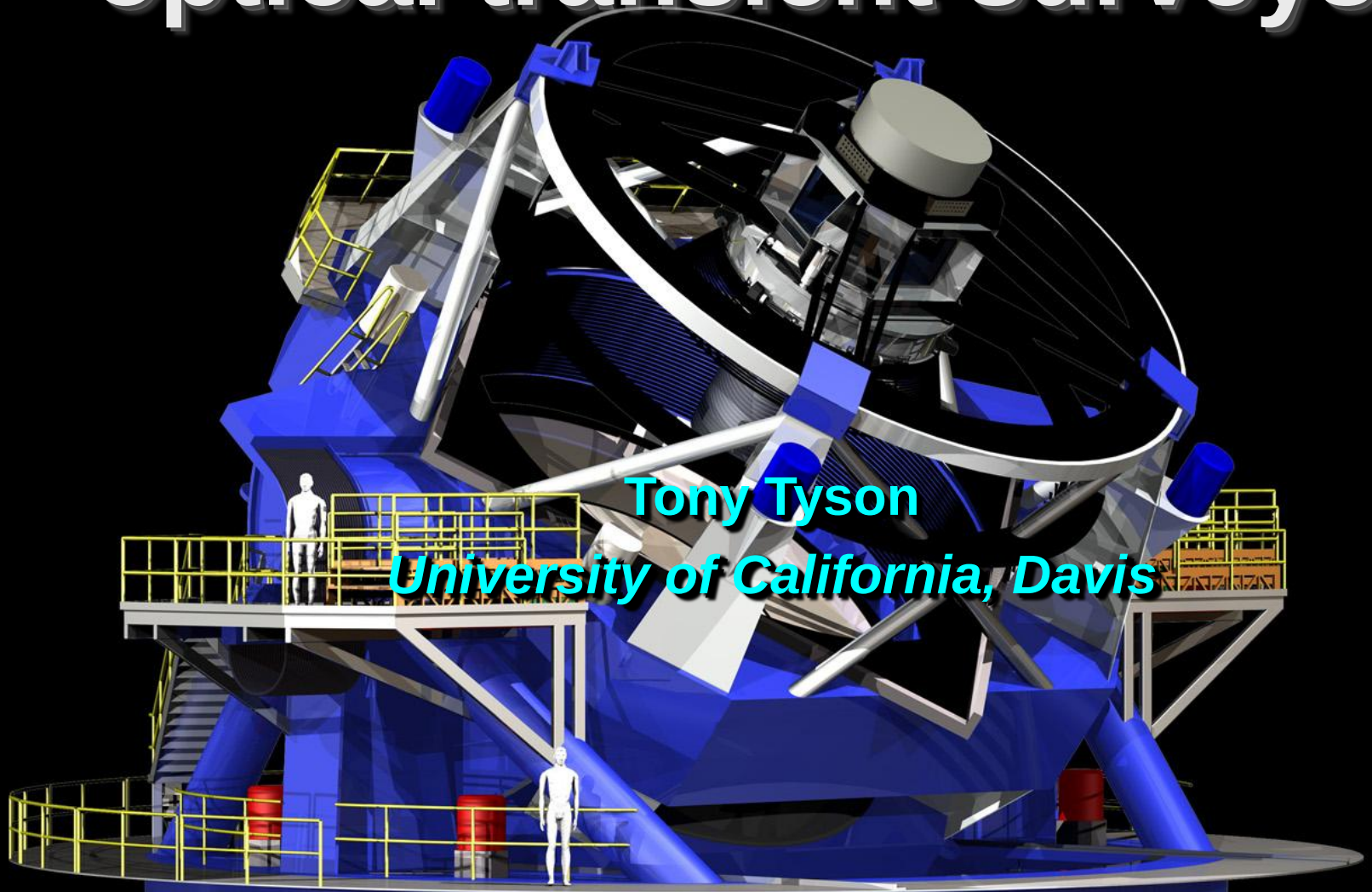
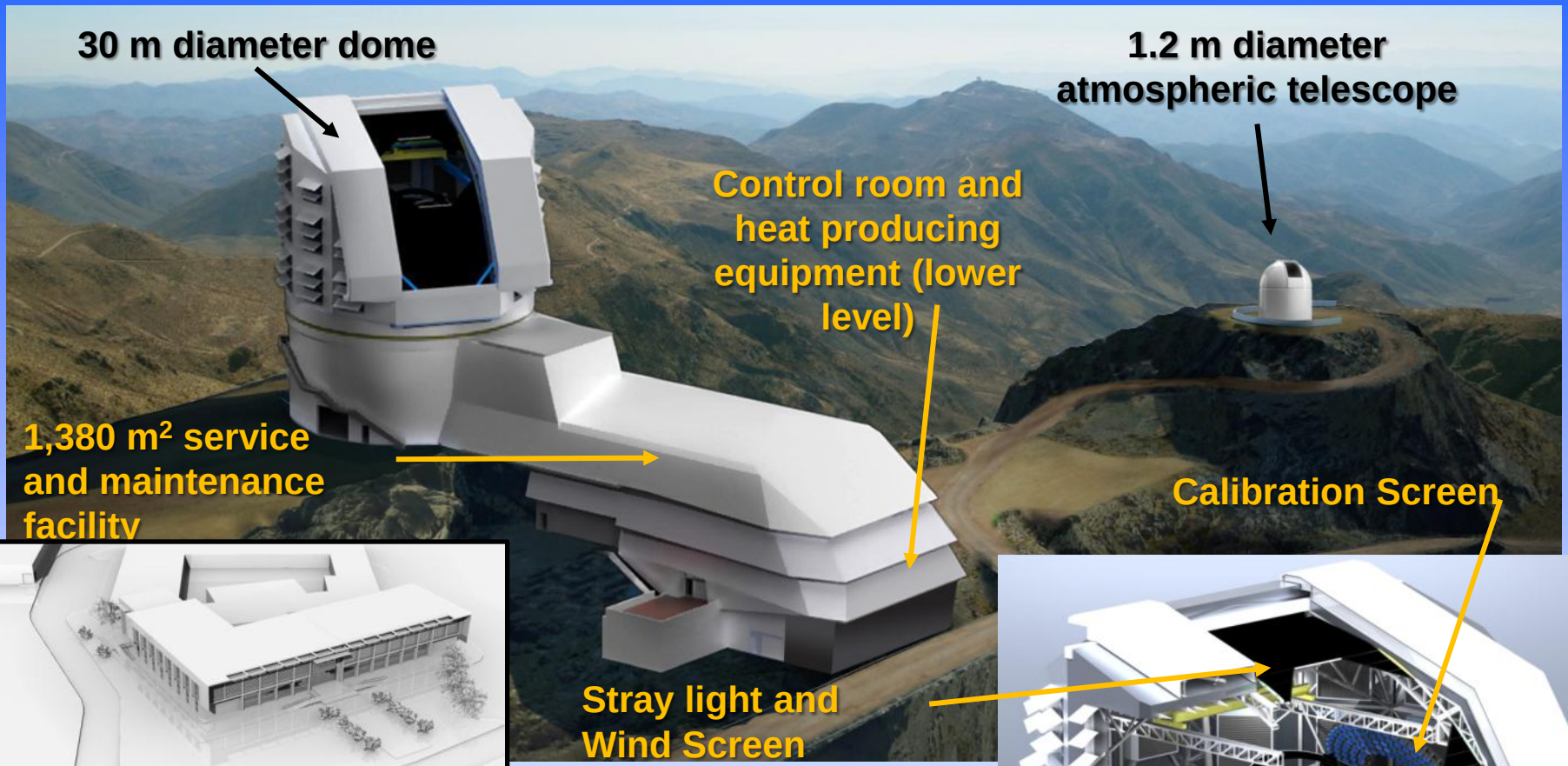
LSST and the future decade of optical transient surveys

