VERA C. RUBIN OBSERVATORY

Rubin Observatory and the Legacy Survey of Space and Time

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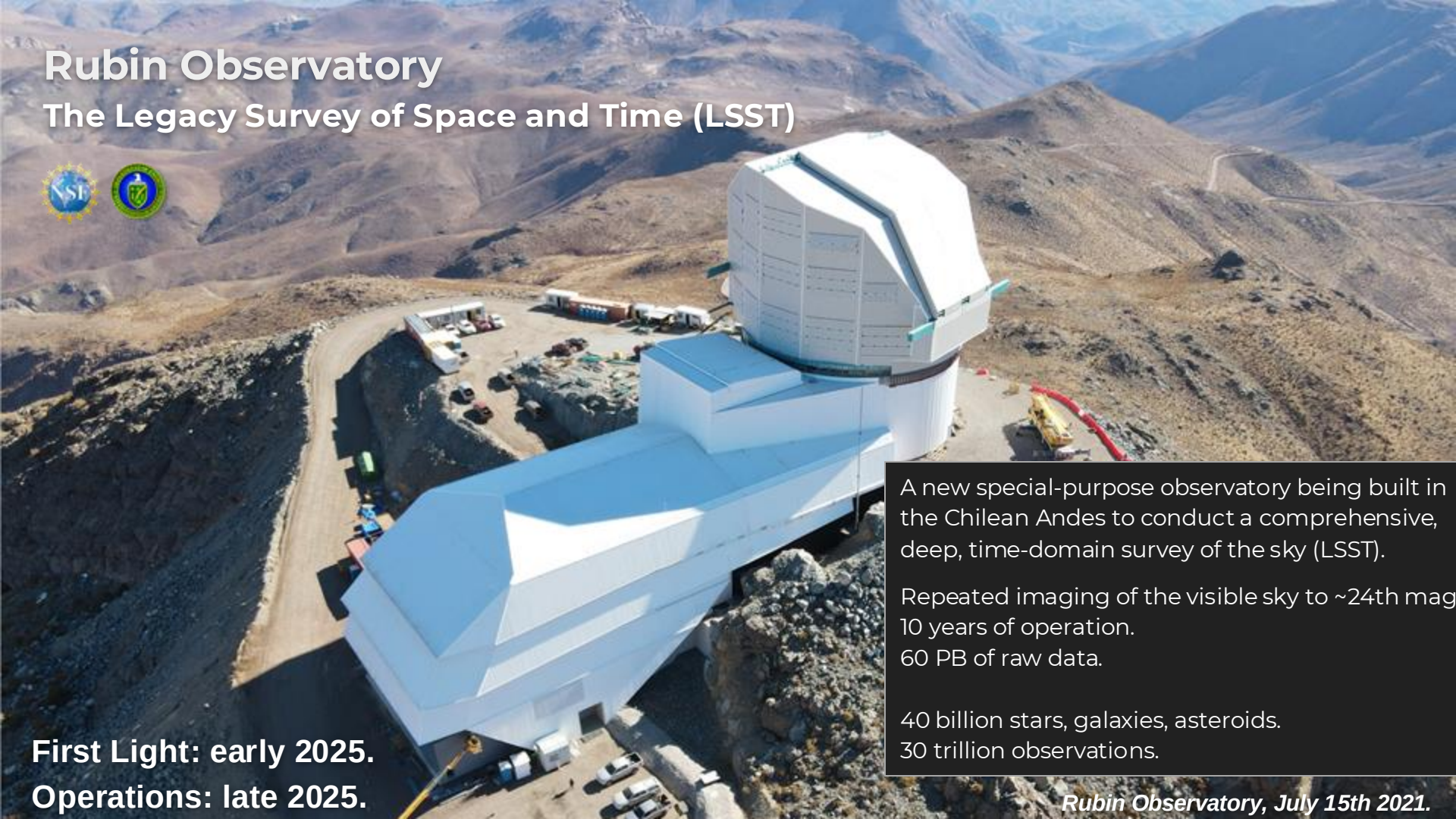
NSF AURA U.S. DEPARTMENT OF ENERGY Office of Science NOIR Lab SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST Discovery Alliance

Rubin Observatory

The Legacy Survey of Space and Time (LSST)



A new special-purpose observatory being built in the Chilean Andes to conduct a comprehensive, deep, time-domain survey of the sky (LSST).

