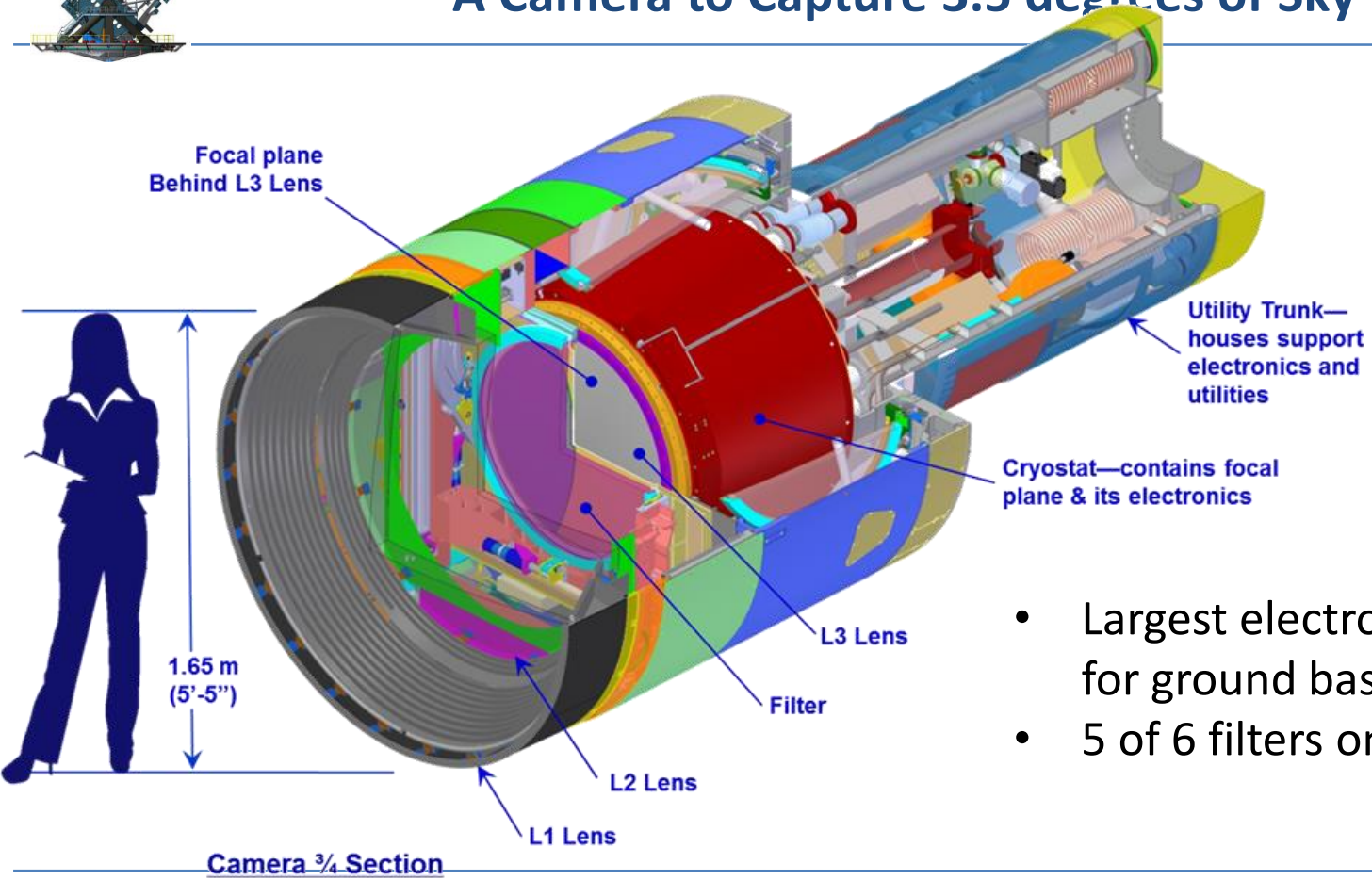




Telescope Mount factory tested and now being integrated on site

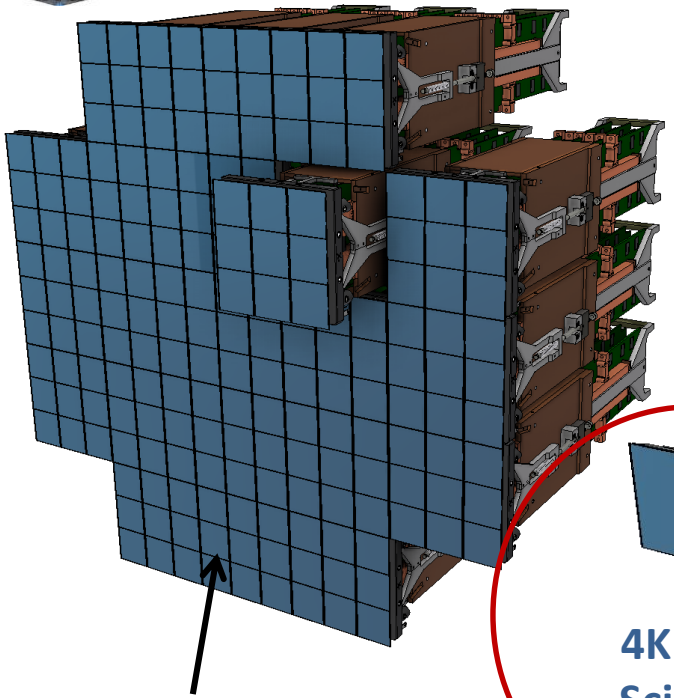


A Camera to Capture 3.5 degrees of Sky



- Largest electronic camera built for ground based astronomy
