VERA C. RUBIN
OBSERVATORY

Rubin Observatory: Construction Status and Opportunities for Imminent Impactor Detection

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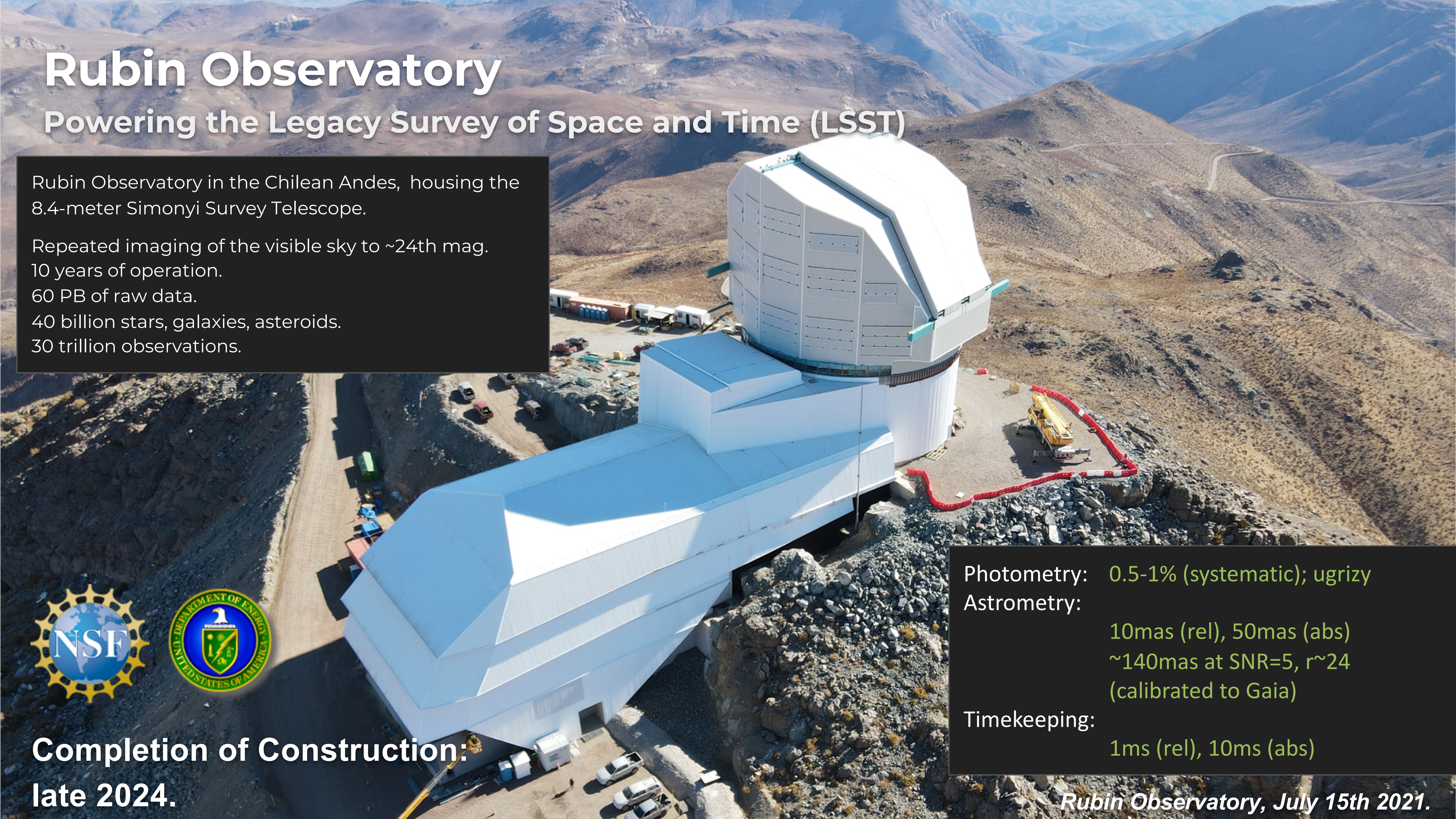
Rubin Observatory

Powering the Legacy Survey of Space and Time (LSST)

Rubin Observatory in the Chilean Andes, housing the 8.4-meter Simonyi Survey Telescope.

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.

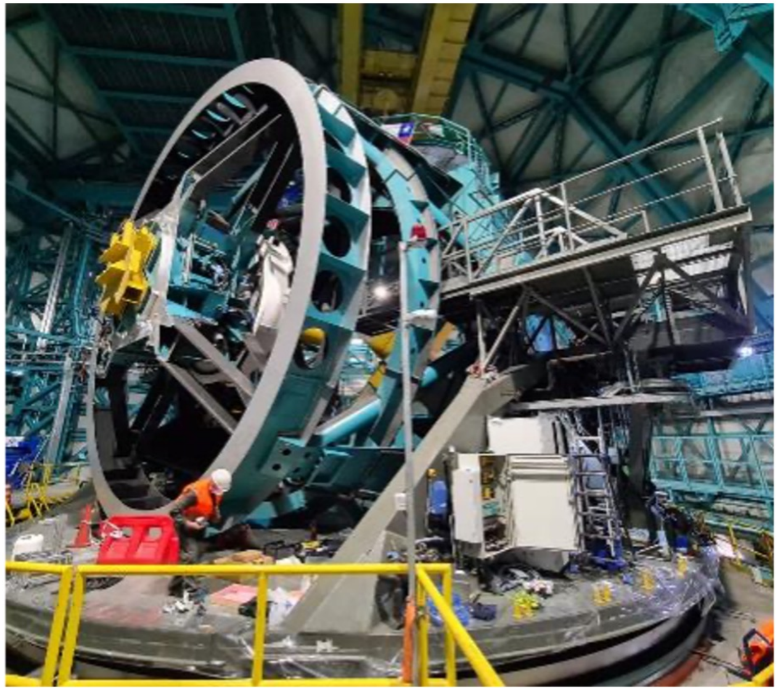


Photometry: 0.5-1% (systematic); ugrizy
Astrometry:
10mas (rel), 50mas (abs)
~140mas at SNR=5, r~24
(calibrated to Gaia)
Timekeeping:
1ms (rel), 10ms (abs)

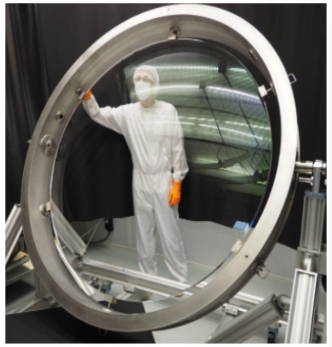
Completion of Construction: late 2024.