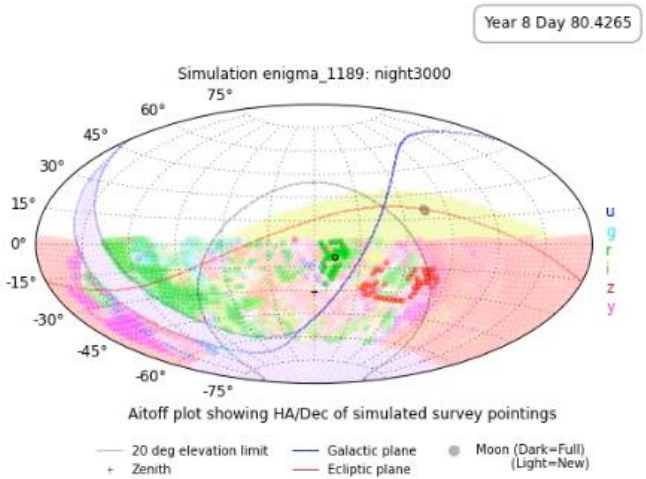
Repeated imaging of the visible sky to ~24th mag
10 years of operation.
60 PB of raw data.

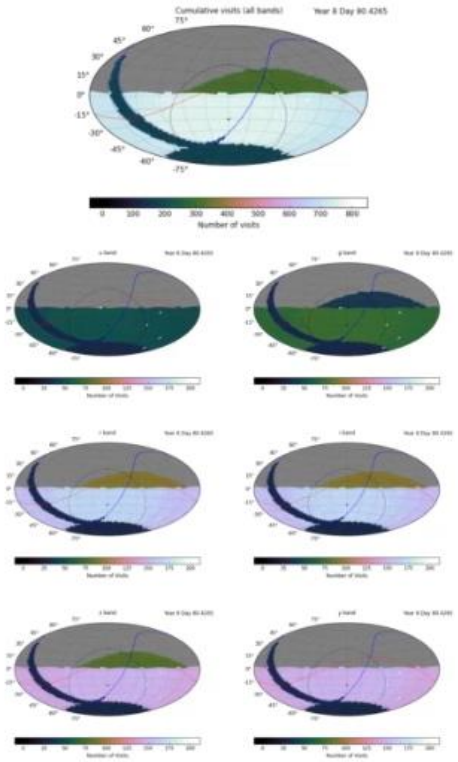
40 billion stars, galaxies, asteroids.
30 trillion observations.

First Light: early 2025.
Operations: late 2025.

Rubin Observatory, July 15th 2021.

The Legacy Survey of Space and Time (LSST)





Rubin will execute a single* survey designed to meet the basic requirements to achieve the four core science goals.

How to think about LSST:

- 500 pointings per night
- 2 visits to each pointing
- 10 deg^2 per visit, to r~24th mag

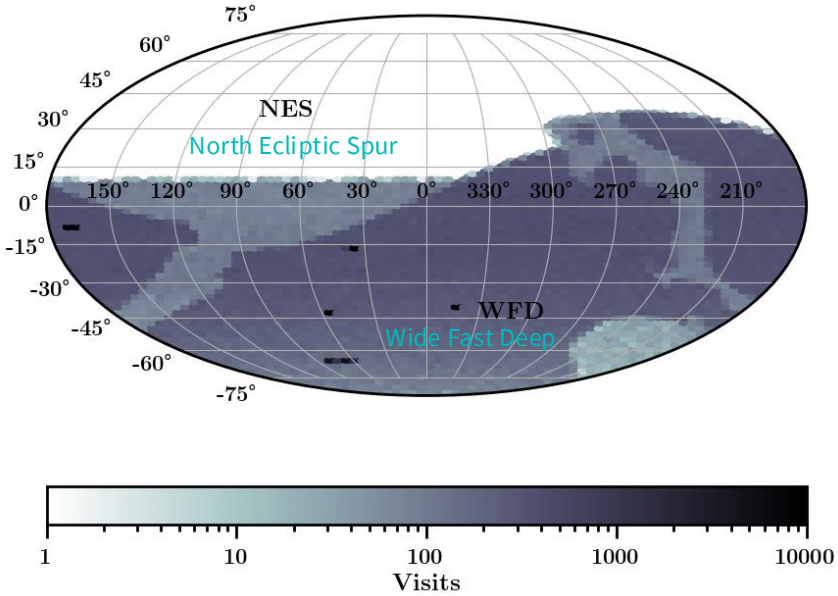
- ~4000 unique deg^2 surveyed per night
- Repeat for ~3300 nights

*There's also a smaller (<10% of time) set of "special survey programs" designed to explore extreme corners of discovery space.

