LSST's NEO Survey Capabilities

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for the

LSST Collaboration

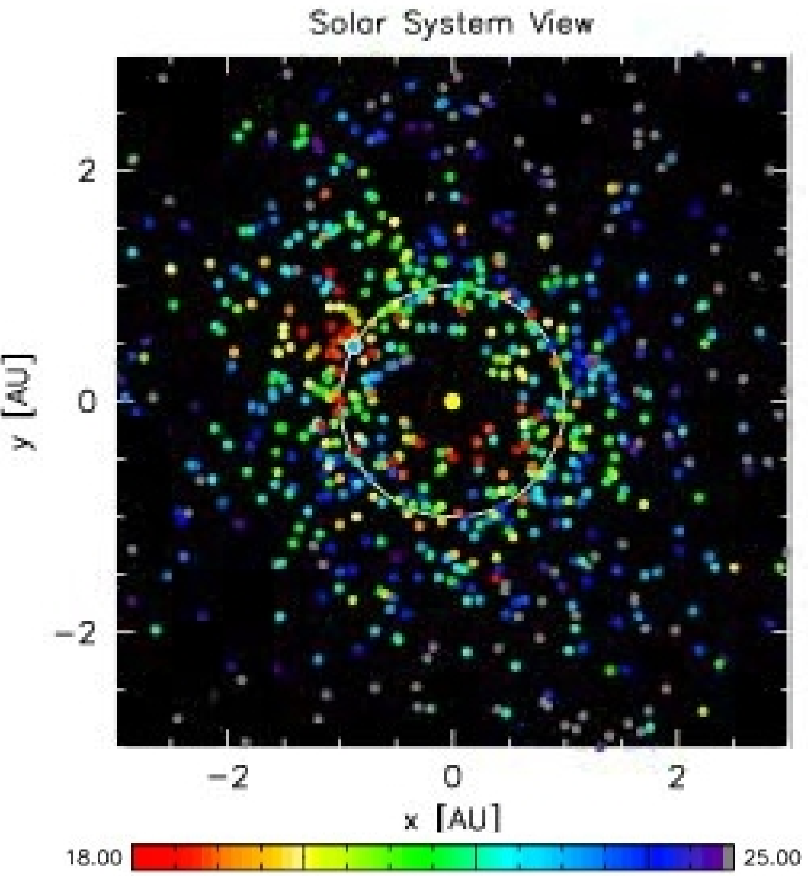
NEO Survey/Detection Panel, National Research Council

January 28, 2009, Washington, D.C.

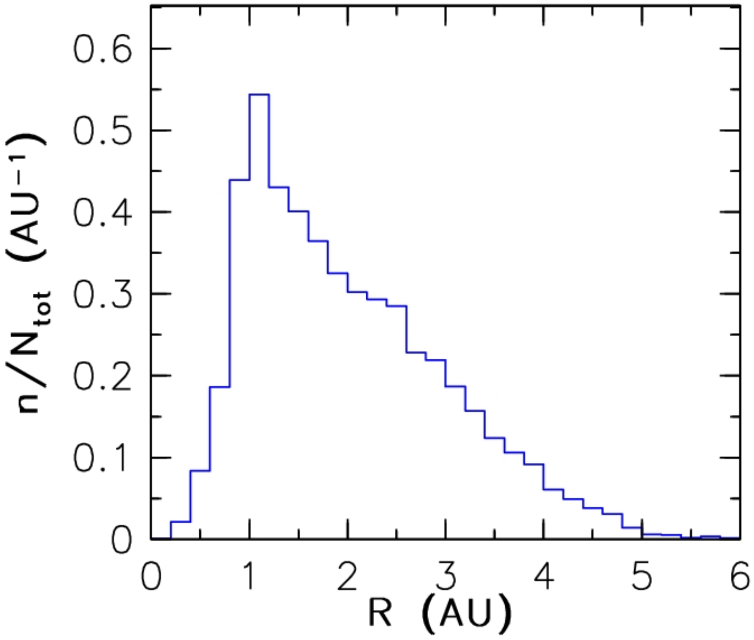
Outline

1. Direct implications of the Congressional mandate to catalog 90% of 140m and larger NEOs:
   - Telescope Aperture, System Etendue, Data Rate
2. Large Synoptic Survey Telescope:
   - The LSST System: telescope, camera, data management
   - Other Science Drivers and Status Report
3. LSST NEO Survey:
   - The Completeness of the LSST PHA survey
   - PHA characterization
4. Can LSST fulfill the Congressional NEO Mandate?

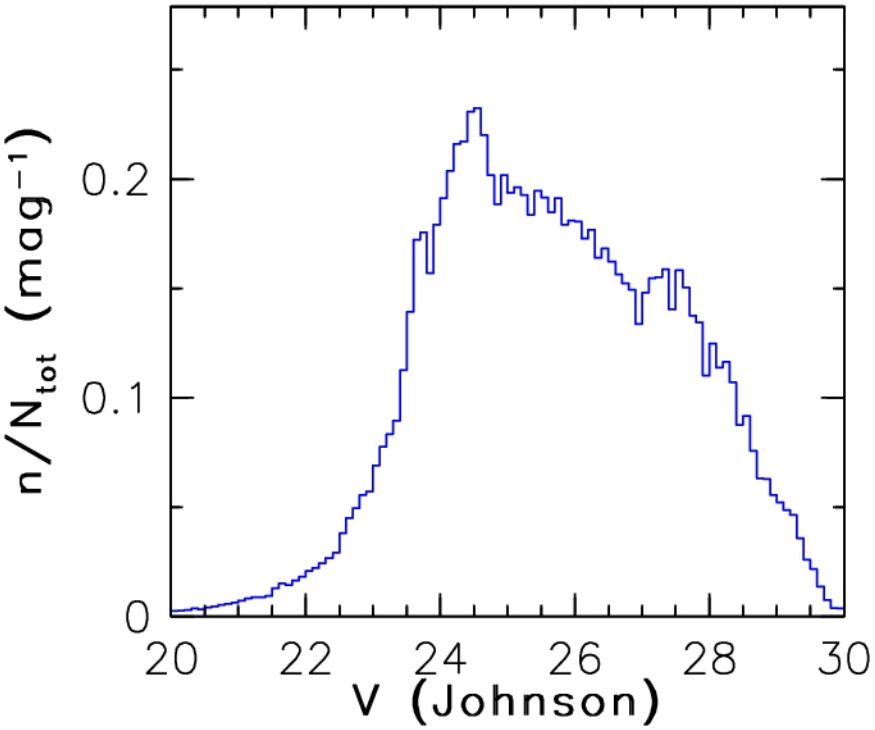
Where are 140m NEOs?