- 5 of 6 filters on board

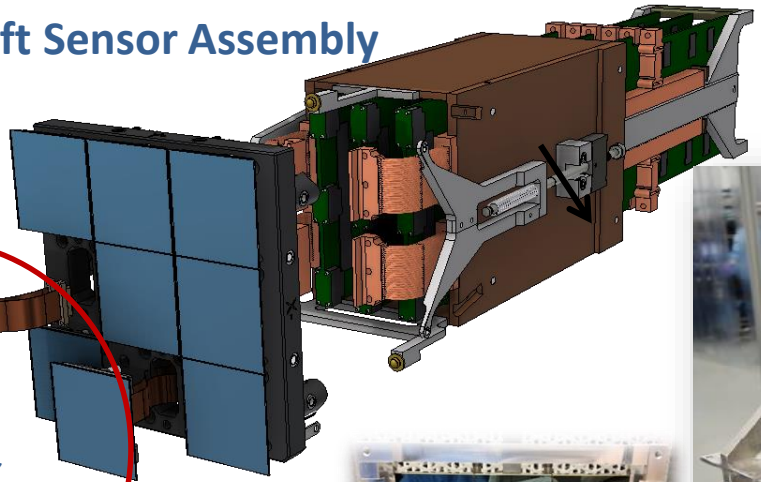
63 CM Diameter Focal Plane with 3.2 GigaPixels



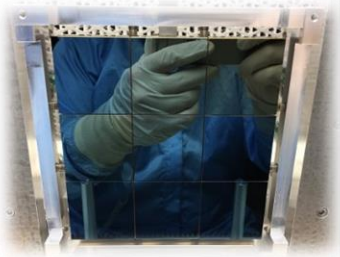
189 sensors packed in 21 rafts of 9 sensors