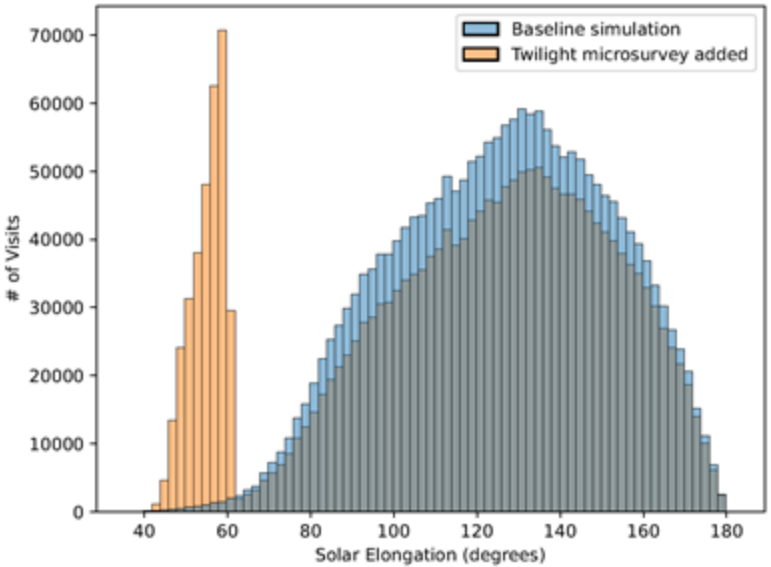
Slide credit: Mario Jurić

The LSST Surveys

Baseline survey v4.0



Near-Sun Twilight NEO Microsurvey



Will use <3% of time to enable discovery of small bodies at low solar-elongations time during twilight, and another 3% for target of opportunity observations (eg d~10-150 m impactors)