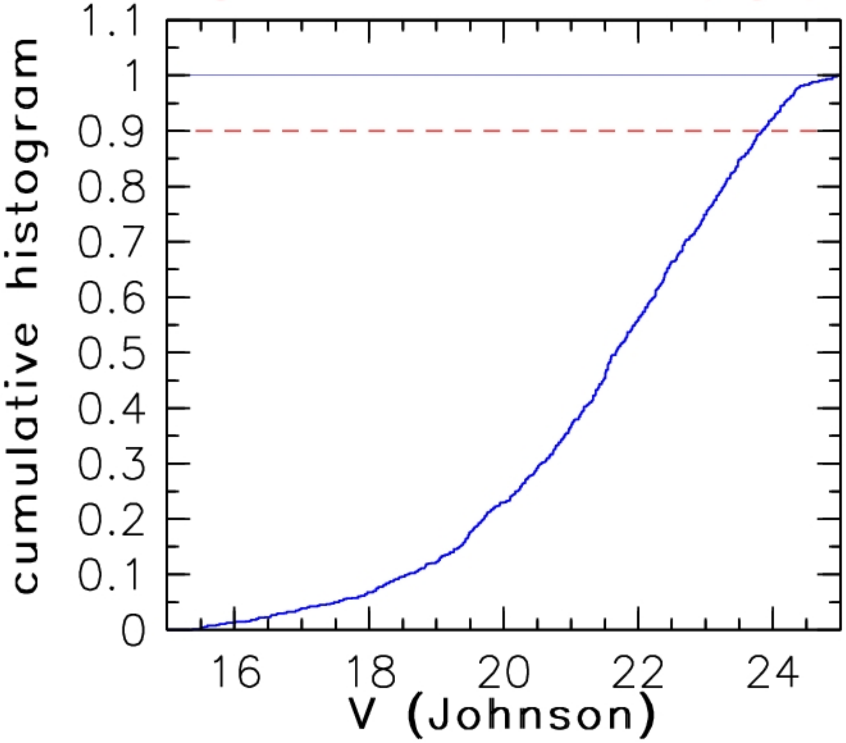

Solar System View

Known NEO heliocentric distance distribution



- The Congressional Mandate: 90% of NEOs with >140m diameter
- Assume:
  1. 140m is equivalent to H=22,
  2. the NEO orbital distribution doesn't depend on NEO's size,
  3. it's PHAs, not NEAs
- Compute: Positions and mags of the known PHA/NEO sample for the period 2015-2025
- **Top Left:** Positions of ~800 known PHAs taken from MPC, coded by V mag (red:bright, blue: faint)
- **Bottom Left:** The distribution of heliocentric distances averaged over 10 years; 14% at $R < 1$, median $\bar{R}$ ~2 AU, but median $\bar{D}$ ~2.1 AU!


V distribution for 140m NEOs (night)

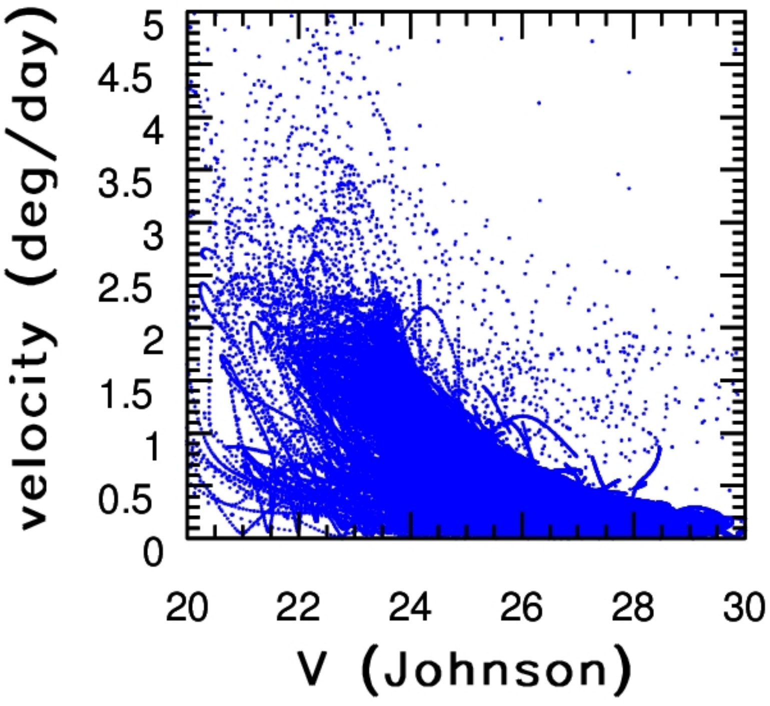

Brightest V for 140m NEOs (night)

How bright are 140m NEOs?

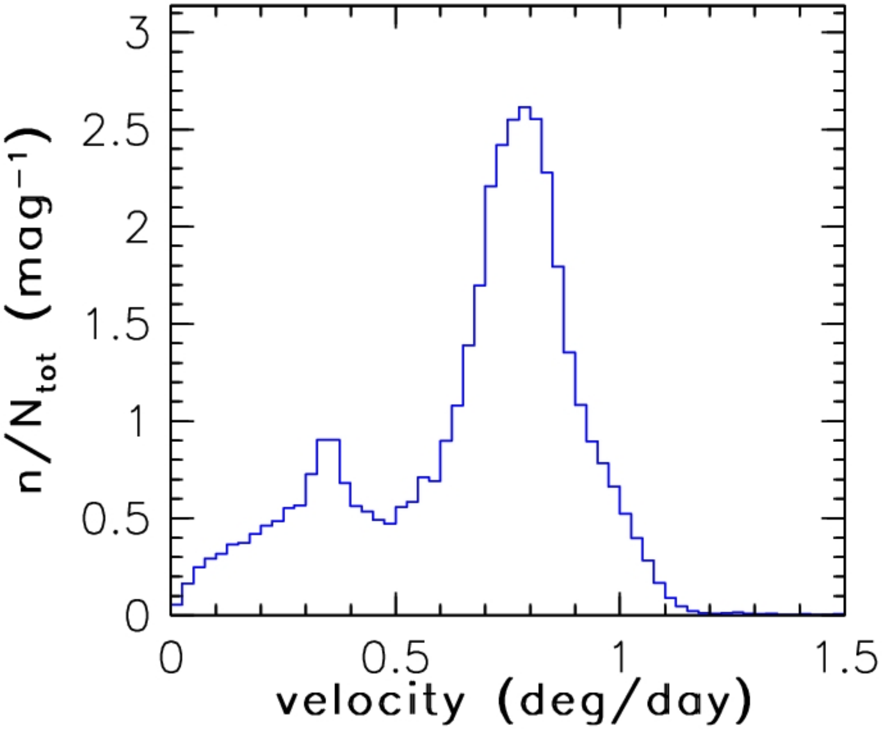
- Median Values: $\bar{R} \sim 2$ AU and $\bar{D} \sim 2.1$ AU, implies $V \sim 25$
- Full Analysis: R, D, phase effects, etc.
- **Top Left:** the distribution of the Johnson V band apparent magnitudes for 140m NEOs observed during night time, median $\bar{V} = 25.5$
- **Bottom Left:** the cumulative distribution of the brightest V magnitude over 10 years: **10% of 140m NEOs are NEVER brighter than $V = 23.8$**
- Conclusion: **It is impossible to fulfill the NASA goal unless $V > 24$.** Need to reach the equivalent of $V \sim 25$ in **each** observation.
- Question: moving objects suffer from trailing losses (effective sky area increases with time) – what is the longest acceptable exposure time?