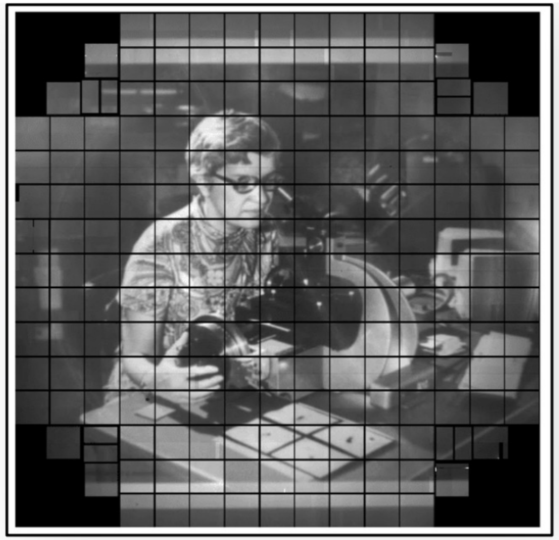
Rubin Observatory, July 15th 2021.

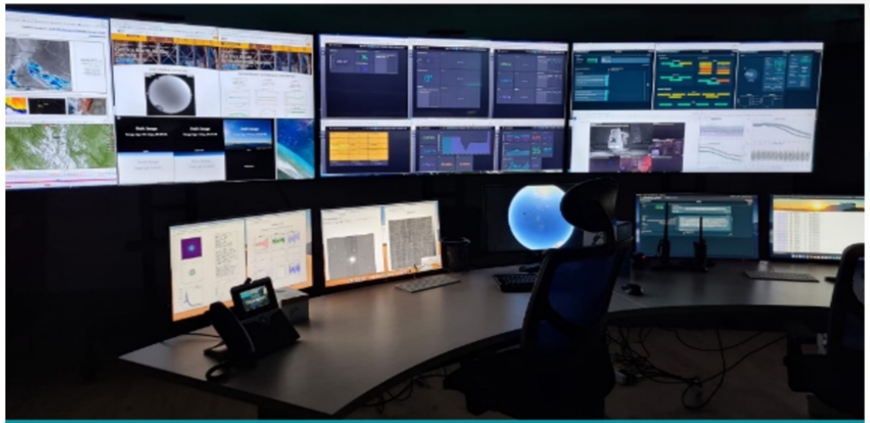
Two years away from completion of construction and commissioning



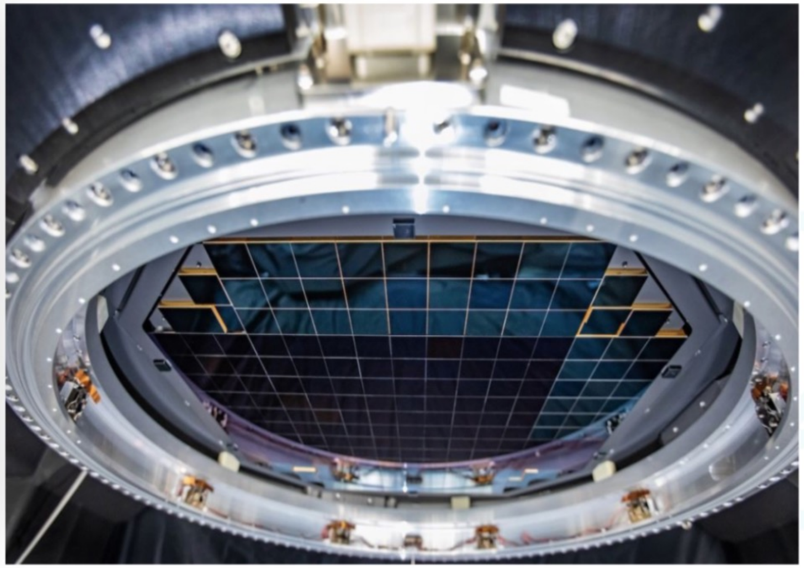
Telescope Mount Assembly





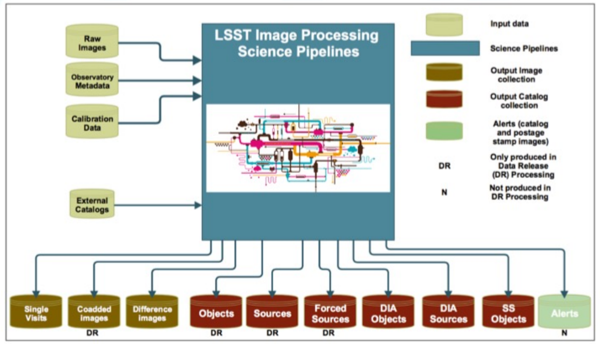


Summit Control Room with



The complete focal plane of the future LSST Camera is more than 2 feet wide and contains 189 individual sensors that will produce 3,200-megapixel images.

LSST camera focal plane (3.2 Gpix)