Survey Cadence Optimization Report: https://pstn-055.lsst.io/

Slide credit: Sarah Greenstreet

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Construction updates

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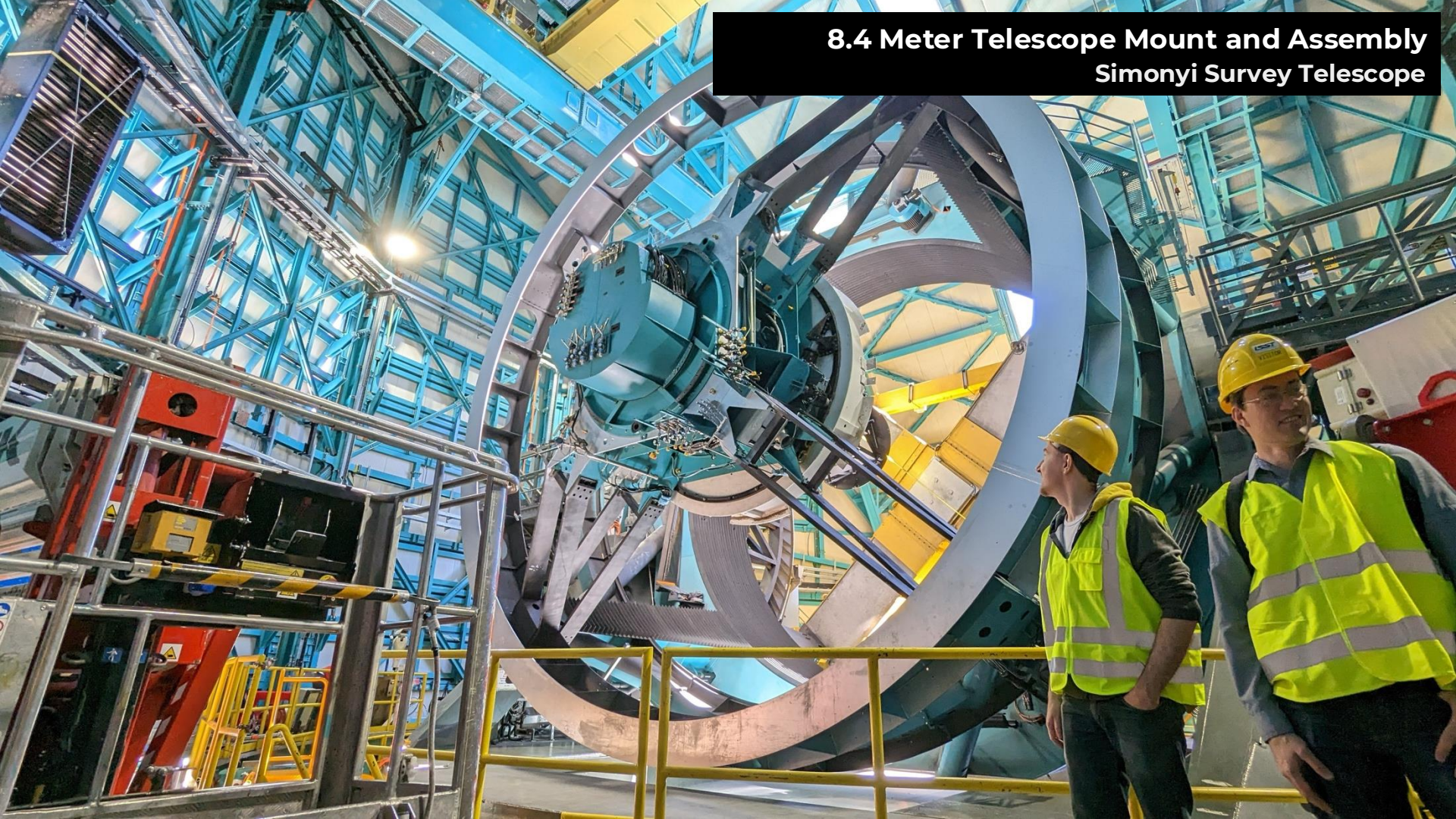
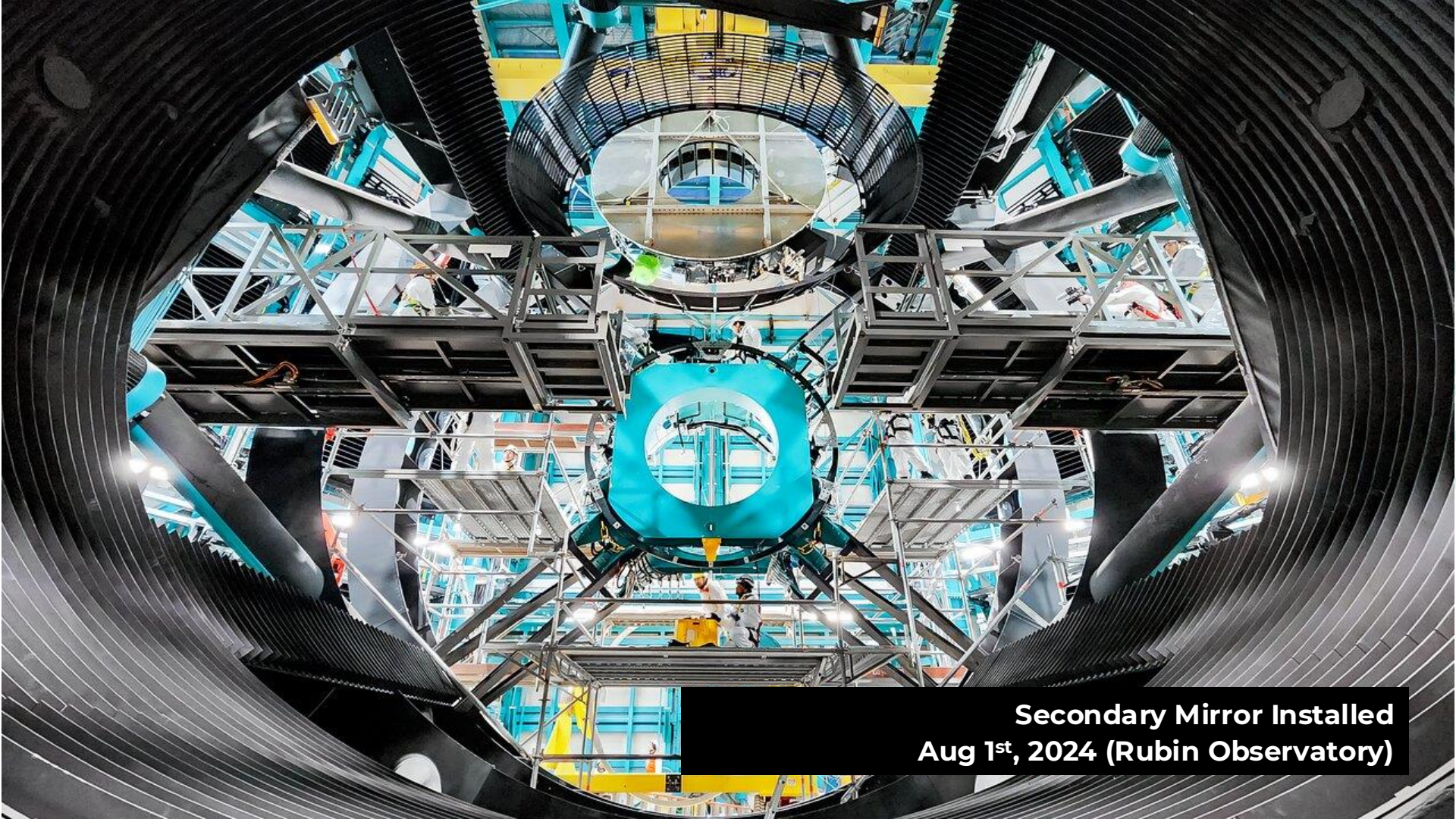