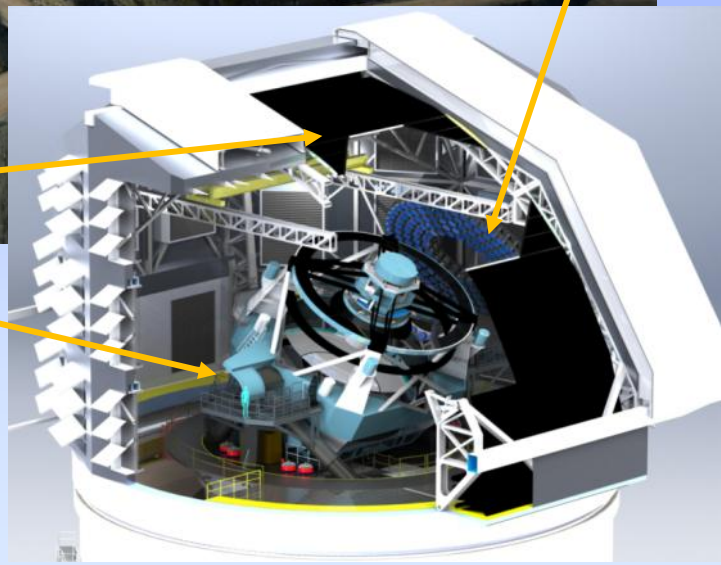


Tony Tyson
University of California, Davis

STELLANOVAE, CAPE TOWN SOUTH AFRICA, FEBRUARY 2013

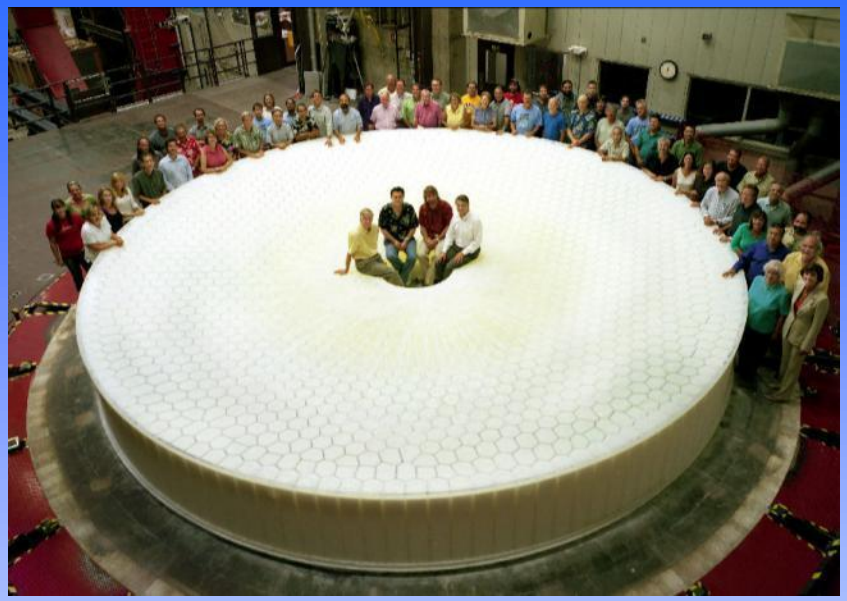
Telescope and Site



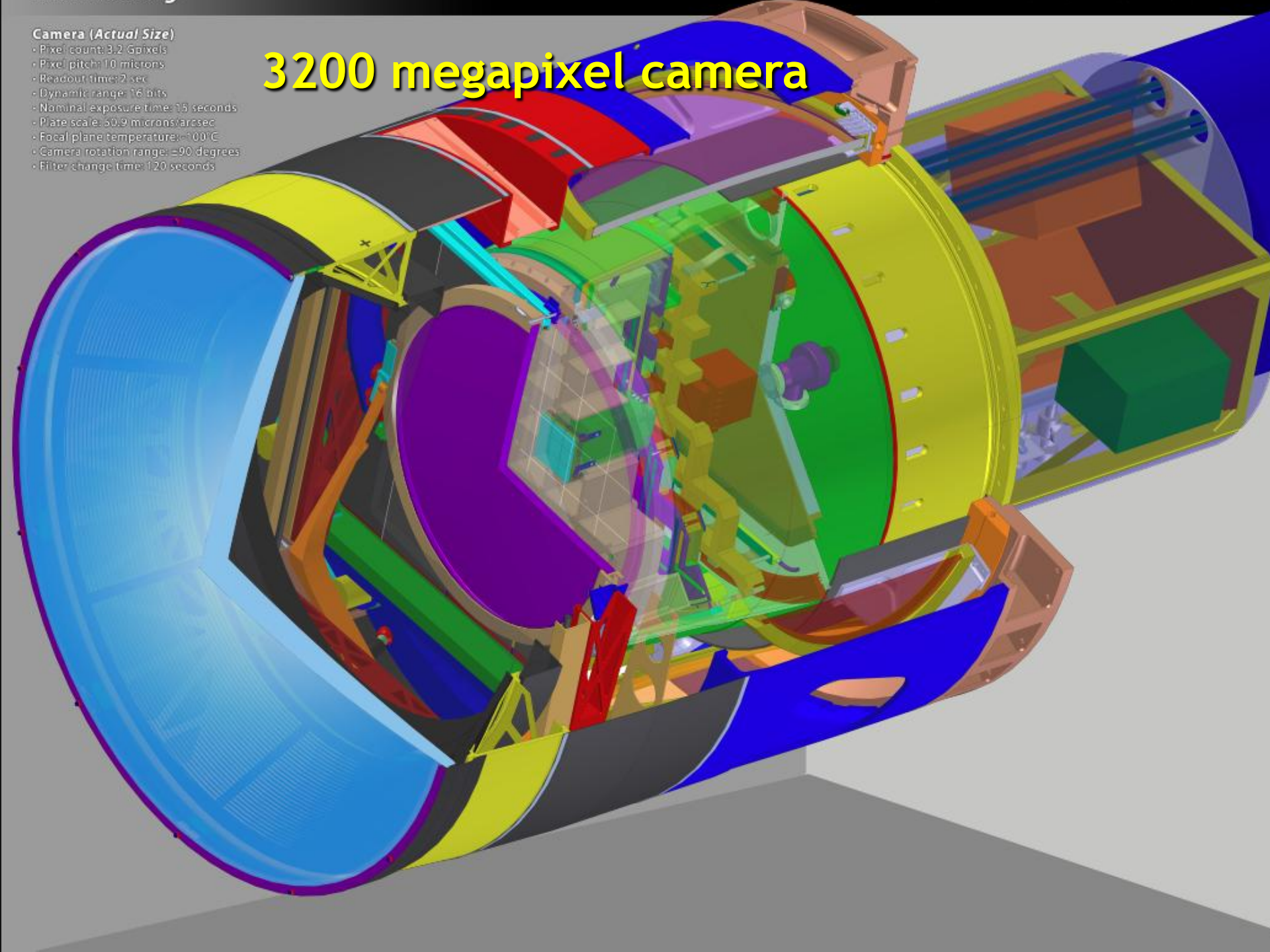


Includes the facilities, and hardware to collect the light, control the survey, calibrate conditions, and support all LSST summit and base operations.