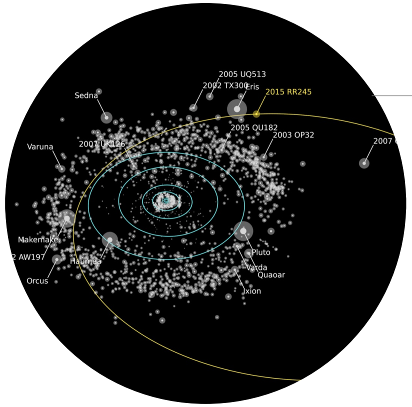
LSST Science Themes

VERA C. RUBIN OBSERVATORY

Probing Dark Matter & Dark Energy

- Strong & Weak Lensing
- Large Scale Structure
- Galaxy Clusters, Supernovae

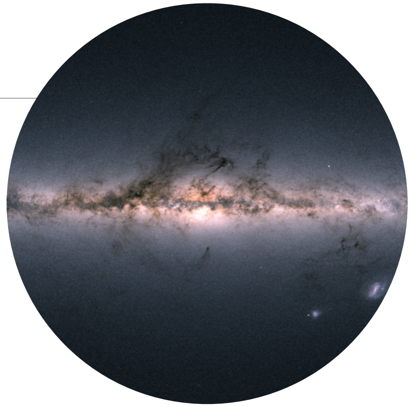
Inventory of the Solar System

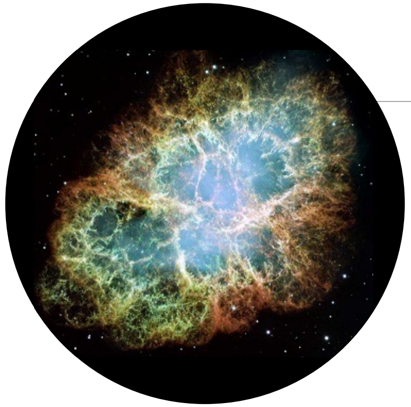


- Comprehensive small body census
- Comets and ISOs
- Planetary defence

Mapping the Milky Way

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

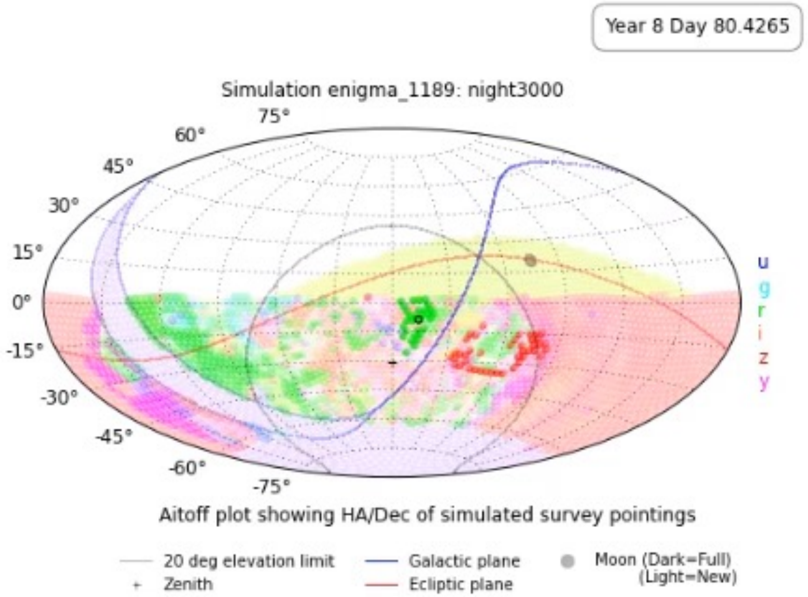


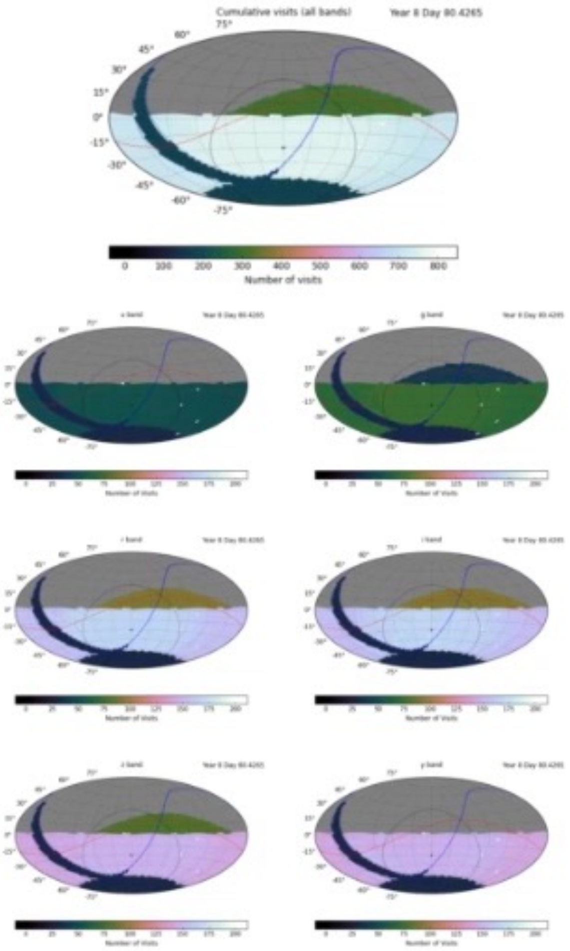


Exploring the Transient Optical Sky

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

A single uniform survey of the visible sky





LSST will execute a single* survey designed to support all four science themes.

How to think about LSST:

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

- ~5000 unique deg^2 surveyed per night
- Repeat for ~3300 nights.

- No targeted follow-up.

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

A comprehensive census of the Solar System

Animation: SDSS Asteroids (Alex Parker, SwRI)