8.4 Meter Telescope Mount and Assembly

Simonyi Survey Telescope



Secondary Mirror Installed
Aug 1st, 2024 (Rubin Observatory)

Arrival to Chile
May 15th, 2024 (Rubin Observatory)

ComCam on-sky testing

A single “raft” of CCDs, with three filters available in the filter exchanger.

Used to kickstart commissioning before LSSTCam is ready, and burn down some integration risk early

October 24, 2024: first end-to-end test of the telescope system

Photo on the left taken with ComCam with the dome closed through a pinhole

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Science expectations

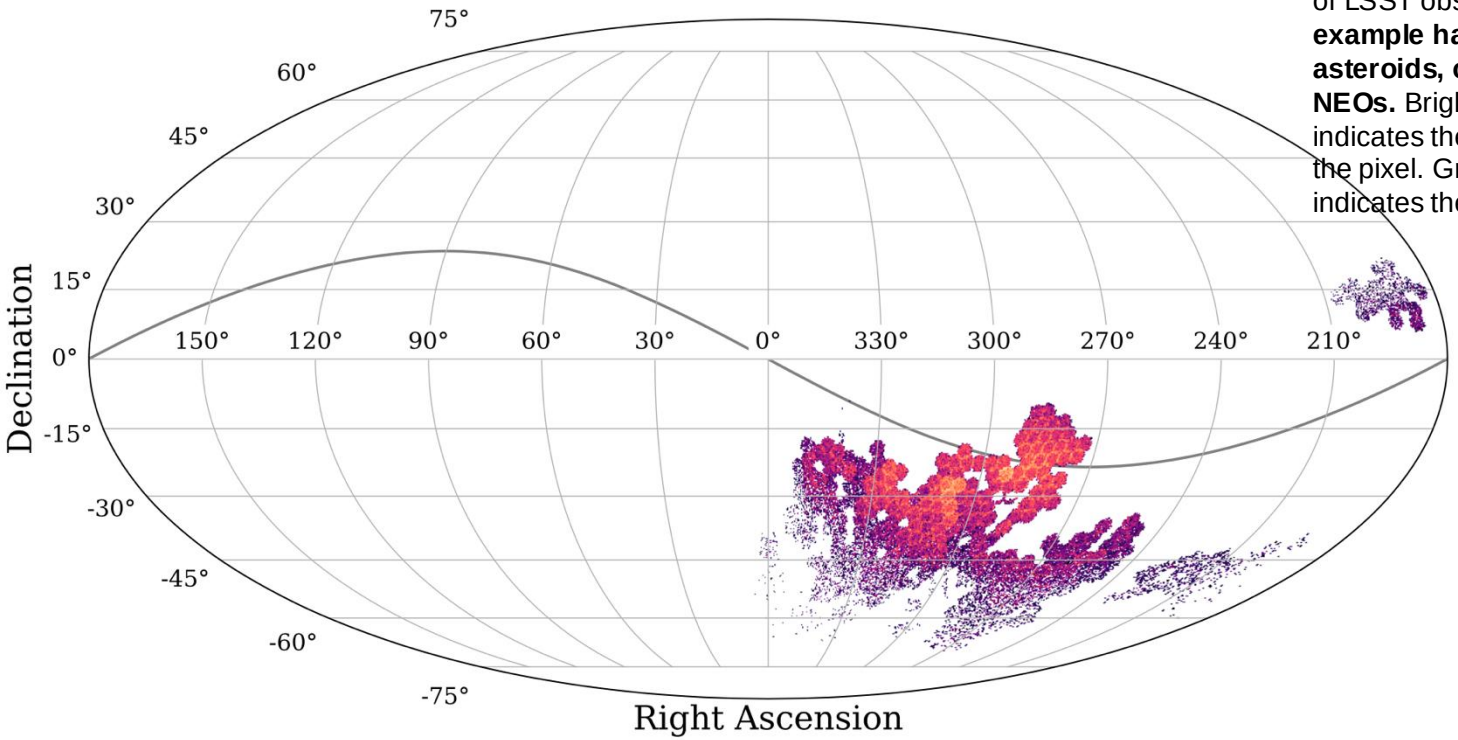
Expected Solar System Discoveries

New state-of-the-art simulations given current status of the LSST system and populations

	Currently Known	LSST Discoveries (Kurlander, PB+25, Murtagh+25)	Median # Observations	Median Orbital arc
Near-Earth Objects	~35,000	126,000	25	3 months
Main-Belt Asteroids	~1,300,000	5,100,000	160	9 years
Jupiter Trojans	~13,000	104,000	274	9 years
Trans-Neptunian Objects	~5,000	37,000	234	9.4 years
Centaurs	~200	~1000	200	9.0 years

Hundreds of visits per object will enable high quality orbits and photometric measurements
~Half of the discoveries (except for NEOs) within 1 year of operations

A typical LSST night



Asteroids detected in a single night of LSST observations. **This example has ~420,000 observed asteroids, of which a ~1000 are NEOs.** Brightness of points indicates the number of asteroids in the pixel. Grey curve indicates the ecliptic plane.

Wagg et al., 2408.12517

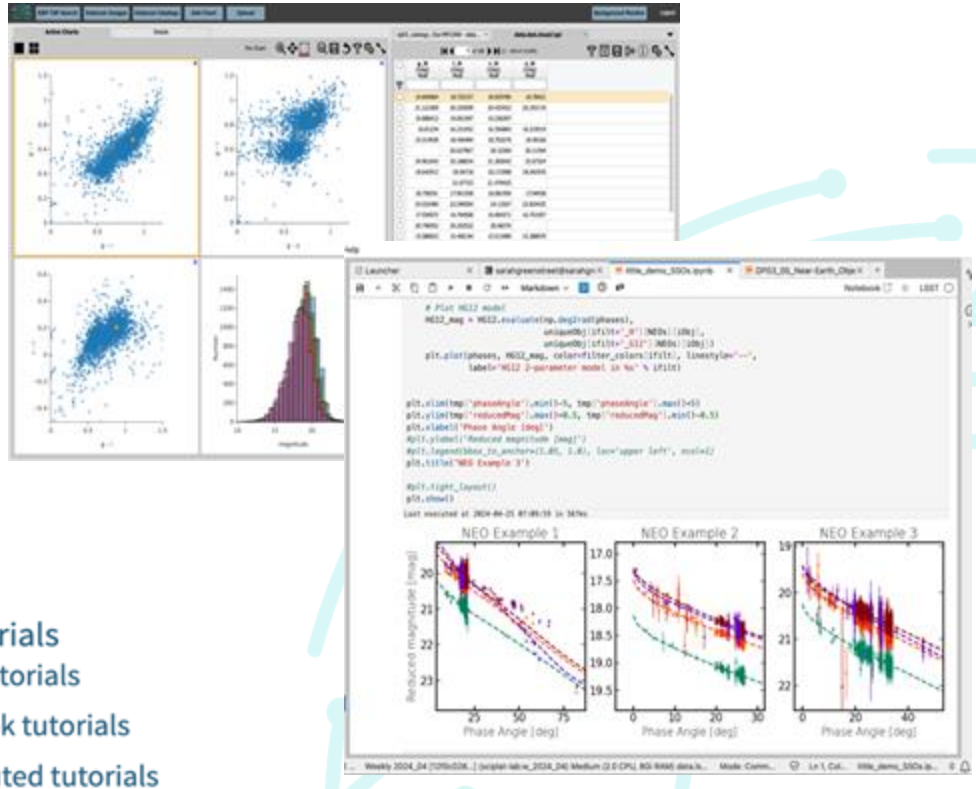
Data Preview 0.3 and the Rubin Science Platform