4K x 4K Science Sensor

Raft Sensor Assembly

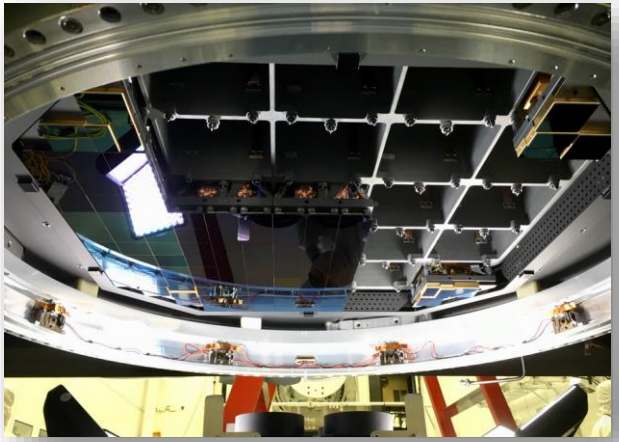


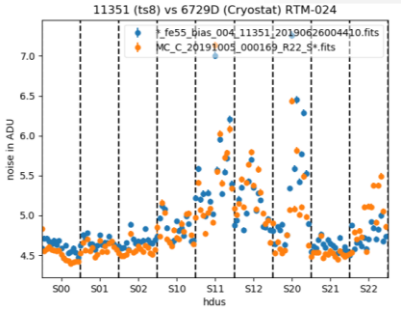
Raft Electronics Board (REB) with Custom Integrated circuits make a 166M Pix camera

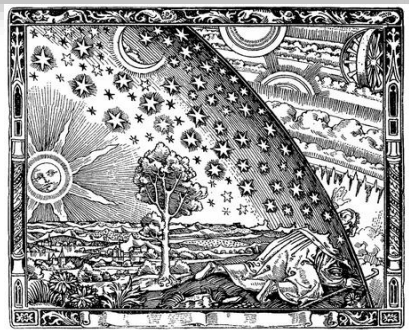


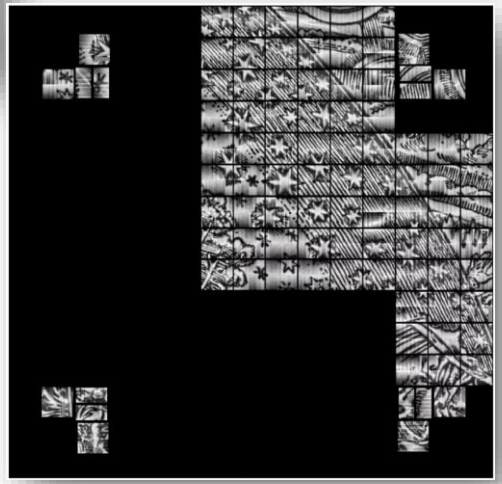
Focal Plane Progressing well

- 9-rafts installed in cryostat
- Cold electro-optical test completed 11/04/2019 with good results
- Full Focal Plane by Jan







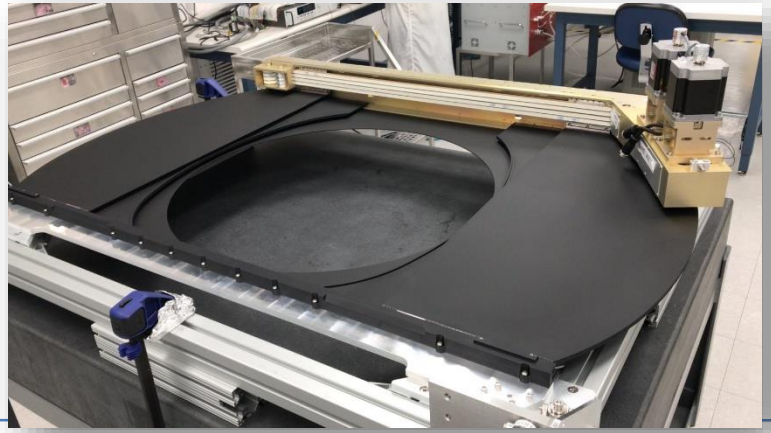


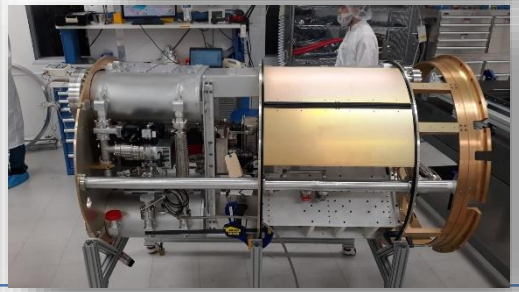
Camera Lenses completed and at SLAC

- L3 assembly delivered to SLAC 10/08/2019
- L1-L2 assembly delivered to SLAC 8/15/2019