How fast are 140m NEOs?

140m NEOs



Velocity for 140m NEOs w/ 24.8<V<25.2



- Requirement: need to reach $V \sim 25$ in each observation, but **how fast?**
- **Top Left:** the angular velocity vs. V magnitude for 140m NEOs, sampled over 1 year
- **Bottom Left:** the angular velocity distribution for 140m NEOs with $24.8 < V < 25.2$
- Conclusion: Need to prevent trailing losses for objects as fast as $\sim$1 deg/day
- Implications: assuming a seeing of 0.7 arcsec, an object moving at 1 deg/day will cross the seeing disk in $\sim$**15 sec; the exposure time shouldn't be much longer than this limit!**

Direct implications of the Congressional mandate:

1. **Telescope Aperture:** 140m object size implies V ~25 imaging, to reach V ~25 in 15 sec **need a 10m-class telescope**

2. **Field of view:** in order to cover the sky frequently enough, **need a ~5-10 deg^2 large field of view**, therefore $A\Omega$ product (etendue) needs to be at least several hundred m^{2}deg^2 (also, a large FOV implies a gigapixel-class camera)

3. **Data Rate:** frequent coverage of the whole sky at subarcsec resolution implies **enormous data rates** (e.g. for LSST ~30 TB/night, 60 PB over 10 years)

Inescapable conclusions: **A system** with an etendue of several hundred m^{2}deg^2, with a gigapixel-class camera and a sophisticated and robust data system, **is required to fulfill the Congressional mandate.**

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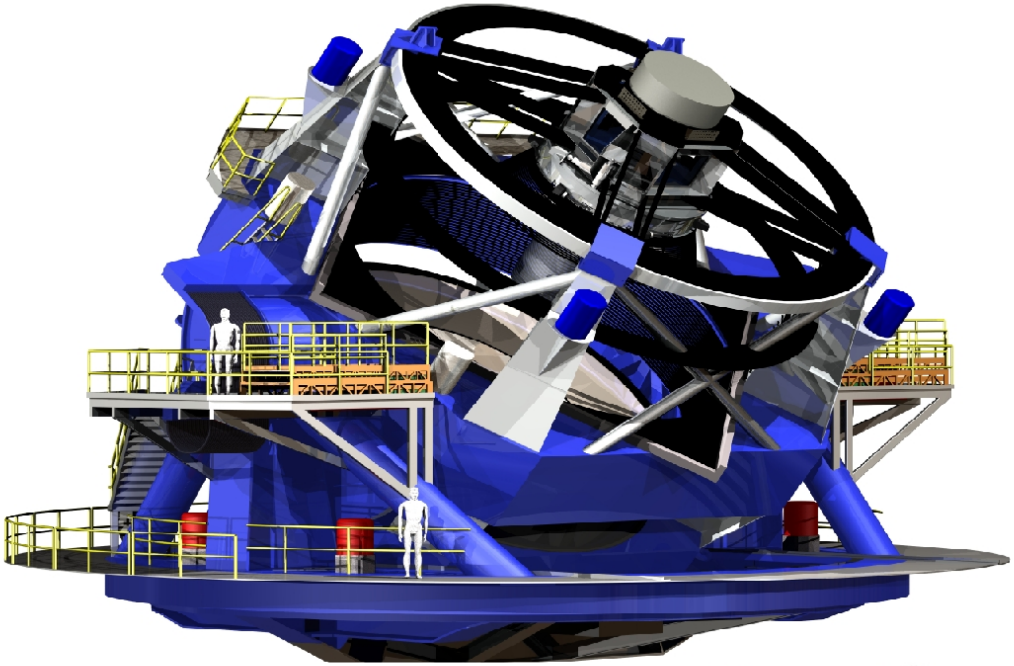
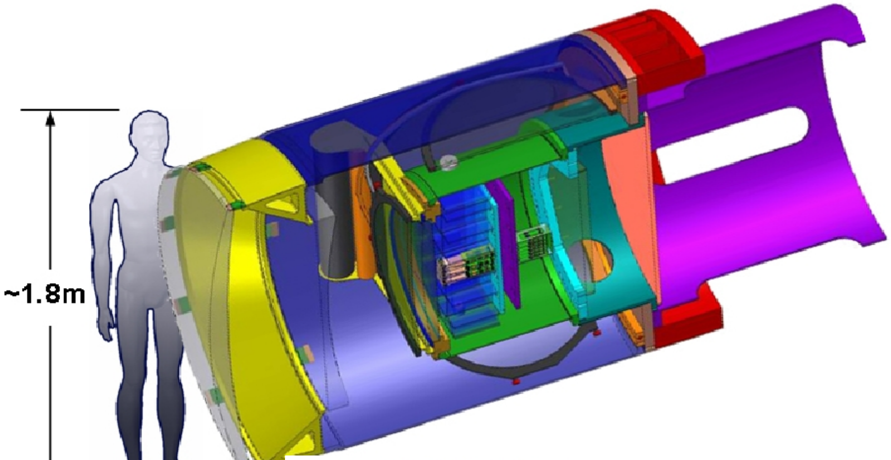
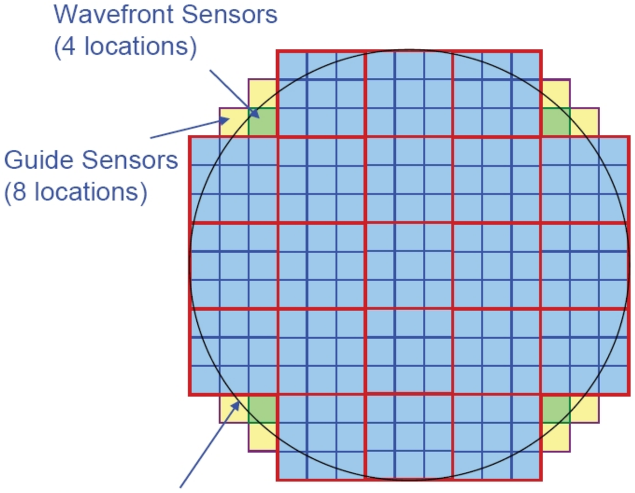