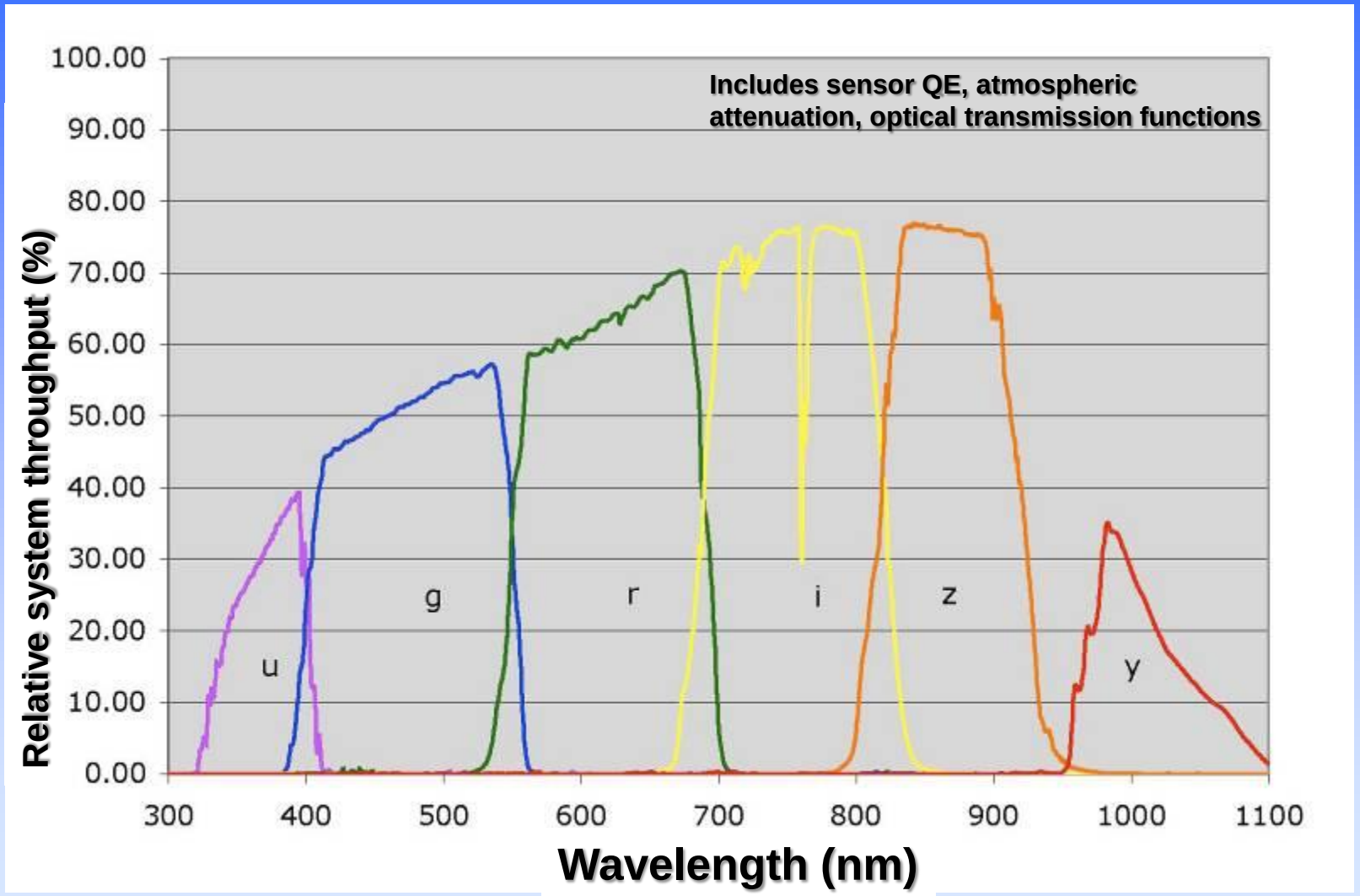
Mirror fabrication is advanced - Private funding enabled early start of both reflective optics



- Primary-Tertiary was cast in 2008
- Fabrication completed by the early 2013
- Secondary substrate fabricated by Corning in 2009.


Camera (Actual Size)
• Pixel count: 3.2 Gpixels
• Pixel pitch: 10 microns
• Readout time: 2 sec
• Dynamic range: 16 bits
• Nominal exposure time: 15 seconds
• Plate scale: 50.9 microns/arcsec
• Focal plane temperature: -100°C
• Camera rotation range: ±90 degrees
• Filter change time: 120 seconds
3200 megapixel camera

LSST six color system



LSST: Joint US DOE/NSF Project

National Science Foundation

- **Lead agency**
  - **Project Management**
  - **Telescope and site**
  - **Data Management**
  - **Education and Public Outreach**
- ***National Science Board approval: July 2012***
  - **Possible NSF construction start: 2014**