Camera Body and Mechanism Status

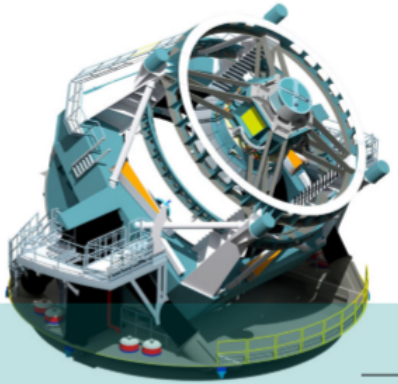
- Carousel received at SLAC and integrated with the backflange and camera body 10/30/2019
- Utility trunk with fabrication is underway
- Filter Exchange system was completed and tested in France and on its way to SLAC
- Two shutter systems are complete





Raw Data: 20TB/night

Sequential 30s images covering the entire visible sky every few days



LSST SCIENCE PIPELINES

Prompt Data Products

Alerts: up to 10 million per night

60s via nightly alert streams

Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~ 6 million

24h via Prompt Products Database

Data Release Data Products

Final 10yr Data Release: Michitaro Koike

- Images: 5.5 million x 3.2 Gpx
- Catalog: 15PB, 37 billion objects

via Data Releases

Community Brokers

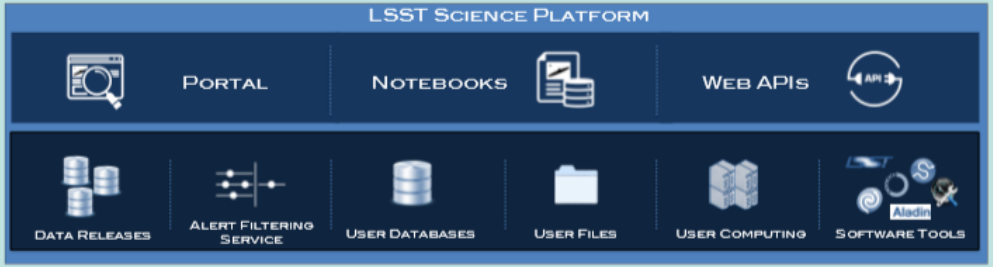
LSST Alert Filtering Service

LSST DACs (Chile & NCSA)

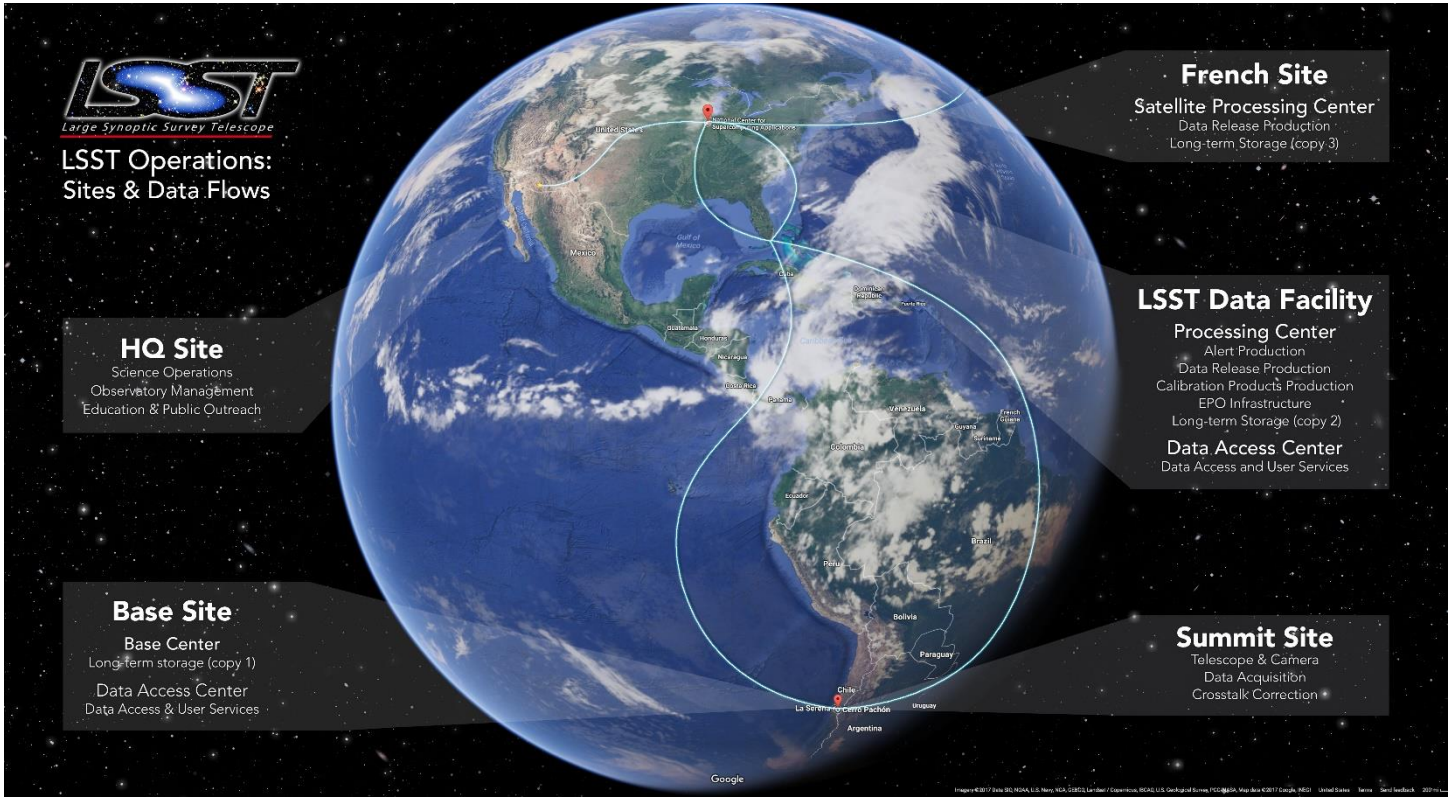
Independent DACs (iDACs)