The LSST System

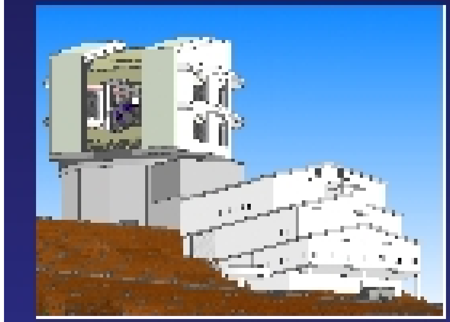
- **Site:** Cerro Pachon, Chile
- **Telescope:** 8.4 m (6.7m effective) diameter primary mirror, a novel three-mirror design (modified Paul-Baker) with a very fast f/1.2 beam, the field of view of 9.6 deg^2
- **Camera:** 3,200 Megapixel with 189 4kx4k science sensors
- **Data Management:** rate of ∼30 TB/day, 60 PB over 10 years, transient alerts within 30 seconds; astrometry accurate to 10 milliarcsec relative and 50 milliarcsec absolute

- **LSST system will reach $V = 24.5-25.0$ in two back-to-back 15 sec exposures: capable of fulfilling the Congressional mandate.**

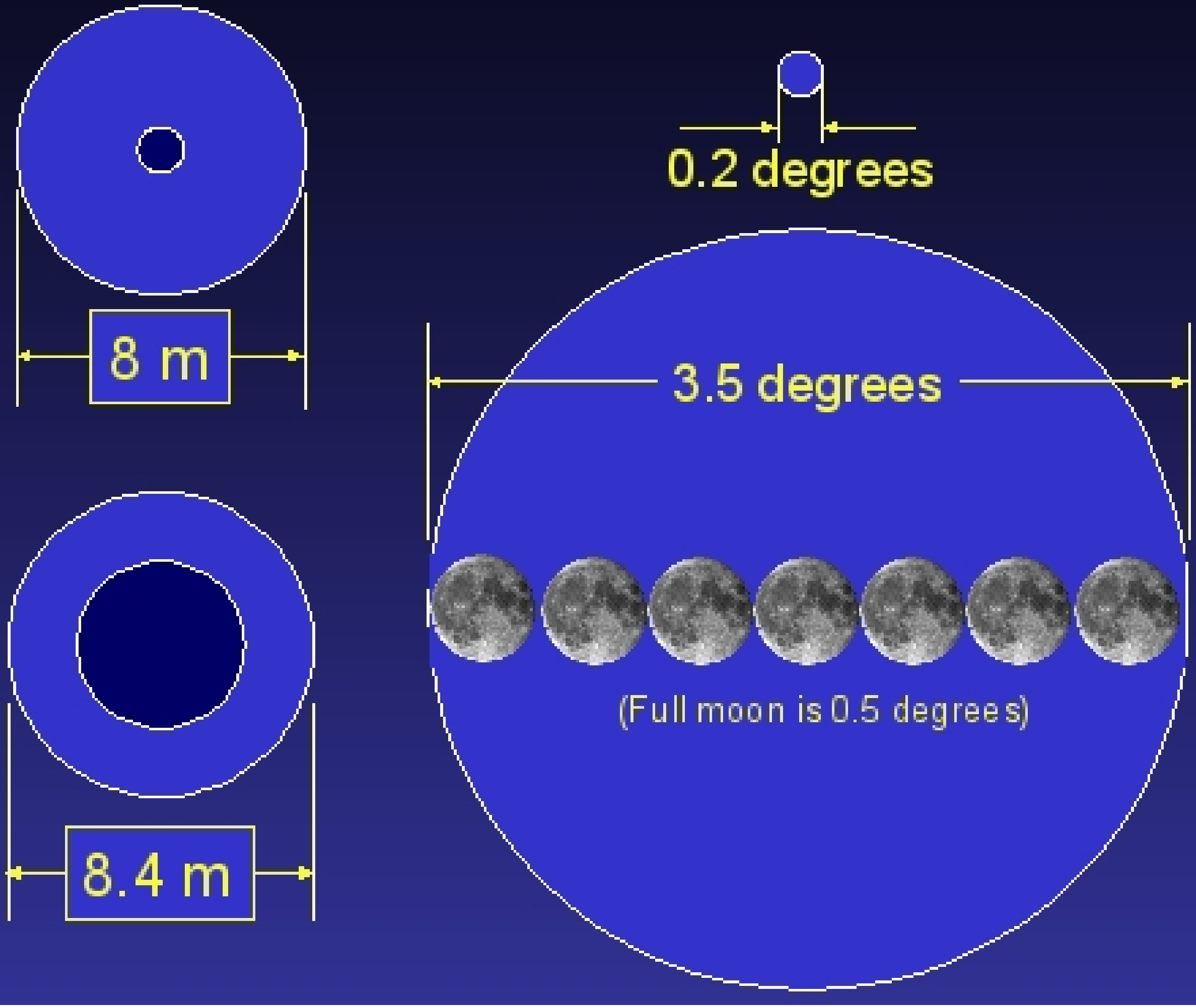
Primary Mirror Diameter

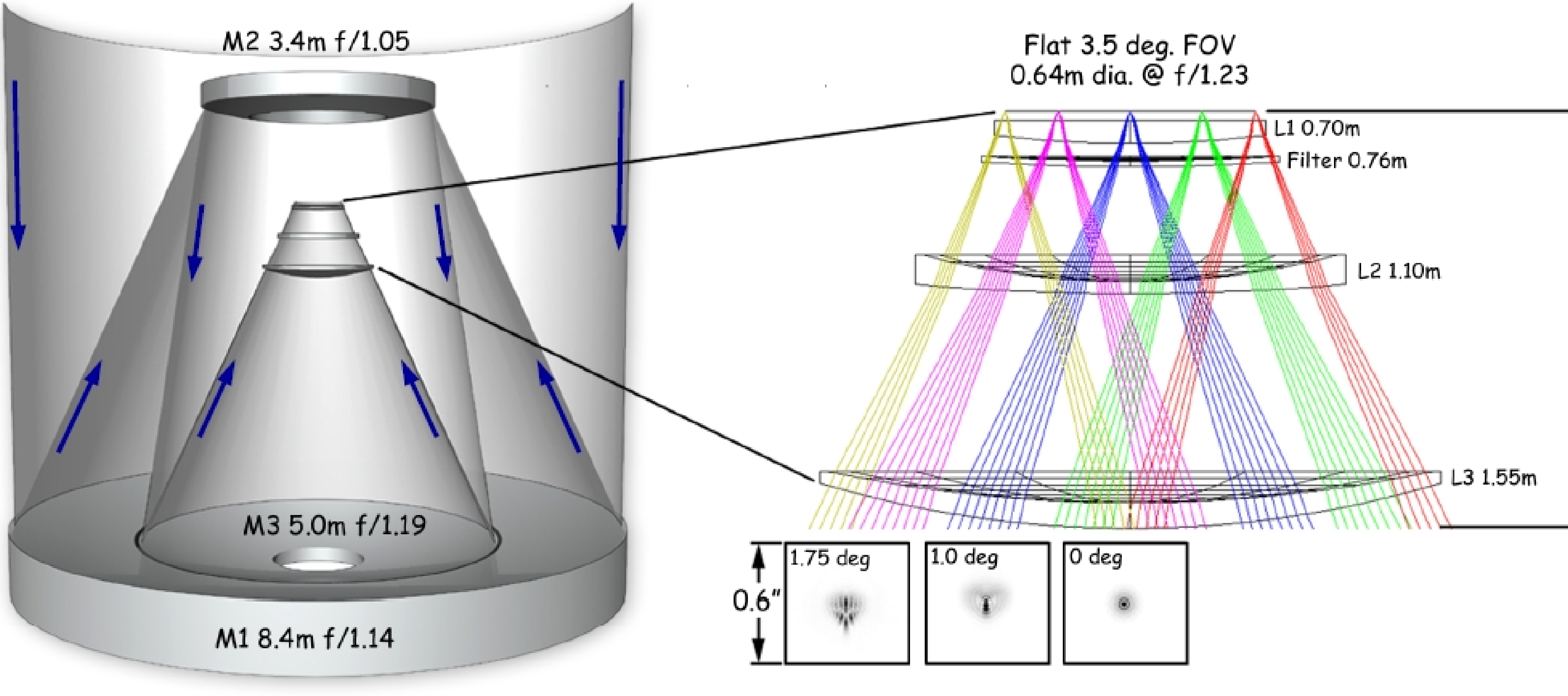
Field of View

Gemini South Telescope



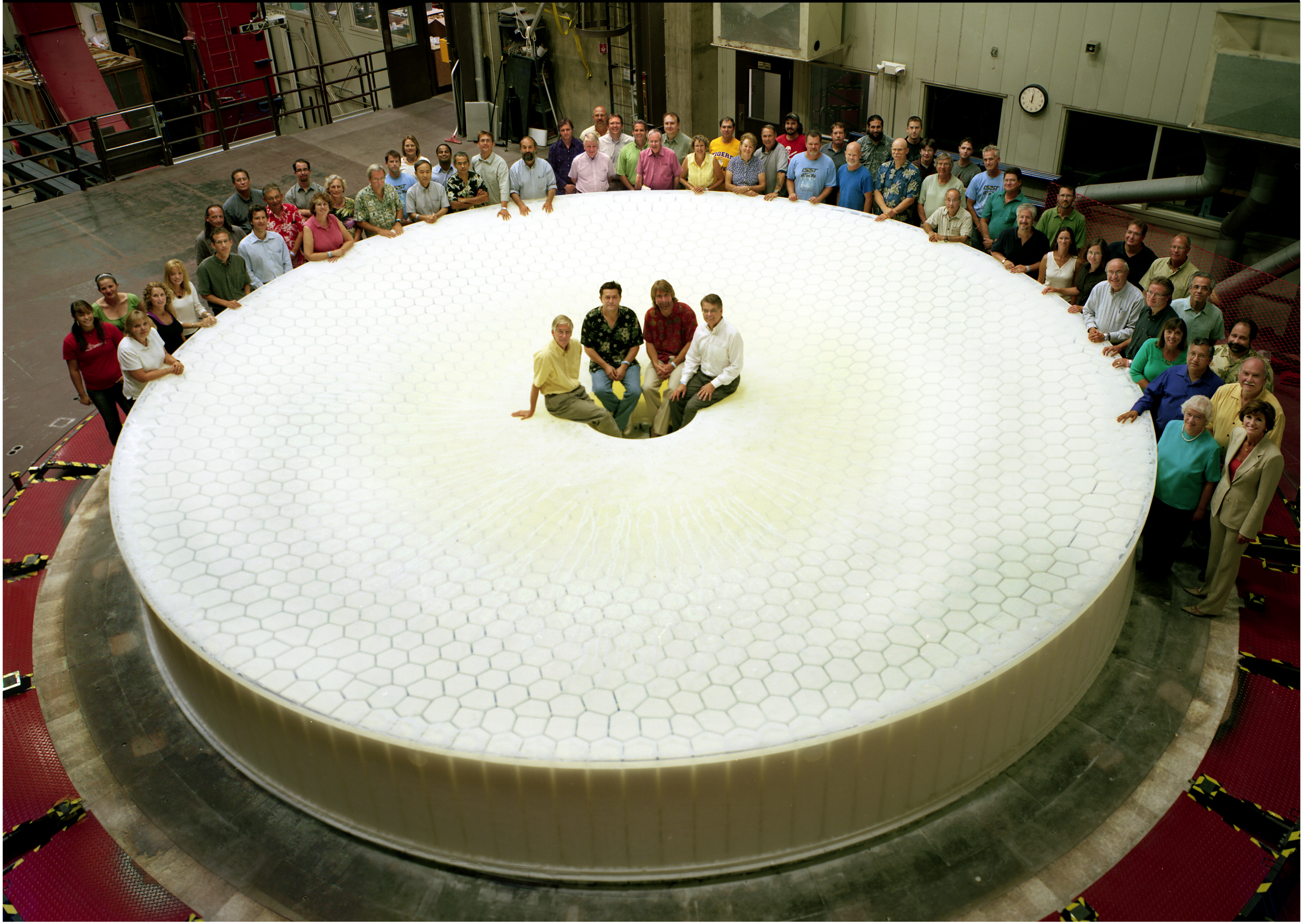
LSST





The primary/tertiary mirror has already been cast, and is now undergoing polishing at the Steward Observatory Mirror Lab.