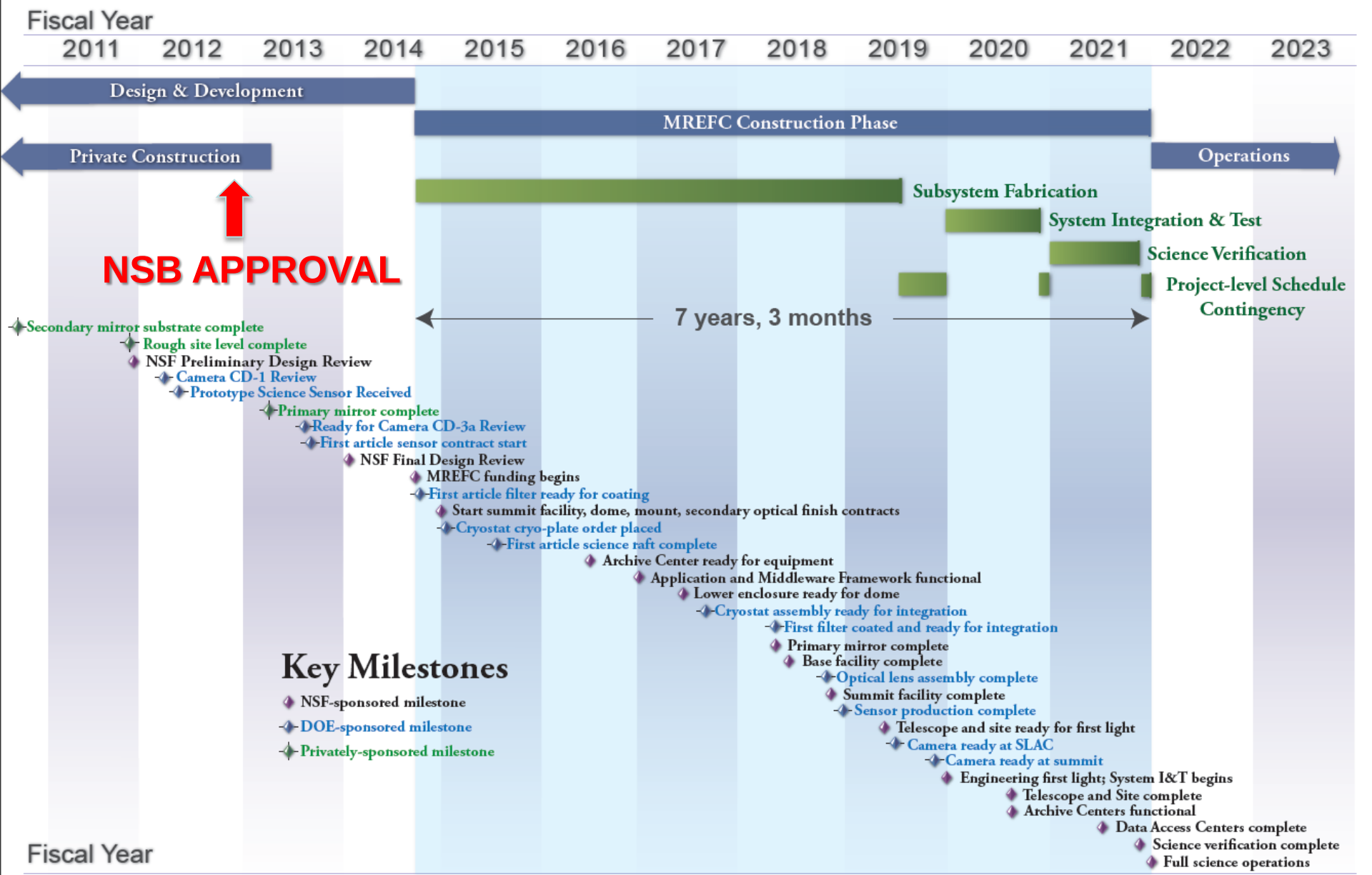
Joint DOE/NSF Project

Department of Energy

- **Deliver a 3.2 Giga-pixel camera that meets project requirements**
- **Agency status:**
  - **CD-0: Approve Mission Need: Dark Energy Stage IV Experiment(s)**
  - **CD-1: Select option to move forward and set cost range**

    CD-1 granted: March 2012

Integrated Project Schedule with Key Milestones



LSST Observing Cadence

Pairs of 15 second exposures (*to 24.5 mag*) per visit to a given position in the sky.