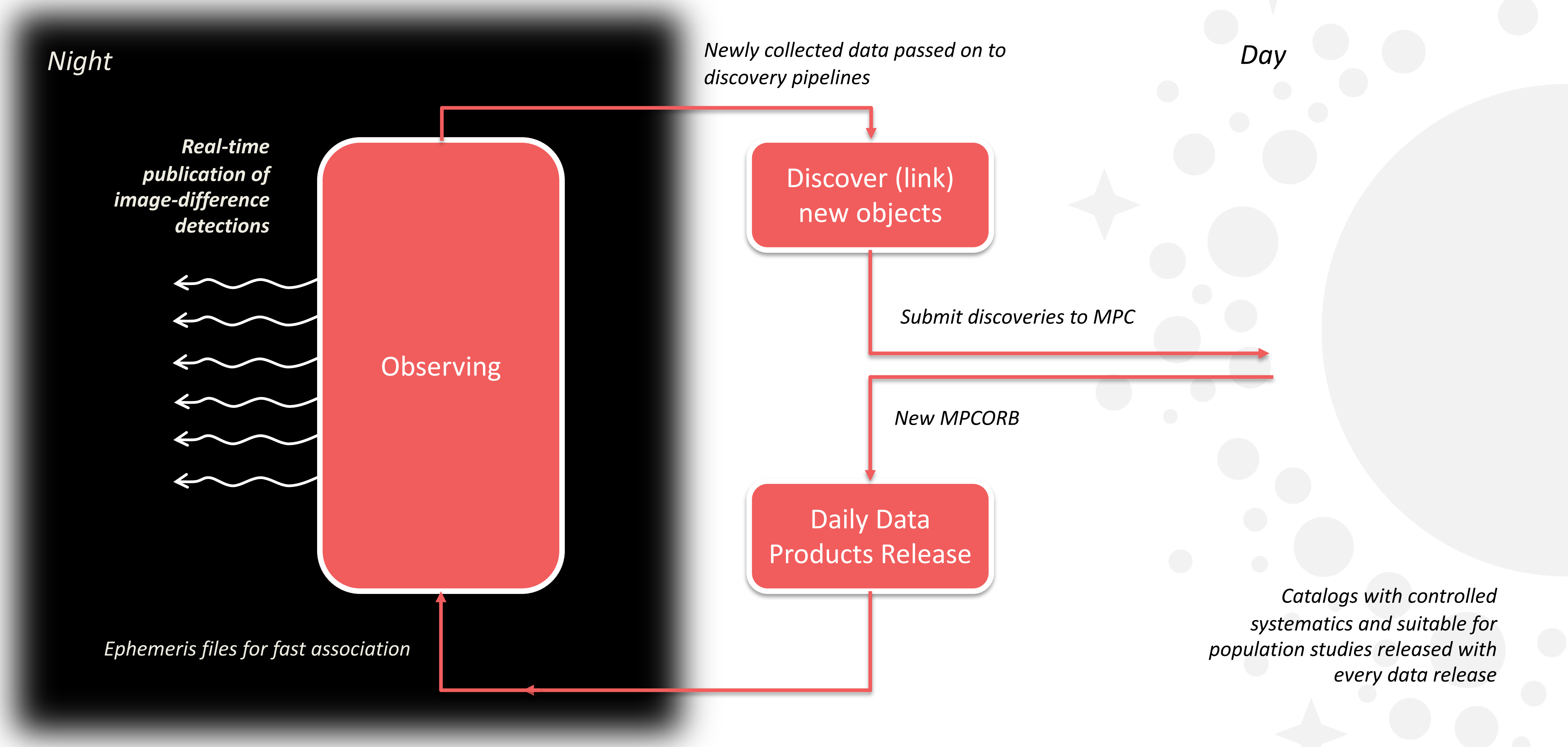
Estimates: Lynne Jones et al.

The LSST data can increase the number of known objects between 5x-30x, depending on the population.

	Currently Known*	LSST Discoveries**	Typical number of observations+
Near Earth Objects (NEOs)	~25,500	100,000	(D>250m) 60
Main Belt Asteroids (MBAs)	~1,000,000	5,000,000	(D>500m) 200
Jupiter Trojans	~10,000	280,000	(D>2km) 300
TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOs)	~4000	40,000	(D>200km) 450
Comets	~4000	10,000	?
Interstellar Objects (ISOs)	2	>10	?

These objects will be well-characterized (orbits, light curves, absmag estimates), and discovered with an exceptionally well understood selection function.

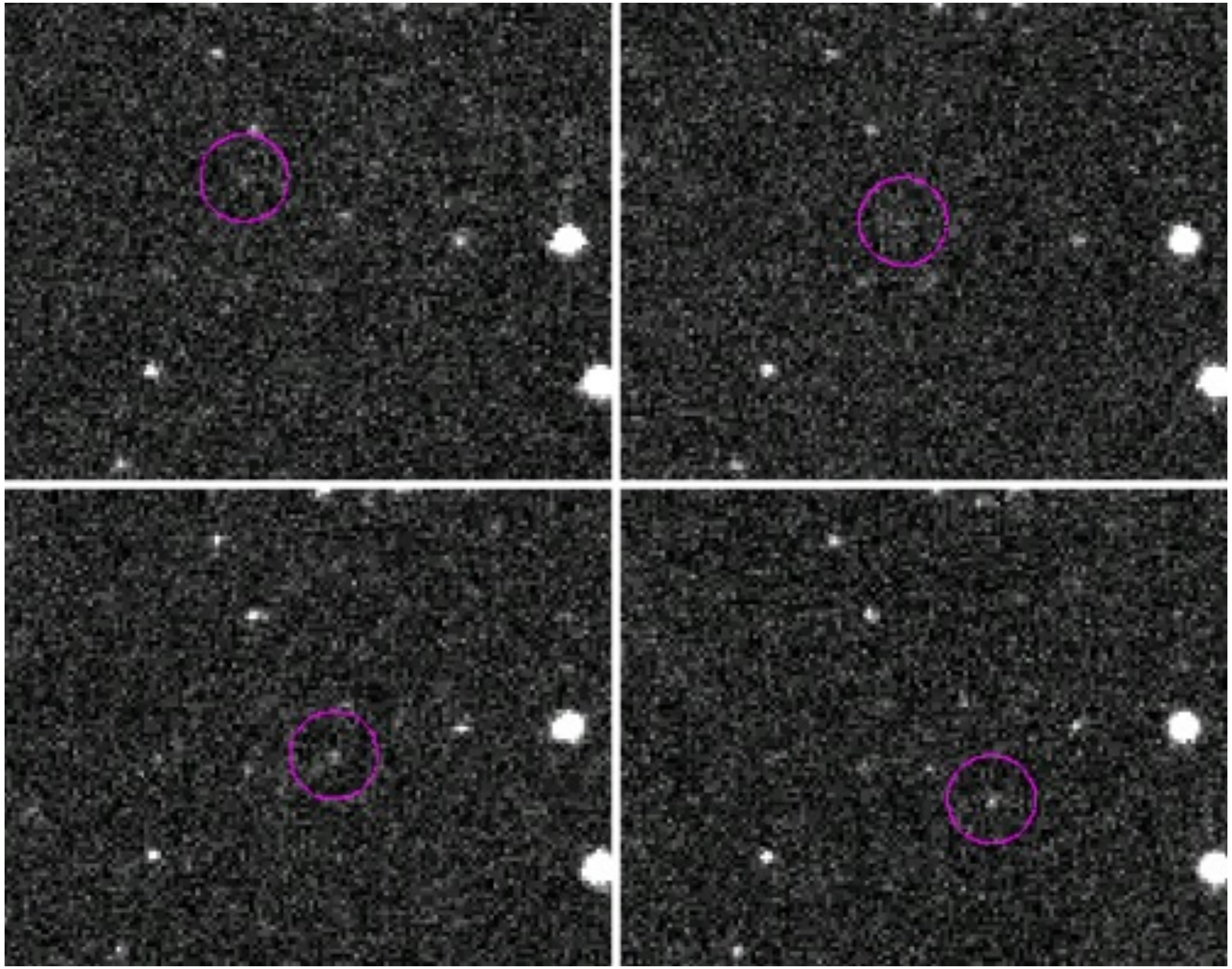
LSST Nightly/Daily Processing Loop



A one-page summary available at http://ls.st/Document-29545

Rubin will use an atypical search strategy

- Most present day surveys take 3- or 4-observation tracklets and report them in a single night.
- Rubin will take pairs of pointings each night, separated by ~20-60 minutes.
- Tracklets *can* be constructed from pairs. But the purity of such tracklets would be low: there's a high chance of misassociation, association to artefacts, etc.