Large Synoptic Survey Telescope



The University of Arizona
Tucson Arizona

LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

LSST Science Drivers

1. **The Fate of the Universe: Dark Energy and Dark Matter** (weak lensing, supernovae, baryon accoustic oscillations, galaxy clusters with 10 billion galaxies, millions of Type Ia SNe)
2. **Taking an Inventory of the Solar System** (NEOs to a small size limit, several million main-belt asteroids, ~100,000 TNOs and Jovian Trojans)
3. **Exploring the Unknown: Time Domain** (gamma-ray bursts, variable stars, quasars, unknown phenomena)
4. **Deciphering the Past: mapping the Milky Way** (10 billion stars, from solar neighborhood to the edge of halo)

Different science drivers lead to similar system requirements (NEOs, main-sequence stars to 100 kpc, weak lensing, SNe,...):

And also to the same observing strategy (cadence): a homogeneuos dataset will utilize 90% of observing time and serve the majority of science programs (with a high system efficiency)

LSST Management, Timeline, and Funding

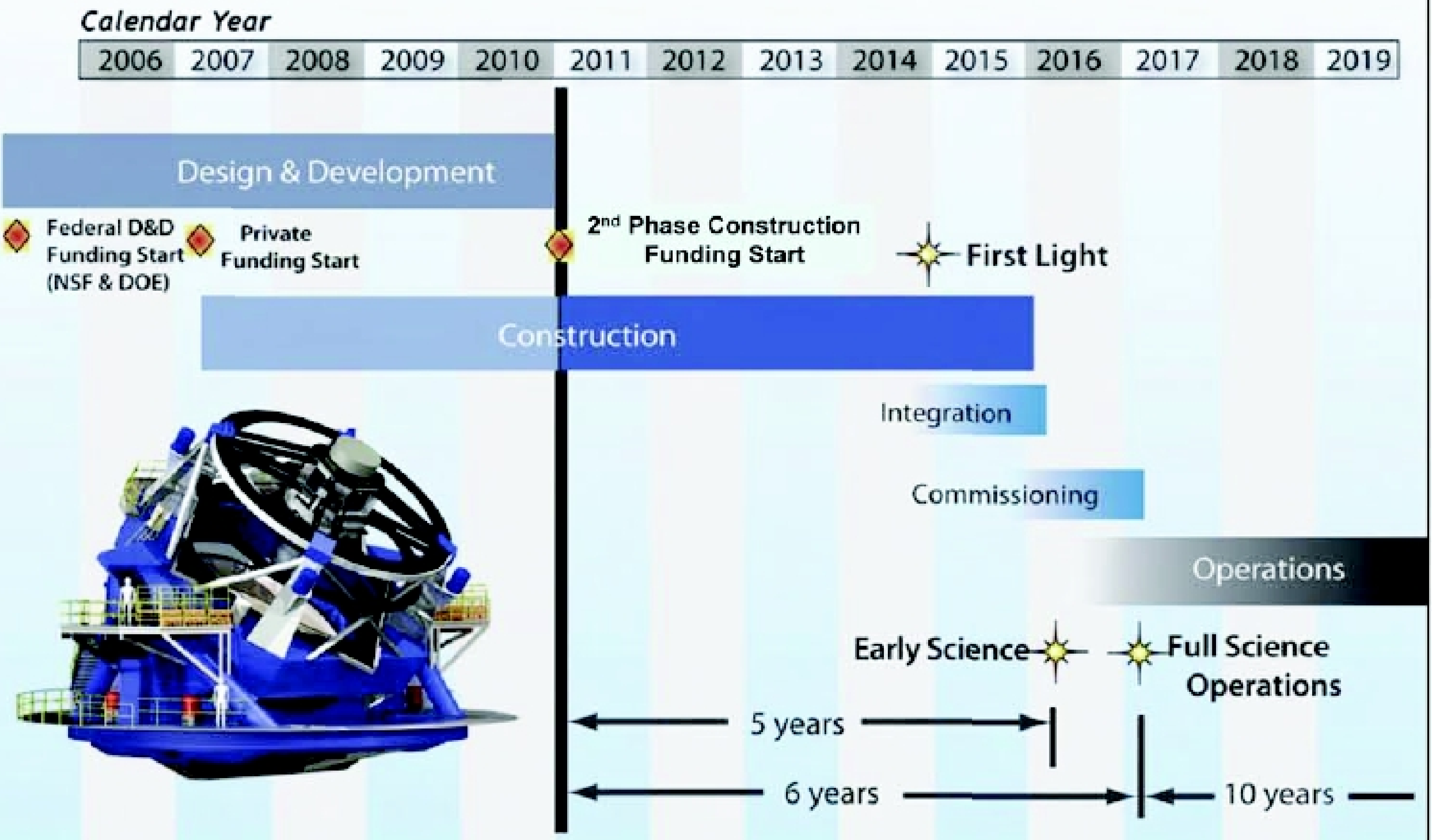
- **LSST is a collaboration** of numerous (>20) US institutions

- **Management:** solid structure mandated by numerous institutions and participants, following best business practices (Board of Directors, Project Director and Manager, Science Council and Advisory Council, Change Control Board, WBS)

- **Funding:** the construction budget is \$390M (in 2007 \$) and will come from the NSF and the DOE, with \$50M from private and other sources. The NSF is currently funding Design and Development phase. Three national laboratories (SLAC, BNL, and LLNL) are already spending significant DOE lab funds to design the LSST camera. Operations budget is \$37M/year

- **Timeline:** if funding stream according to plan, construction begins in 2011, first light in 2015

LSST Project Schedule



Calendar Year

2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019

Design & Development

Federal D&D Funding Start (NSF & DOE)