Visit the same position again within the hour with another pair of exposures.

Number of 9.6 sq.deg field-of-view visits per night: 850

Detection of transients announced within 60 seconds.
Expect 1-2 million alerts per night!

Two planned LSST surveys

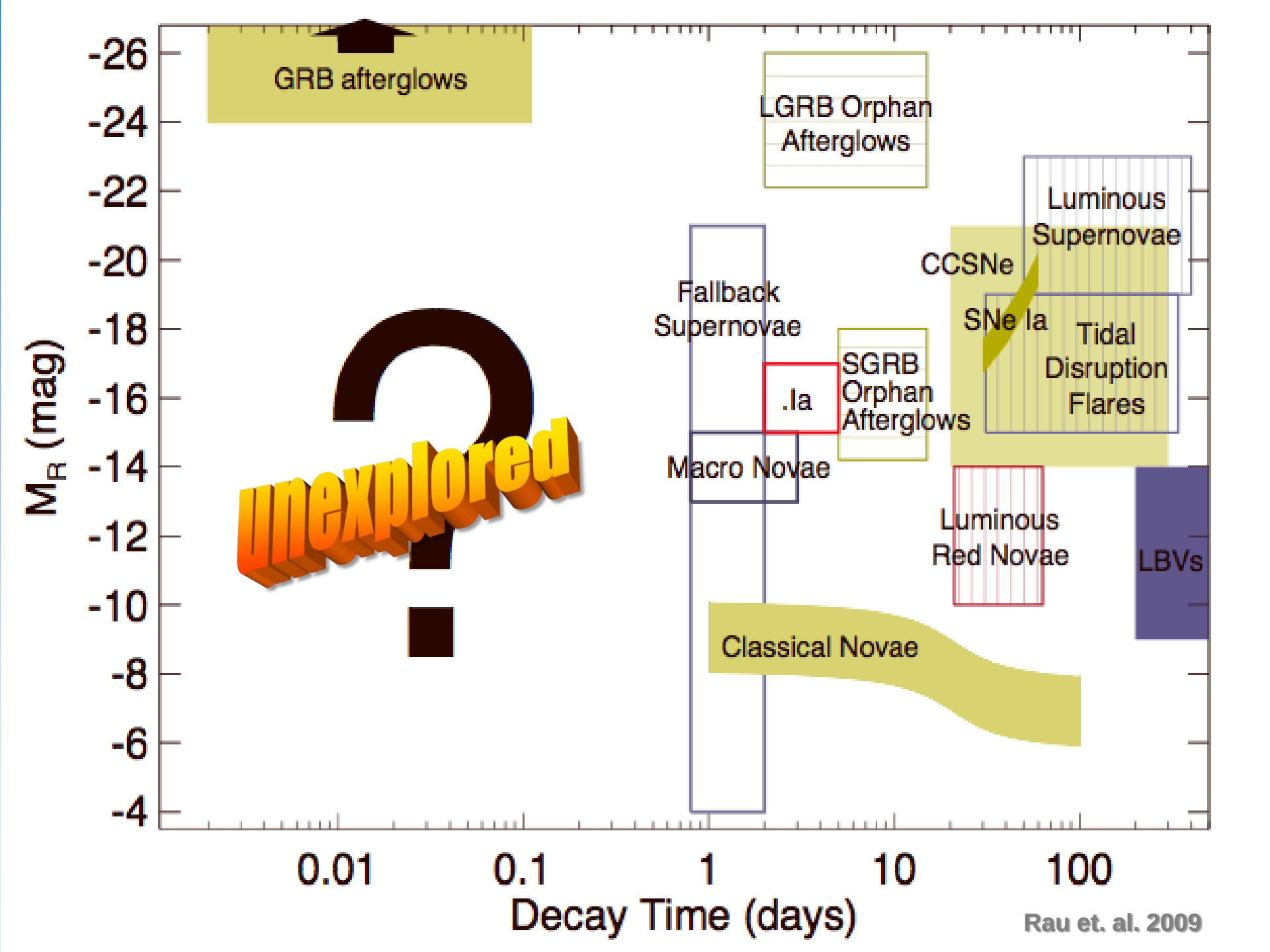
MAIN SURVEY
Deep Wide Survey: 18,000 square degrees to a uniform depth of
***u*: 26.1 *g*: 27.4 *r*: 27.5 *i*: 26.8 *z*: 26.1 *y*: 24.9**