LSST Science Platform

Provides access to LSST Data Products and services for all science users and project staff

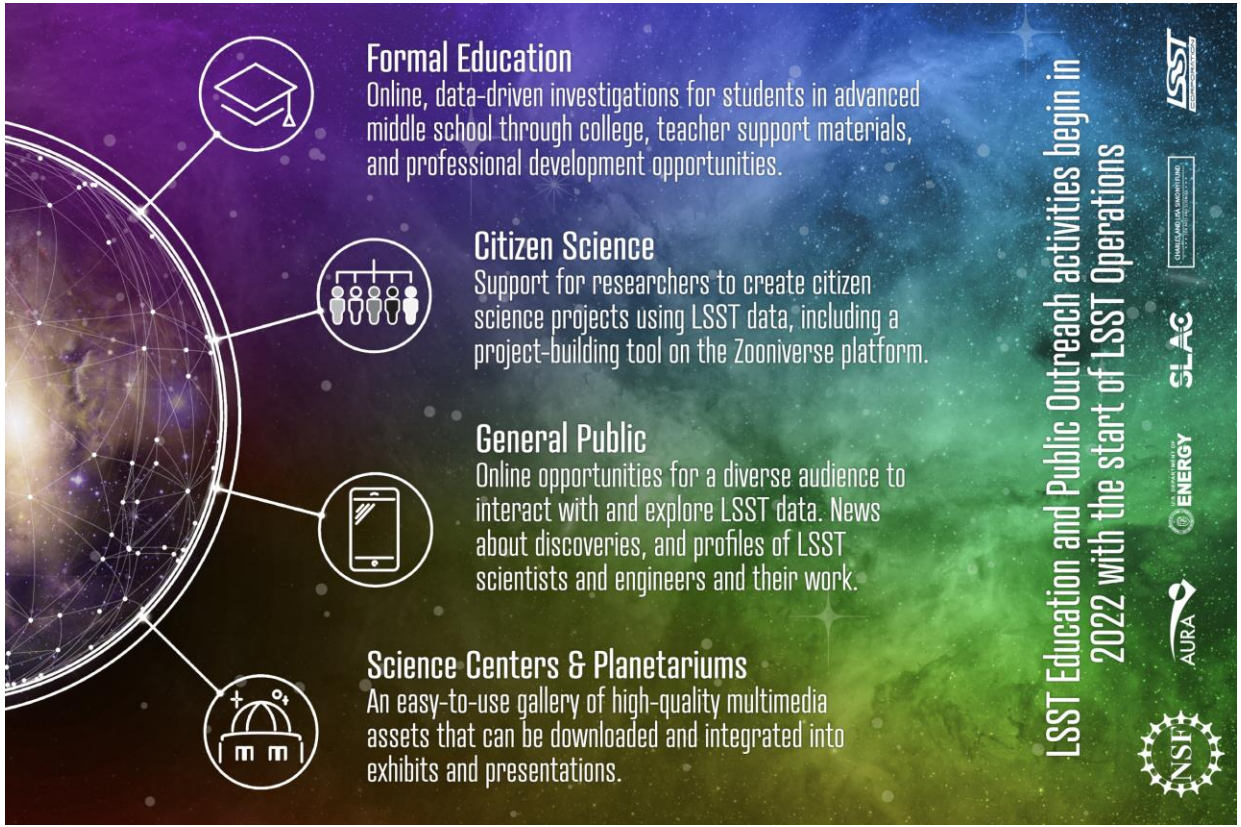


LSST Data Sites and Data Transfer



LSST Science Platform and Pipelines

LSST Education and Public Outreach system is under development and testing



Construction Funding Partners and Managing Organizations

US$ 473 M

MREFC Project

→ AURA

U.S. DEPARTMENT OF ENERGY

US$ 168 M

MIE Project

→ SLAC NATIONAL ACCELERATOR LABORATORY

Private, Corporate, and Institutional Donors

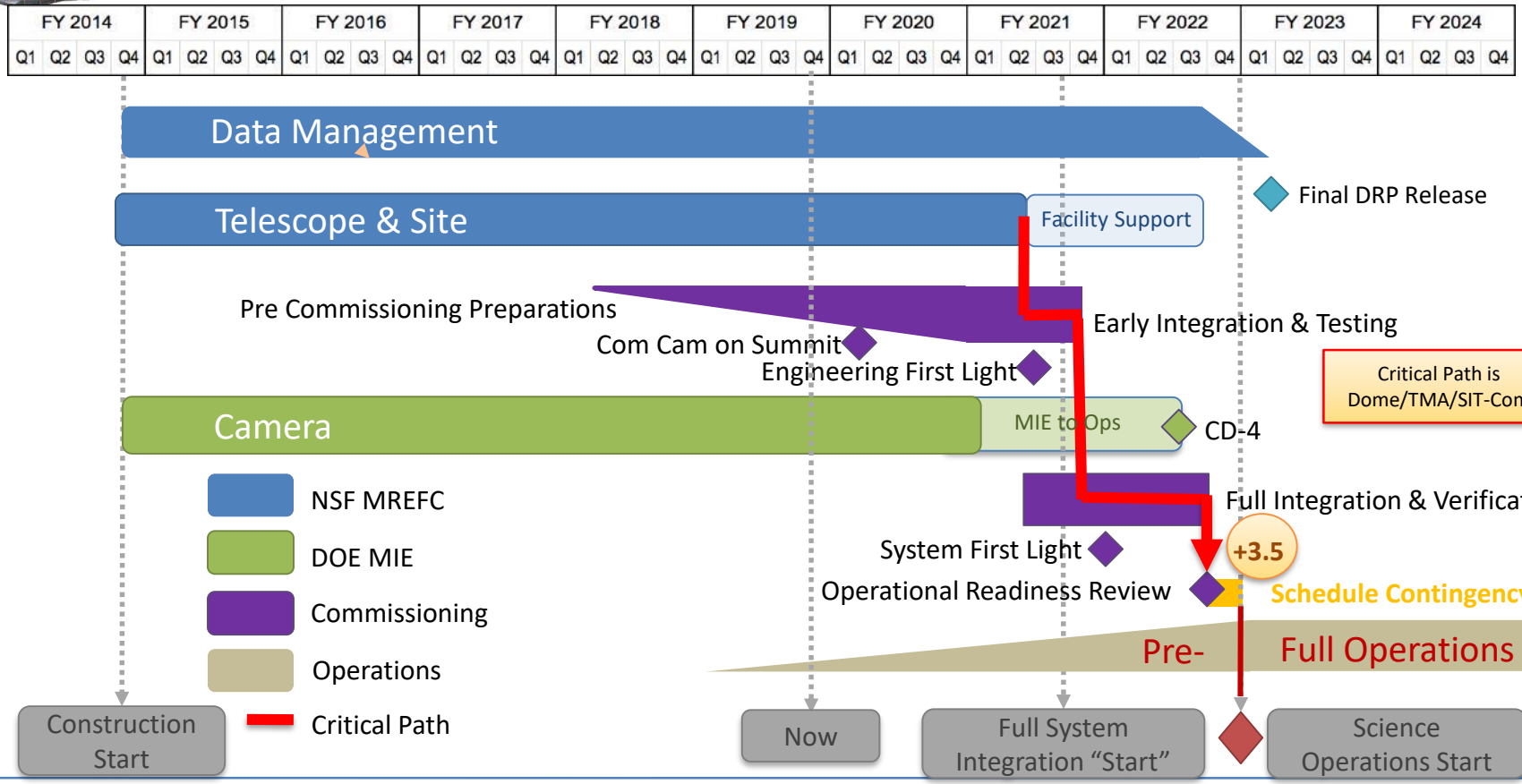
US$ 40 M was key to early development

EVMS Executive Summary – September 2019 Data