Private Funding Start

2nd Phase Construction Funding Start

First Light

Construction

Integration

Commissioning

Operations

Early Science

Full Science Operations

5 years

6 years

10 years

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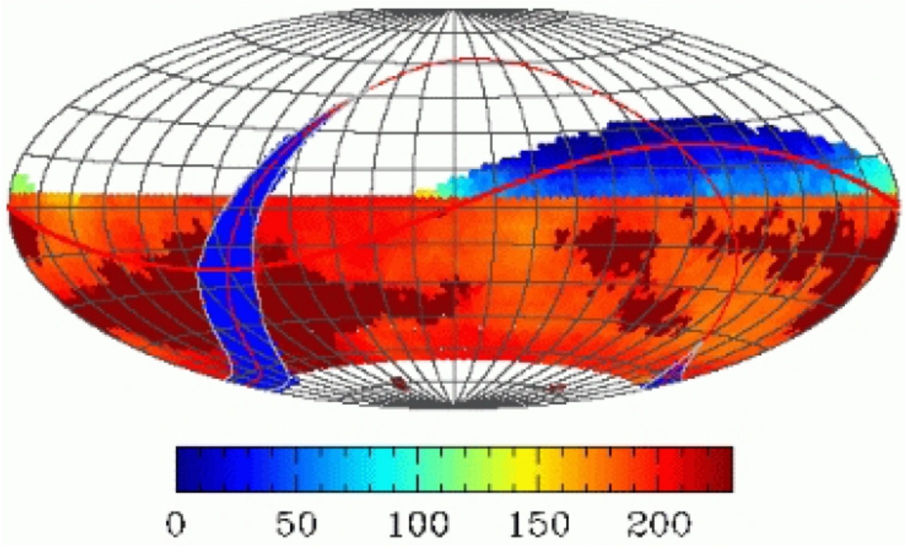
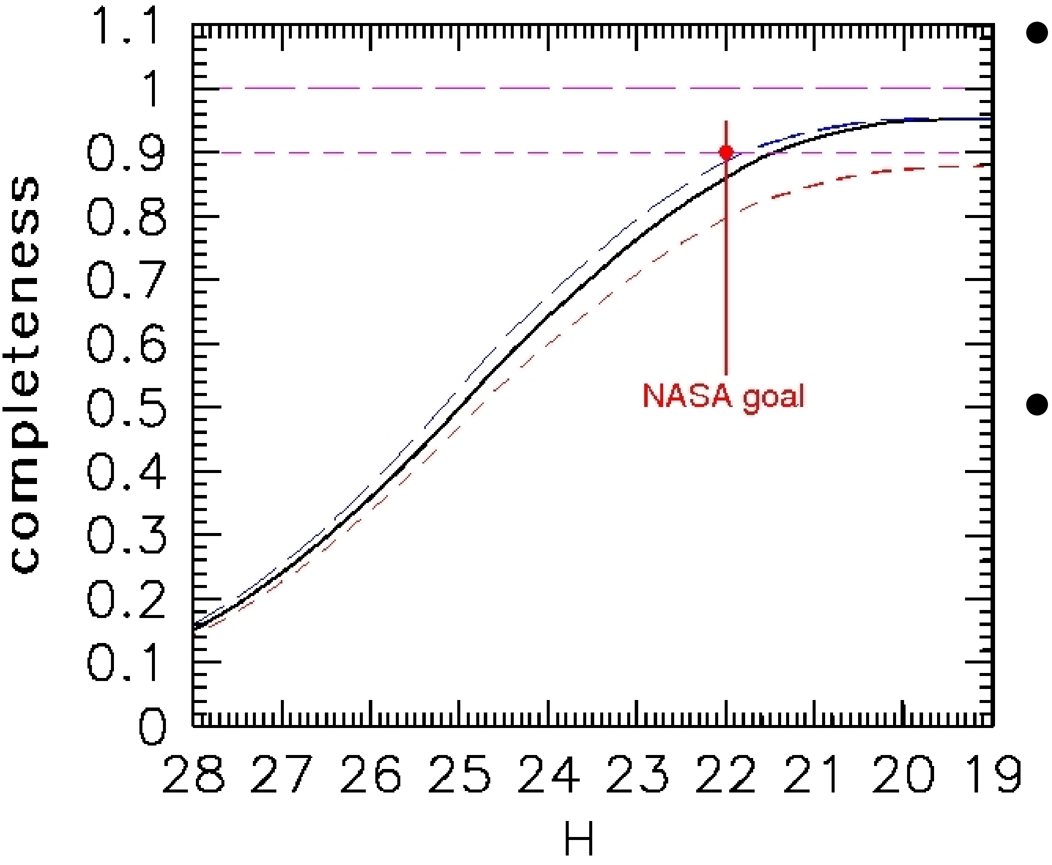
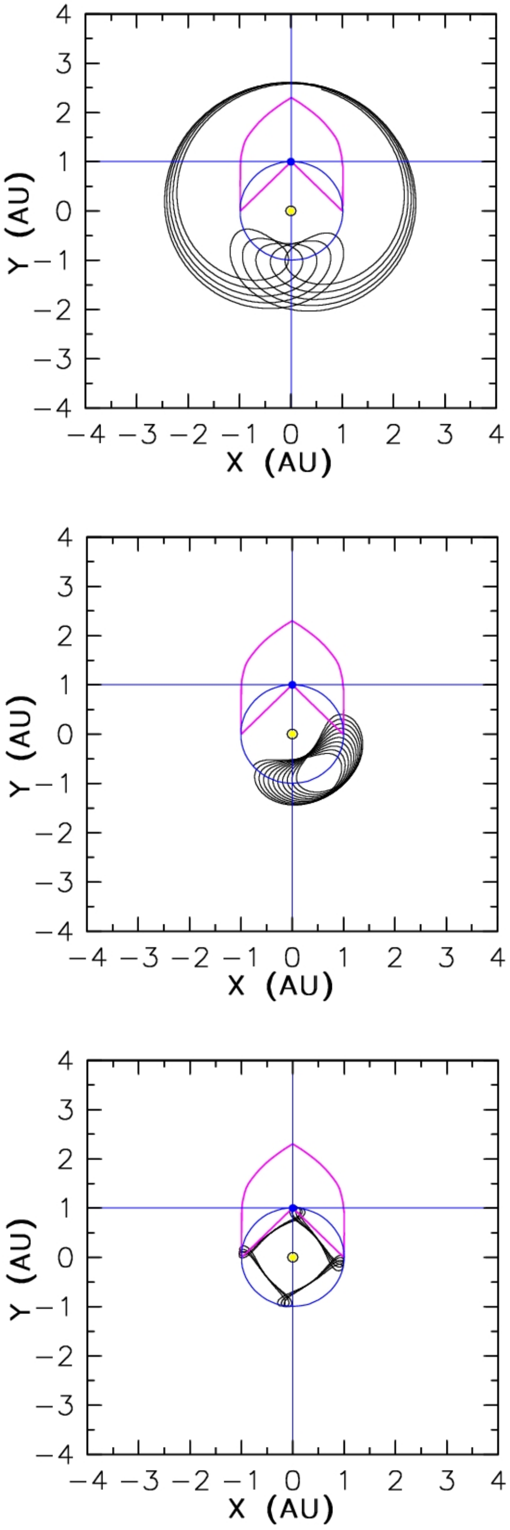
LSST PHA survey