2012 BX34 discovery image (Catalina Sky Survey)

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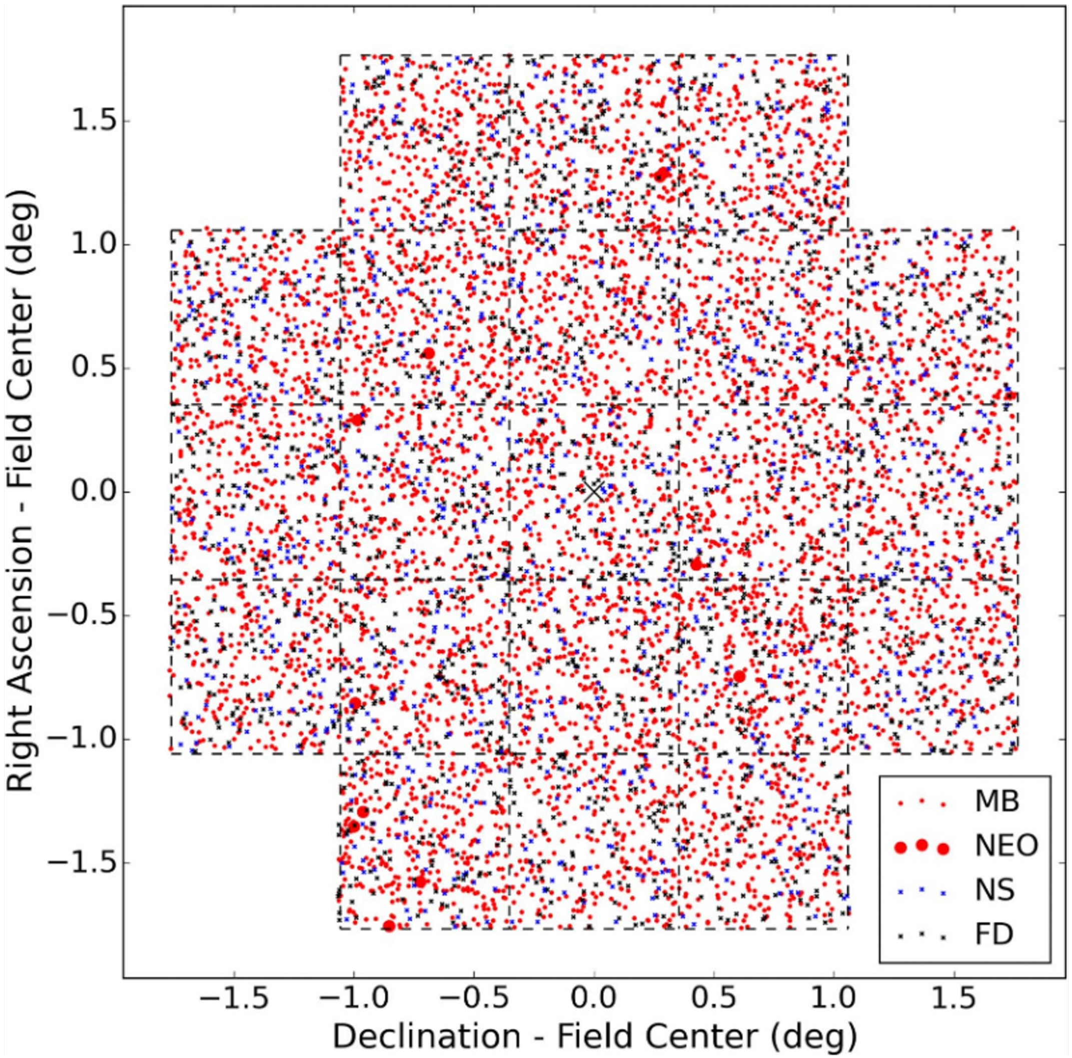
- Instead, a tracklet is only a candidate; it is confirmed by finding two more within a 15-day window. If the tree admit an orbit solution, the chance of mislinkage is negligible (~1e-5).



Above: Simulation by Veres & Chesley (2017)

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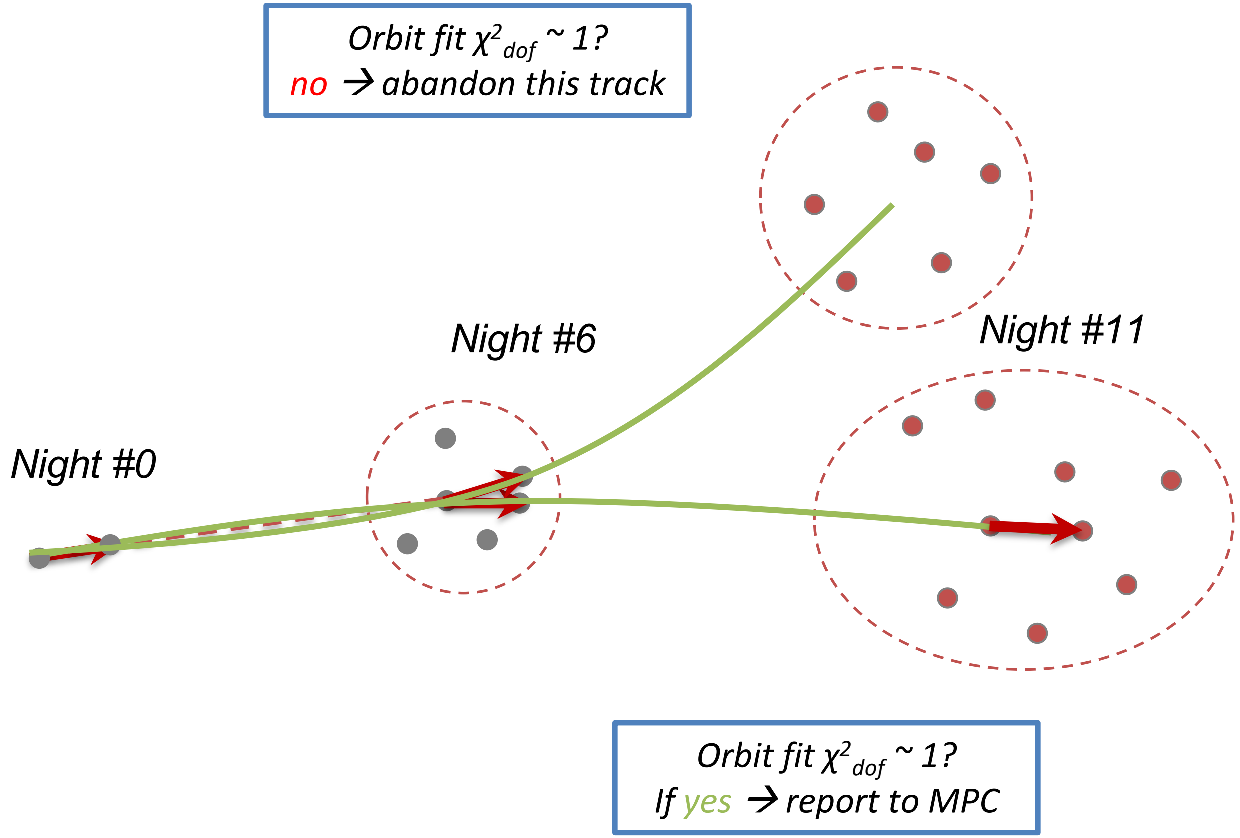