DEEP DRILLING SURVEY
10% of time: ~30 selected fields. 300 square degrees
Continuous 15 sec exposures. 1hour/night

LSST Wide-Fast-Deep survey

- **Time domain:**
  1 million supernovae
  10 billion stars
  new phenomena

opens the time window!


GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
unexplored
Luminous Red Novae
LBVs
Classical Novae
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
M_R (mag)
0.01
0.1
1
10
100
Decay Time (days)
Rau et. al. 2009

Predicted number of detectable variables in a 10 Sq Deg field at l=96, b=-60, in the g-filter. From Kepler statistics.

Class	Model Star Count	Variability >25 mmag	Variability >10 mmag
G giant	736	3.6	5.9
K giant	33	0.2	0.4
M giant	0	0.0	0.0
A dwarf	0	0.0	0.0
F dwarf	5695	17.8	29.5
G dwarf	8420	27.6	46.6
K dwarf	17556	163.7	267.0
M dwarf	21147	438.9	563.8
Total	**53587**	**651.8**	**913.2**
Fraction		**1.22%**	**1.70%**

Ridgway 2012

LSST is expected to image ~400 fields per night (most at least 2x during the night).

Depending on the photometric cut and the position on the sky, LSST could detect ~500 to 20000 variable stars per field, or ~200,000 per night. These would be among the ~1-2 million transient alerts issued every night.

Most variables stars (~90%) will be K and M dwarfs, readily identified as such from photometry.

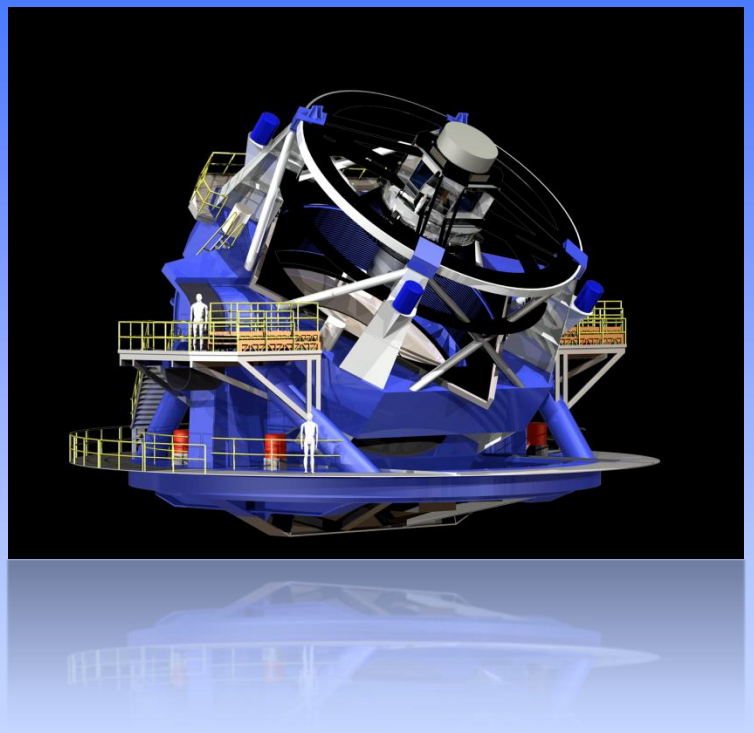
Expected rate of transients

Class	Mag	t (days)	Universal Rate	LSST Rate
Luminous SNe	-19...-23	50 - 400	10^{-7} Mpc^{-3} yr^{-1}	**20000**
Orphan Afterglows SHB	-14...-18	5 -15	3 x$10^{-7...-9}$ Mpc^{-3} yr^{-1}	**~10 - 100**
Orphan Afterglows LSB	-22...-26	2 - 15	3 x $10^{-10...-11}$ Mpc^{-3} yr^{-1}	**1000**
On-axis GRB afterglows	...-37	1 - 15	10^{-11} Mpc^{-3} yr^{-1}	**~50**
Tidal Disruption Flares	-15...-19	30 - 350	10^{-6} Mpc^{-3} yr^{-1}	**6000**
Luminous Red Novae	-9...-13	20 - 60	10^{-13} yr^{-1} Lsun^{-1}	**80 - 3400**
Fallback SNe	-4...-21	0.5 - 2	<5 x 10^{-6} Mpc^{-3} yr^{-1}	**< 800**
SNe Ia	-17...-19.5	30 - 70	3 x 10^{-5} Mpc^{-3} yr^{-1}	**200000**
SNe II	-15...-20	20 - 300	(3..8) x 10^{-5} Mpc^{-3} yr^{-1}	**100000**