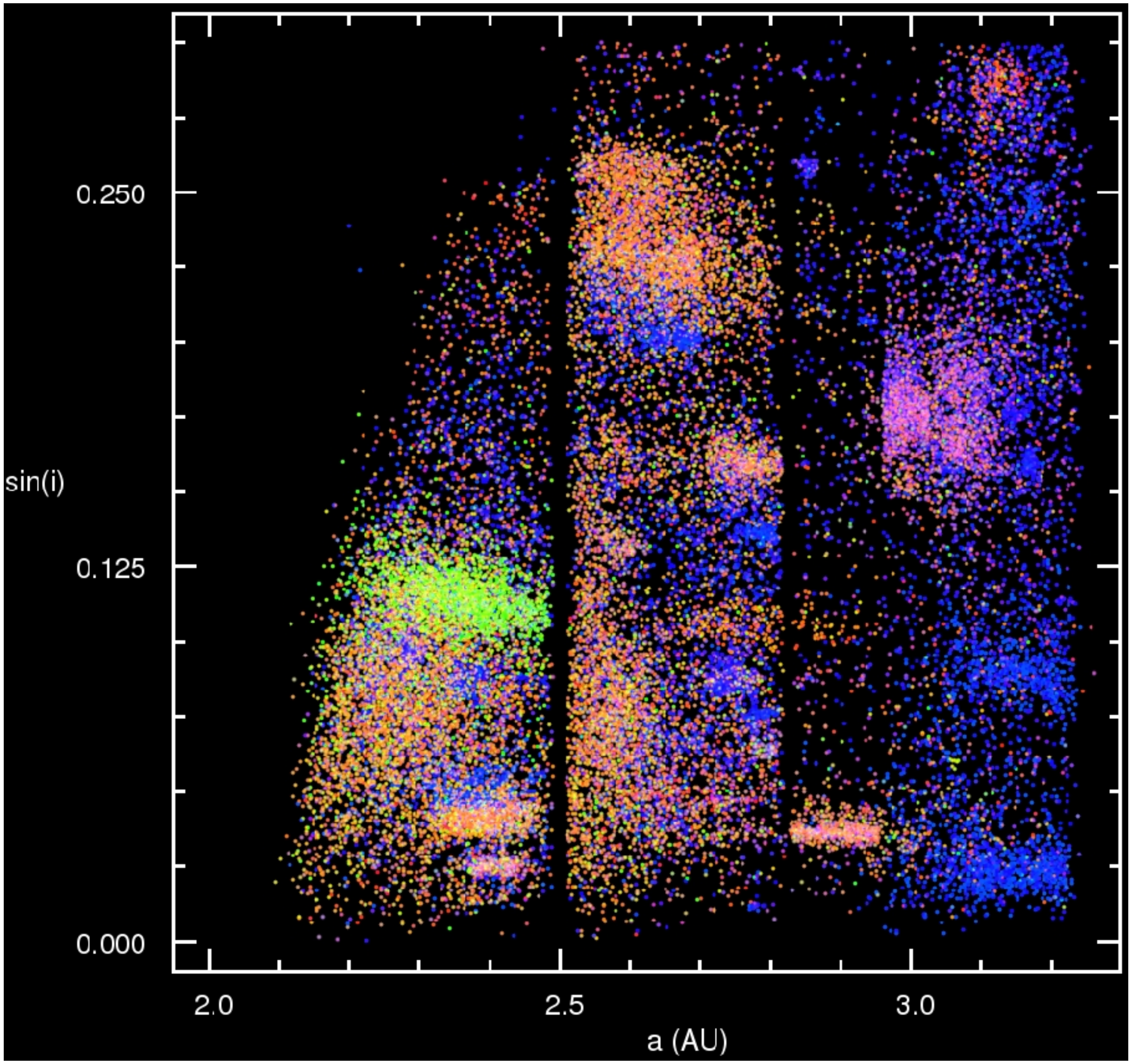


- **Baseline Cadence:** two visits closely separated in time (15-60 min), each visit reaching $V \sim 24.8$, revisiting every few days
- **Simulations:** real historical weather and seeing data, exquisite modeling of observational effects
- **Results:** The LSST baseline design cadence can achieve, over 10 years, a completeness of 90% for objects larger than $\sim$250 m diameter, and 80% completeness for $>$140 m.
- **PHA optimization:** short-dashed: baseline cadence (10 yrs; 5% of time specialized for NEOs); solid: 15%; long-dashed: 15% of time specialized for PHAs: reaches 90% completeness ($>$140m) in 12 yrs.

Survey Optimization



- A large number of simulations confirms expectations: to achieve a high completeness must have two visits per night, need to revisit large area fairly often (a few days), and need to go deep ($V \sim 24.5$)
- **Left: examples of undiscovered objects** in a rotating heliocentric coordinate system (blue dot: Earth; yellow dot: Sun); the cross section of the ecliptic plane and the LSST NEO detectability volume for a 140m object is shown by the magenta line.
- Analysis of Undiscovered Objects: need to have a long survey, and need to, at least sometimes, observe at small solar elongation angles (i.e. large airmass).
- **LSST NEO survey optimization is a work in progress, but existing simulations already represent a robust proof of concept, and a detailed demonstration of its capability.**



The correlation between color and albedo can be used to estimate object size to within 30%, and with gaussian error distribution.

PHA characterization

- **LSST will not only obtain orbits for PHAs, but will also provide valuable data on their physical and chemical characteristics** (e.g. colors and variability), constraining the PHA properties relevant for risk mitigation strategies.
- **Left:** a recent example obtained by a modern large-area multi-color survey: a correlation between orbital elements and optical colors for ∼30,000 main-belt asteroids measured by the Sloan Digital Sky Survey

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Yes, we can!

LSST system can reach the 90% completeness level for 140m and larger objects in about 12 years, with about 15% of the observing time optimized for NEO survey.

1. The time of first light will be driven by funding. The earliest plausible date, 2015, implies that the 90% completeness level for PHAs could be reached around 2027.

2. The LSST NEO Survey will provide accurate orbits and exquisite taxonomic and physical characterization

3. **The "effective" cost of an optimized NEO survey would be about $120M.** This funding would be most useful during operations, with a small fraction spent during construction phase.

Summary and Conclusions

- The Congressional mandate to discover 140m objects directly and unavoidably leads to a requirement for a 10m-class telescope with a large field of view, gigapixel-class camera and a sophisticated and robust data management system.

- The LSST system satisfies these requirements, and can reach 90% completeness for $>$140m PHAs in 12 years.

- LSST is already well underway and is nearing construction readiness.

- The same hardware, software and cadence requirements are driven by science unrelated to NEOs: LSST reaches the threshold where different science drivers and different agencies (NSF, DOE and NASA) can work together to efficiently achieve seemingly disjoint, but deeply connected, goals.