LSST SSO Detectability Criterion: **Well-fitting tracklets, with ≥2 observations, must be observed in at least three nights within a 15-day window.**

Algorithm and Implementation Details

THE ASTRONOMICAL JOURNAL

HelioLinC: A Novel Approach to the Minor Planet Linking Problem

Matthew J. Holman[1,2], Matthew J. Payne[1], Paul Blankley[2], Ryan Janssen[2], and Scott Kuindersma[2]

Published 2018 August 30 •

The Astronomical Journal, Volume 156, Number 3

+ Article information

Abstract

We present HelioLinC, a novel approach to the minor planet linking problem. Our heliocentric transformation-and-propagation algorithm clusters tracklets at common epochs, allowing for the efficient identification of tracklets that represent the same minor planet. This algorithm scales as $\mathcal{O}(N \log N)$ with the number of tracklets N, a significant advance over standard methods, which scale as $\mathcal{O}(N^3)$. This overcomes one of the primary computational bottlenecks faced by current and future asteroid surveys. We apply our algorithm to the Minor Planet Center's Isolated Tracklet File, establishing orbits for more than 200,000 new minor planets. A detailed analysis of the influence of false detections on the efficiency of our approach, along with an examination of detection biases, will be presented in future work.

(Holman et al. 2018)
(Heinze et al.; in prep)

Performance

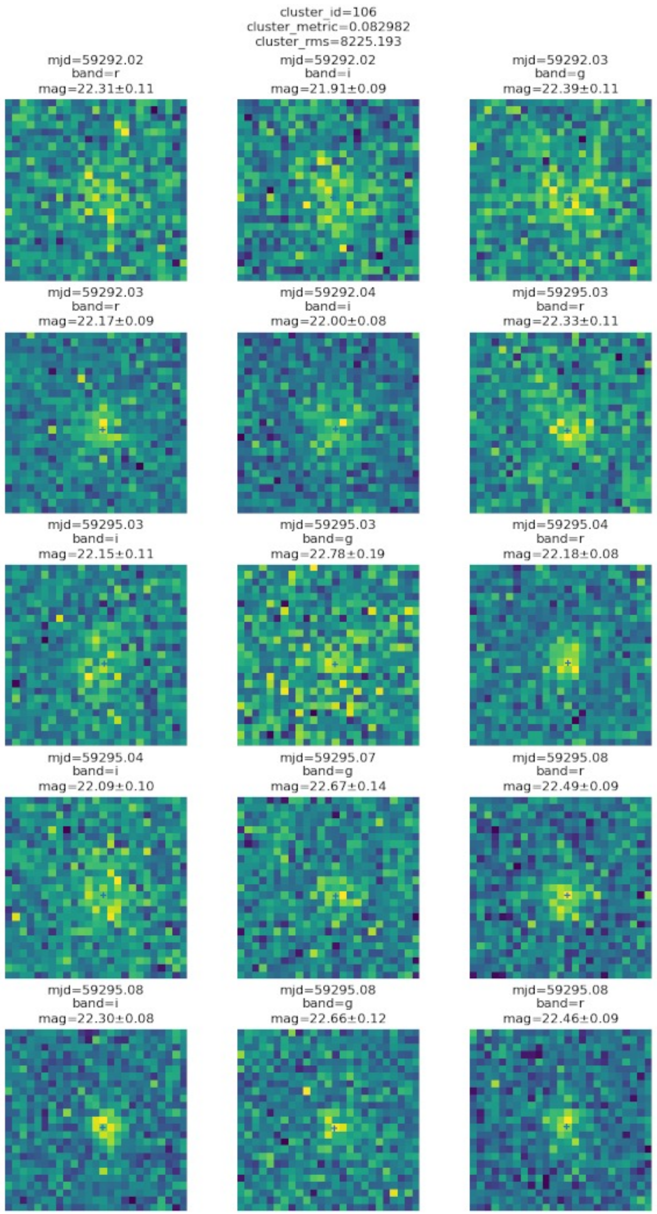
- Full-sky LSST tests : **97% completeness**.
- Full-sky LSST test for ISOs: **96% completeness**.
- NEO discovery being worked on
- In all cases, **purity >90%**, without using orbit determination chi^2 as a filter.
- **Scales as O(N *log* N)** with the number of tracklets

Code

- Completely in C++ (working on a small Python wrapper). **Fast.**
- https://github.com/lsst-dm/heliolinc2

Running on LSST-like data being acquired with DECam.
Also testing on ATLAS data.

Code: Ari Heinze;
Cutouts: Steven Stetzler; Data: DECat, Melissa Graham



Imminent Impactors

Imminent Impactor Opportunities

Back of the envelope calculation indicates LSST data could provide between 1-10 imminent impactor detections per year.

<u>All these objects will be small (not dangerous).</u>

They make excellent opportunities for a) *planetary defense coordination and reaction exercises* and b) *connecting the properties of observed bolides and meteorites to above-atmosphere characterization*.