Extrapolated from Rau, et al. 2009, based on PTF data

Example: The Science Enabled by LSST

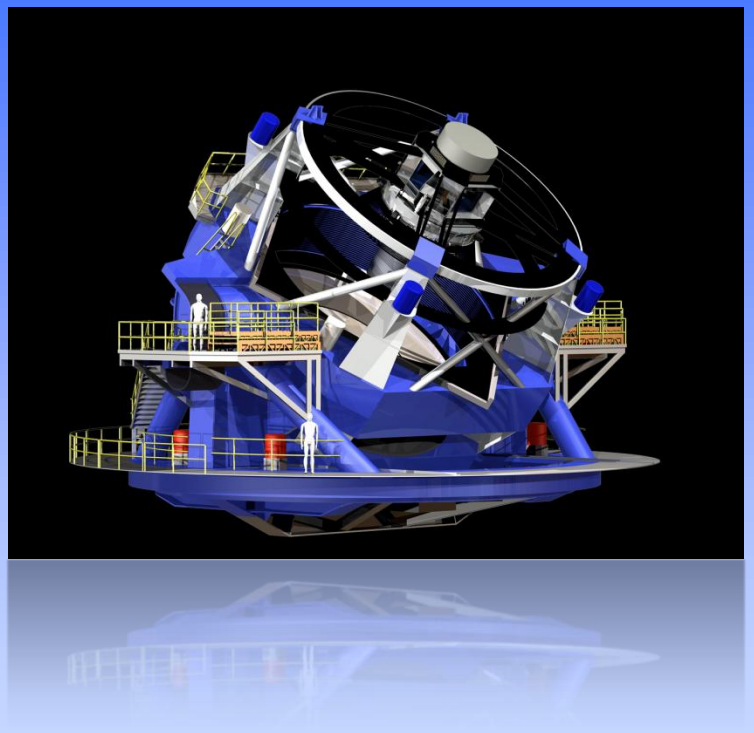
- **Time domain science**
  - Novae, supernovae, GRBs
  - Source characterization
  - Instantaneous discovery
- **Finding moving sources**
  - Asteroids and comets
  - Proper motions of stars
- **Mapping the Milky Way**
  - Tidal streams
  - Galactic structure
- **Dark energy and dark matter**
  - Gravitational lensing
  - Slight distortion in shape
  - Trace the nature of dark energy



How does one do research when faced with trillions of catalog entries, and potentially millions of measurements for each class of objects?

Getting to the Science Enabled by LSST

- **Finding the unusual**
  - Anomaly detection
  - Dimensionality reduction
  - Cross-matching data
- **Finding moving sources**
  - Tracking algorithms
  - Kalman filters
- **Mapping the Milky Way**
  - Density estimation
  - Clustering (n-tuples)
- **Dark energy and dark matter**
  - Computer vision
  - Weak Classifiers
  - High-D Model fitting



To take advantage of LSST, Euclid, SKA, and large surveys in general, the next generation of students must grow up with terms such as these.