The Rubin Science Platform (RSP) is a set of integrated web-based applications and services running at the Rubin Observatory Data Access Centers (DACs).

DP0.3 contains simulated catalogs of Solar System objects:

- Astrometric measurements
- Photometric measurements
- Orbits

DP0.3 is the first opportunity to learn how the RSP works: https://dp0-3.lsst.io/



DP0.3 Data Products

- The Simulated Data Set
- DP0.3 Data Products Definition Document (DPDD)

DP0.3 Tutorials

- Portal tutorials
- Notebook tutorials
- Contributed tutorials

Slide credit: Sarah Greenstreet

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Commissioning

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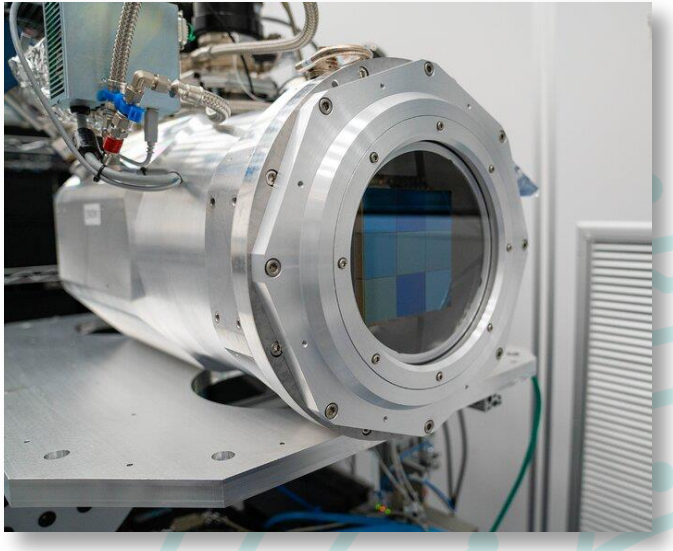
Limitations on disclosing of commissioning progress

- **I am not allowed to disclose any Rubin commissioning data, metadata, performance or plans unless they have been previously made public by the Project.** Public updates are posted at https://community.lsst.org/tag/commissioning-update.

- **Pixel data are especially sensitive.** Per current plans, no pixel data are expected to be made public until the first light event around ~June 2025.
- **No ComCam images will be shown**

ComCam commissioning: done!



16k ComCam exposures taken

- 10k for AOS commissioning
- 2k dark/bias
- 2k for science pipelines testing

Key tests

- AOS (closed loop)
- Telescope control software and survey scheduler
- TMA motion up to 20% nominal speed
- Stray/scattered light tests and debugging
- Science pipelines through asteroid discovery

Achieved better than .7” FWHM, and typical <1” (note: environmental controls are not fully in place, this is an upper limit).

Demonstrated 90% duty cycles (3 seconds between 30 sec exposures), 75% with tran+rot dithers and filter changes (90 30sec exposures/hr). Ran the image differencing/alert processing pipeline.

Slide credit: Mario Jurić

ComCam highlights

Science pipelines commissioning observations highlights

Extended Chandra Deep Field South (ECDFS) LSST Deep Drilling Field:

- Collected about 800 exposures total, with integrated exposure time comparable to 10yr depth in griz bands.

Euclid Deep Field South (EDFS), Low Galactic latitude field (Rubin SV 95 -25):

- Collected 1-2 year equivalent depth in ugrizy.