A Challenge

LSST's baseline observing and discovery strategy results in an inherent **delay of a few days between the first recorded observation of an asteroid and the object being recognized as such.** **This will work for many objects (see Dora Fohring's talk)**

but

… faint, nearby, imminent impactors require faster reaction time.

Reducing Discovery Latency

1. Pairs of observation do not allow for *immediate* construction of reliable tracklets; multi-day observations needed for reportable discovery.

2. Tracklet construction is planned to occur in daytime.

3. While trailed sources are identified in real-time, they're not reported until the next day

4. Triggering on a single trailed source may result in many spurious reports; it's likely we'd prefer a (trailed) tracklet.

5. Precovery and data publishing timelines

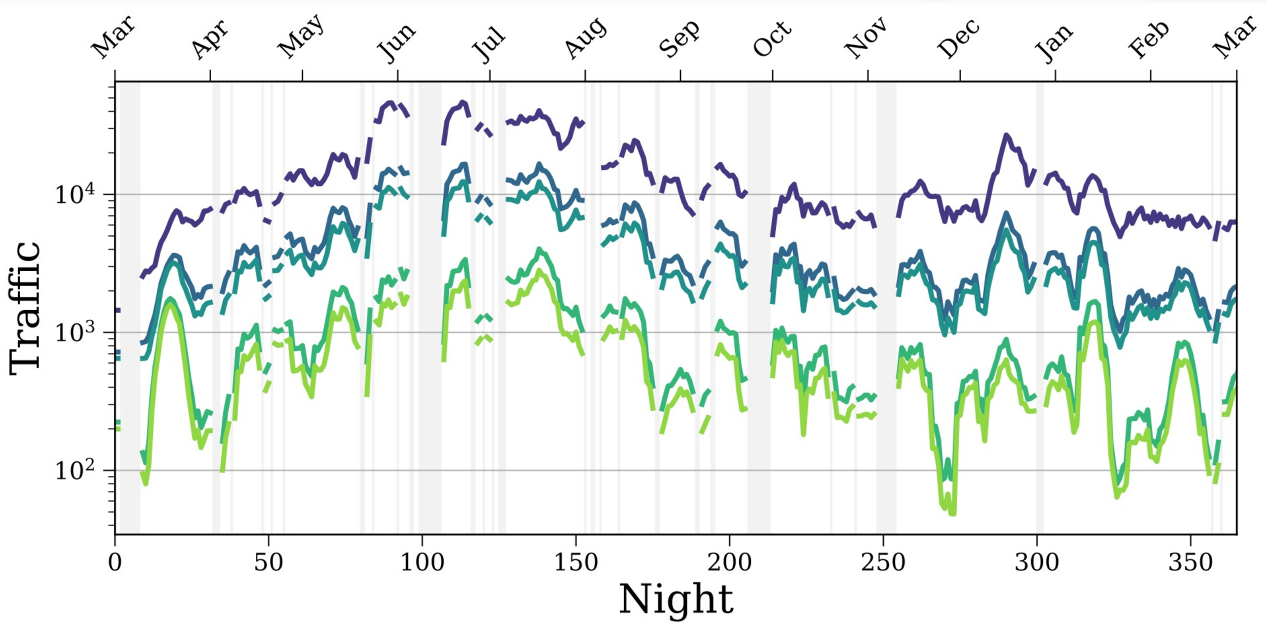
1. Report 3+ obsv. tracklets immediately

Tom Wagg @ UW

Rubin will serendipitously image tens of thousands of objects/night with 3+ observations per tracklet. These could be reported to the MPC w/o waiting for linking.

Right now this is not in Rubin's baseline operations plan, but we're studying the feasibility of adding it.

These would get picked up by JPL's Scout and any other monitoring services, and the system would function as it does today.



The number of 2, 3, 4, 5, 6-observation tracklets with digest2>65 that could be reported nightly to the MPC.

(Wagg et al., in prep)

2. Real-time tracklet construction

Sending 3+ observation tracklets to the MPC w/o waiting for linking reduces the latency from O(few days) to O(10 hours).

Better but still not ideal; recent imminent impactor discoveries+action were all on ~hour timescales.

We're looking into upgrading our system to construct and report high-confidence, 3+ observation, tracklets in real-time.

2022 WJ1 (#C8FF042) over London, ON, Canada (Photo by Rob Weryk)

The time from first detection to ~100%-impact likelihood determination was ~1hr.

3. Trailed source identification

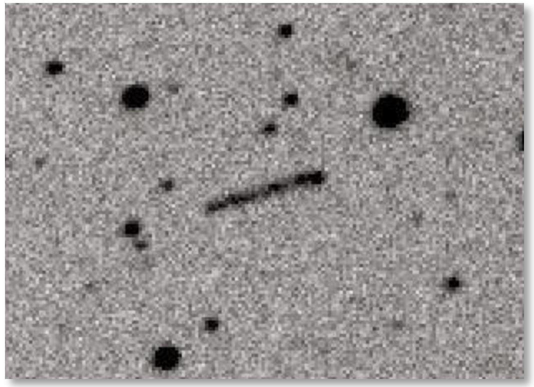
A. Real-time Alerts (>=2M SSO observations/night)	
Astrometry	±10 mas (bright; ±140 faint)
PSF flux	±10 mmag (bright end)
Aperture flux	±10 mmag (bright end)
Trailed source fit	Flux and on-sky motion for fast-moving (trailed) objects
Appearance characterization	Moments and extendedness of the object's image
Spuriousness score	Probability that the detection is an artifact
Nearby static objects	Information on adjacent objects (up to three)
MPC designation	Given for known objects
Predicted position and magnitude	Given for known objects

Details: DIASource tables in http://ls.st/oug

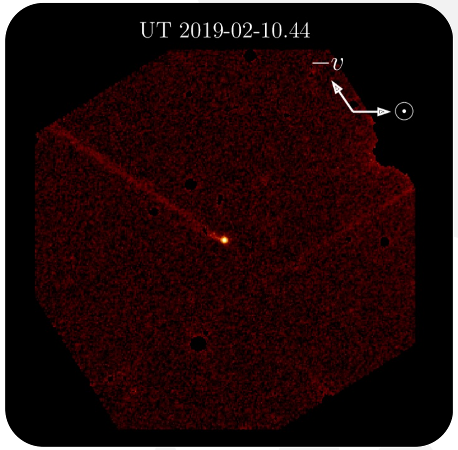
All exposures are differenced, with objects detected and measured within 60 seconds of observation. We can immediately detect trailed objects, and do (this is in the baseline plan). But they're not reported to the MPC until the morning.