Old Paradigm

Astronomer+
pencil+paper

INSTRUMENT

TELESCOPE

New Paradigm

DATA ENABLED DISCOVERY

INSTRUMENT

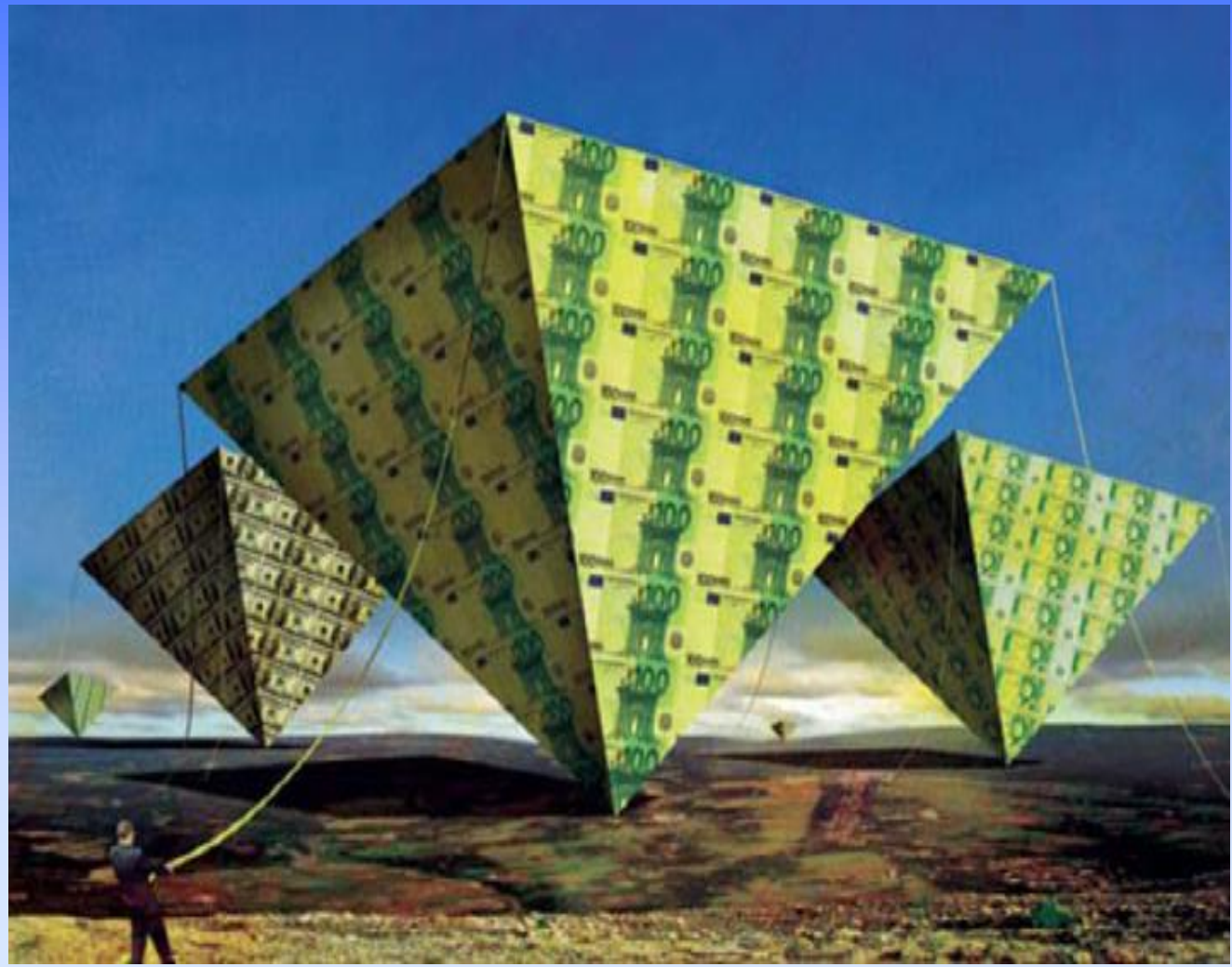
TELESCOPE

Harnessing Survey Data at Exascale

- Number of scientists does not scale with the data!

- *Database* is the new Lab, the new Experiment

Sparse matrix of databases: observations, and simulations of observations



LSST: A Petascale Survey of the Optical Sky

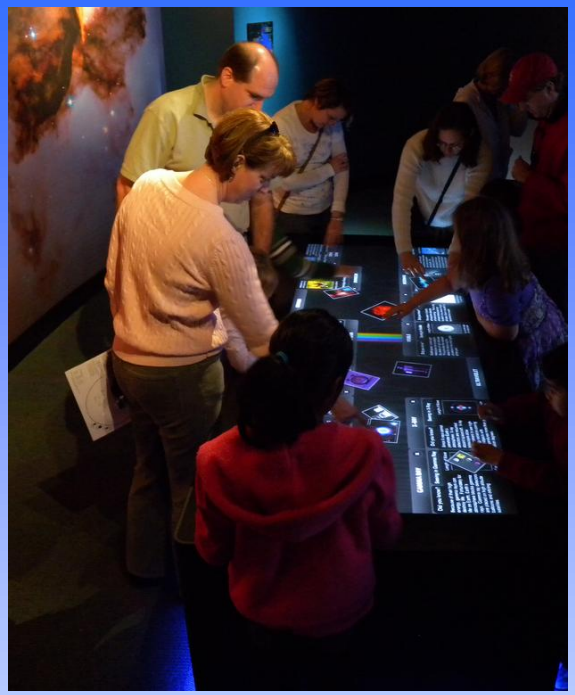
Final Image Archive	345 PB	All Data Releases Includes Virtual Data (315 PB)
Final Image Collection	75 PB	Data Release 11 (Year 10) Includes Virtual Data (57 PB)
Final Catalog Archive	46 PB	All Data Releases
Final Database	9 PB 32 trillion rows	Data Release 11 (Year 10) Includes Data, Indexes, and DB Swap
Final Disk Storage	228 PB 3700 drives	Archive Site Only
Final Tape Storage	83 PB 3800 tapes	Single Copy Only
Number of Nodes	1800	Archive Site Compute and Database Nodes
Number of Alerts Generated	6 billion	Life of survey

*** Virtual Data is data that is dynamically recreated on-demand from provenance information**

Major challenge and opportunity:

Discovering The Unexpected

LSST Outreach Data will be used in classrooms, science museums, and online



Classroom Emphasis on:

- Data-enabled research experiences
- Citizen Science
- College classes
- Collaboration through Social Networking

ZOONIVERSE
REAL SCIENCE ONLINE

DATA PRODUCTS

Application Layer -
Generates open, accessible data products with fully documented quality

Processing Cadence	Image Category (files)	Catalog Category (database)	Alert Category (database)
Nightly	Raw science image Calibrated science image Subtracted science image Noise image Sky image Data quality analysis	Source catalog (from difference images) Object catalog (from difference images) Orbit catalog Data quality analysis	Transient alert Moving object alert Data quality analysis
Data Release (Annual)	Stacked science image Template image Calibration image RGB JPEG Images Data quality analysis	Source catalog (from calibrated science images) Object catalog (optimally measured properties) Data quality analysis	Alert statistics & summaries Data quality analysis

IMAGE SIMULATIONS