Low Ecliptic Latitude Field (λ = 37.77°, β = -7.52°)

- Four nights (three consecutive), to enable asteroid linking tests

ICRS coordinates are shared in units of decimal degrees below.

Extended Chandra Deep Field South (ECDFS)
(ra, dec) = (53.13, -28.10)

Euclid Deep Field South (EDFS)
(ra, dec) = (59.10, -48.73)

Low Ecliptic Latitude Field (Rubin SV 38 7)
(ra, dec) = (37.86, 6.98)

Low Galactic Latitude Field (Rubin SV 95 -25)
(ra, dec) = (95.00, -25.00)

47 Tuc Globular Cluster (47 Tuc)
(ra, dec) = (6.02, -72.08)

Fornax Dwarf Spheroidal Galaxy (Fornax dSph)
(ra, dec) = (40.00, -34.45)

https://community.lsst.org/t/locations-of-target-fields-observed-during-on-sky-commissioning-campaign-with-comcam/9609

Slide credit: Mario Jurić

ComCam and small bodies

- **Photometric and astrometric accuracy and repeatability**
  Photometric repeatability better than 1% (0.5% for griz)
  Systematic astrometric accuracy <50mas

- **Association Pipeline (positional association of known objects; Jake Kurlander)**
  Positional association (2”), no error-ellipses taken into account. Works.

- **Linking Pipeline (tracklet construction and linking, heliolinc-based; Ari Heinze)**
  Demonstrated tracklet building, tracklet linking. Works.

- **MPC Submission Pipeline (MPC submission and bookkeeping; Joachim Moeyens)**
  Manually submitted to UW-based MPC database clone

- **Timing and telescope location (via asteroids and satellites)**
  Know our timekeeping is good to ~1/4 second, location accurate to ~1km.

Slide credit: Mario Jurić

ComCam takeaways

- No major design or implementation issues encountered. A non-trivial finding as this was the first time we ran the fully integrated system.

- Image differencing pipeline and asteroid pipeline perform as expected at this stage. We can build and link tracklets. Work remains to finish the integration and automation, but no critical issues discovered at the algorithmic level.

- Submitted O(100s) of observations and new detections to the MPC sandbox queue. Testing that the communication infrastructure works.

- The major (scaling) test will come around ~May/June, when LSSTCam observations ramp up.

Slide credit: Mario Jurić

Looking ahead

- The real MPC-Rubin operations test will come with LSSTCam, likely around ~May 2025. Expect thousands discoveries, tens of thousands of observations/night (May), ramping up to O(10k) discoveries+O(100k) observations per night (August). All dates are uncertain to +/- month.
- Other works in progress
  - **Early release of tracklets with high digest2 scores:** we've started an internal process to request permission for same-night publication (MPC submission) of possible NEOs
  - **Handling of very fast-moving objects:** we're required to delay reporting of objects moving faster than 10 deg/day *unless* we can show such tracklets are highly unlikely to be due to Earth-orbiting satellites. We're looking into how to provide such assurances.
  - **Incremental templates:** looking how to incrementally build templates to enable discovery in Year 1.

- **Bottom line: things are looking good so far. Expect LSST to start near the end of the year.**

Slide credit: Mario Jurić

Supporting Solar System Science with Rubin/LSST

- Rubin is a facility. The science is funded through usual funding calls (e.g., NASA/SSO or NSF/AAG). **First science-grade data is coming in a few months**. The programs and review panels should watch for good Rubin early science proposals – it's not in the (far) future anymore!

- Follow-up: While Rubin will effectively do much of its own astrometric "self-follow-up", significant additional characterization resources may be needed (high cadence photometry, spectroscopy). Are we ready and do we know how to coordinate?

- Preparedness: The U.S. community is working to get prepared (e.g., through the LSST Solar System Science Collaboration), and needs continuous support. Otherwise, we may miss out on rare discoveries (ISOs, NEOs, etc.) or relinquish them to international teams (Solar System data are immediately public).

Slide credit: Sarah Greenstreet

Summary

- We are a few months away from first light with LSST
- Once operational, the LSST survey will become a prime source of discoveries and data for small bodies in the Solar System, discovering millions of new objects each with hundreds of observations
- Half of LSST discoveries will happen within the first year of observations
- Reaching critical point for getting the community funded, coordinated, and ready for science with LSST