Upgrade: report immediately.

(n.b. also excellent for detection of activity)



2014 MF6 (PHA), 60sec exposure, MPC Q62 (Guido, Howes & Nicolini)

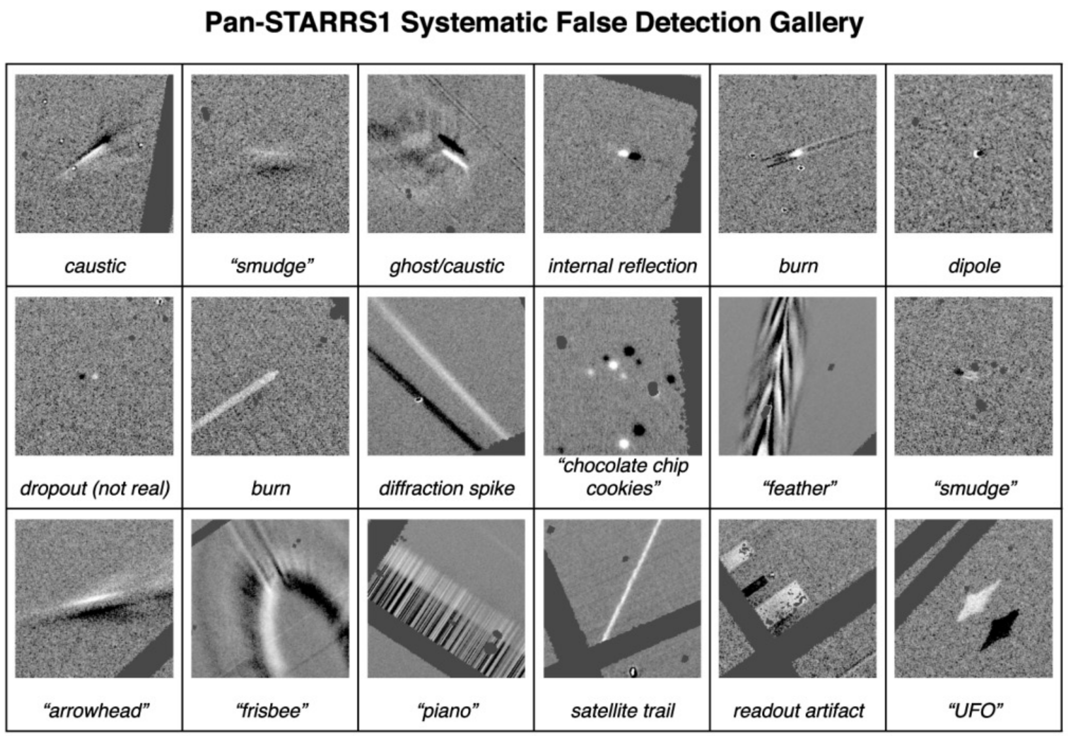


(6478) Gault outburst (Ye et al, for the ZTF Collaboration)

4. Reporting pairs of trails

Nearly every pointing will be observed twice in a ~30-min interval. If single-trail detections prove insufficiently reliable, we could link individual trails to high-confidence tracklets.

Looking into upgrading our system to construct and report pairs of trailed sources ASAP.



Samples of possible false detections (Figure 17. from Denneau et al. 2013

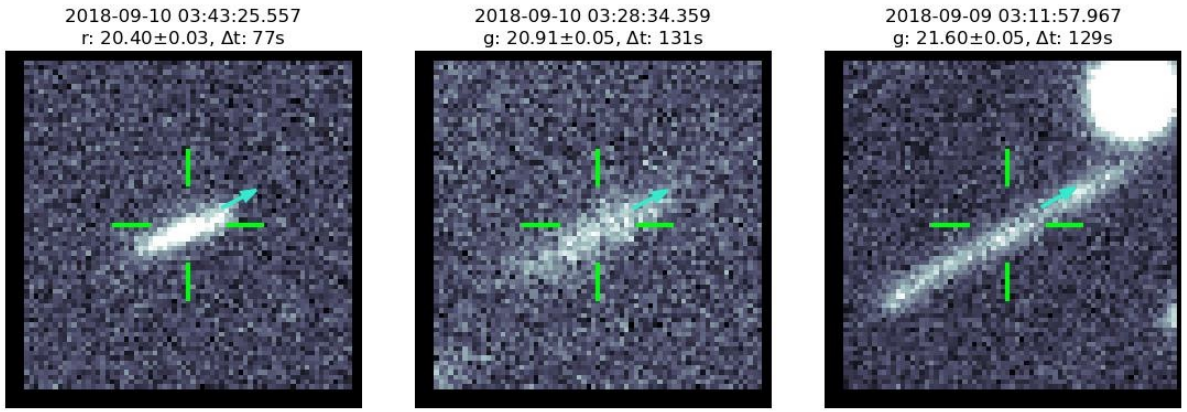
5. Precovery scenarios

The LSST dataset will be also be a fantastic source of precovery detections for objects discovered by other surveys.

LSST could be queried for detections observed in hours or days before a possible imminent impactor detection.

This should be directly possible with alert-stream catalog data (which are public after 60 seconds), but not with **image data** (which are **public after 80 hours**). The latter is needed to detect especially faint or trailed sources.

Looking into adding processes to request urgent high-importance image-level precovery measurements from the Rubin team.



Precovery observations of 2018 RB2 (an NEOCC Risk List Object) taken with Blanco 4m's Dark Energy Camera (DECam).

Mosaic by Joachim Moeyens (UW/DiRAC/B612 Asteroid Institute)

Summary

- Rubin Observatory, to be completed by the end of 2024, will provide a comprehensive census of the Solar System.

- It can discover 1-10+ imminent impactors per year. Many should be discovered with its default linking strategy.

- But we could also do better – our Solar System team is looking for ways to make Rubin maximally sensitive to imminent impactors. Opportunity to add a more powerful new imminent impactor detection capability.

Contact, comments & questions: Mario Juric, mjuric@astro.washington.edu

Thank You! Questions?

https://dirac.astro.washington.edu

DiRAC

A Universe Understood Through
Data-Intensive Discovery

UNIVERSITY of WASHINGTON