	MREFC - NSF	LSSTCam – DOE
% Complete (Sept 2019)	75	96
SPI	0.99	0.98
CPI	0.98	0.97
Contingency (EAC)	$11.5 M	$2.0M
Contingency % Remaining Work (EAC)	25*	27

** Work remaining is $45M for T&S, Sys Eng. and Commissioning – remainder is cost-capped

LSST Schedule – 3.5 Months Contingency



Key Project Dates:

- Formal Project Dates

  CD-1 : 11 April 2012
  CD-2 : 7 January 2015
  CD-3 : 27 August 2015
  CD-4 : 15 September 2020

  FDR : 5 December 2013
  MREFC Start : 1 August 2014
  MREFC End : 30 September 2022

- Key Project Dates to Operational Readiness
  - Cryostat ready for integration : 19 Feb 2020
  - Commissioning Camera on Site : 6 March 2020
  - Telescope Mount Assembly Integrated : 17 June 2020
  - Camera Ready at SLAC : 19 February 2021
  - Engineering First Light : May 2021
  - System First Light : Nov 2021

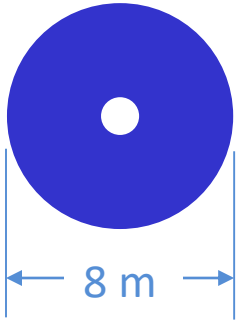
Technical performance still has margin to requirements and we are on schedule for First Light in 2021 and start of 10-year Survey in 2022

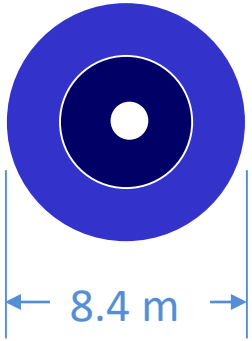
LSST vs Gemini

Gemini South Telescope

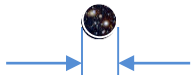
LSST

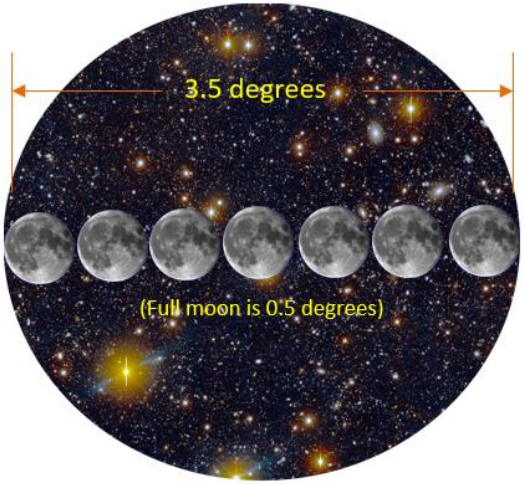
Primary Mirror Diameter





Field of View





Summary of High Level Requirements

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually