Small Bodies with the Rubin Observatory/LSST

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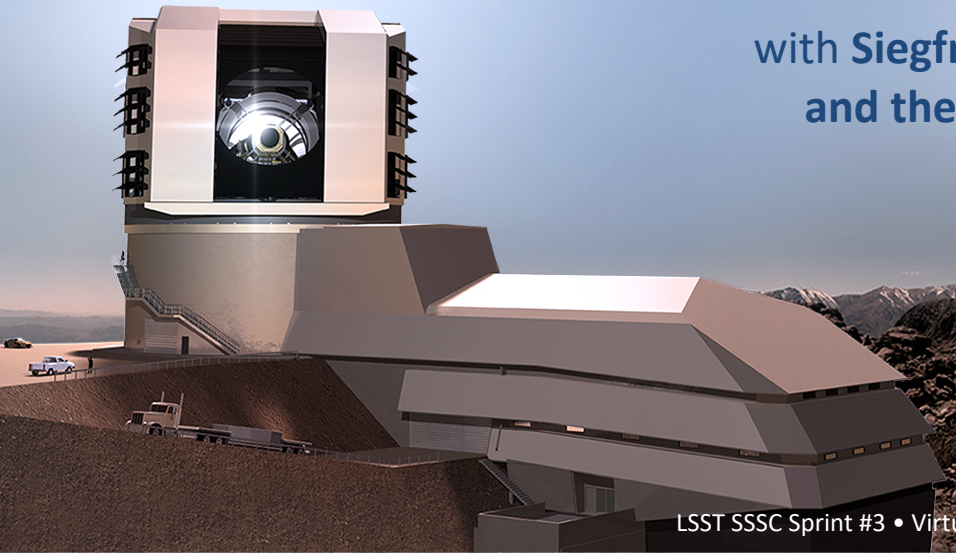
with **Siegfried Eggl, Joachim Moeyens, Lynne Jones and the Rubin Observatory Construction Project**



NSF Vera C. Rubin Observatory | LSST

LSST: Legacy Survey of Space and Time

An 8.4m optical survey telescope, on Cerro Pachón, Chile

3.2Gpix, 2-second readout camera (ugrizy filters, 0.2”/pix)

Site construction began April 2015

10 year survey starting
in late 2022*

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

* COVID-19 impacts currently
being accessed.

Total Solar Eclipse over Cerro Pachon, July 2, 2019
Photo: K. Reil LSST/DOE/SLAC

A Survey with Multiple Science Drivers

Four science programs as the key drivers of the science requirements

Dark Matter, Dark Energy

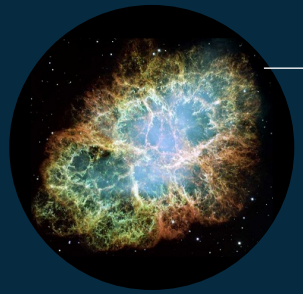
- Weak Lensing
- Baryon acoustic oscillations
- Supernovae, Quasars

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

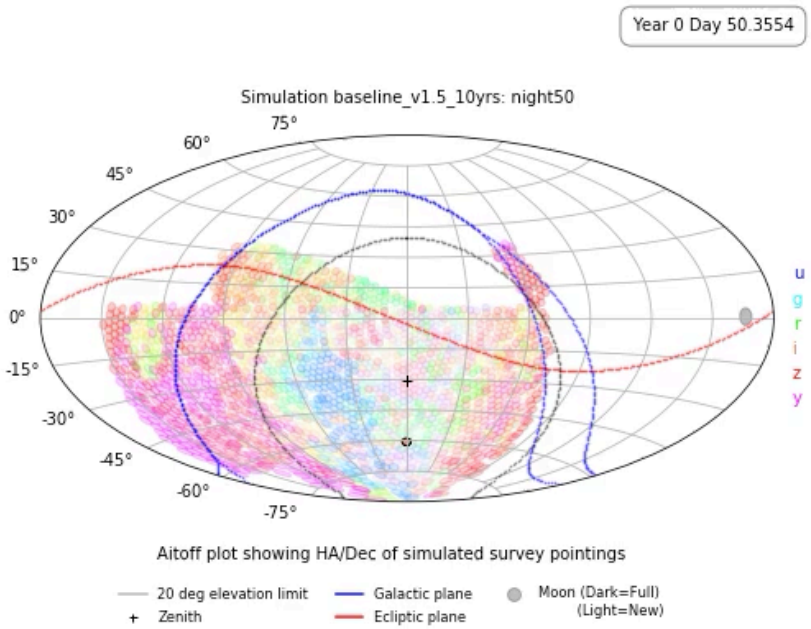


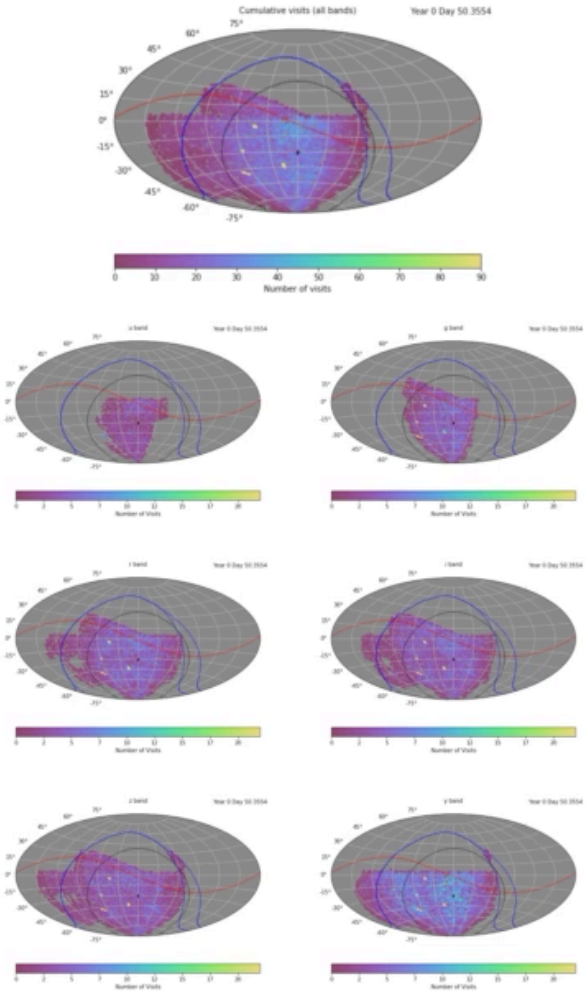
Exploring the Transient sky

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

Ivezić et al. (2008), V5(2018)

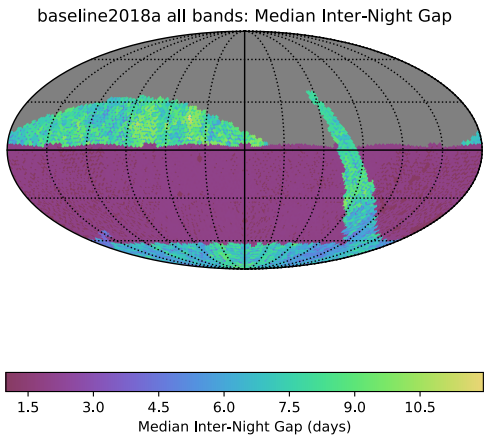
A deep, fast, survey of the visible sky

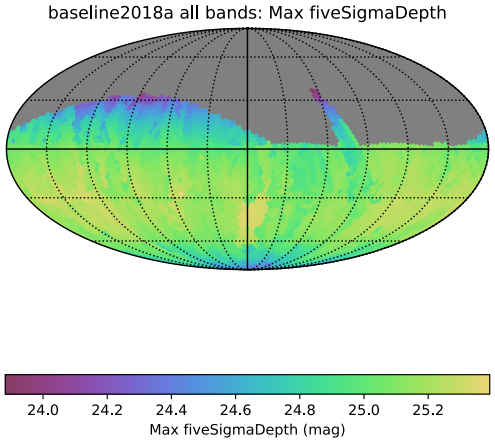


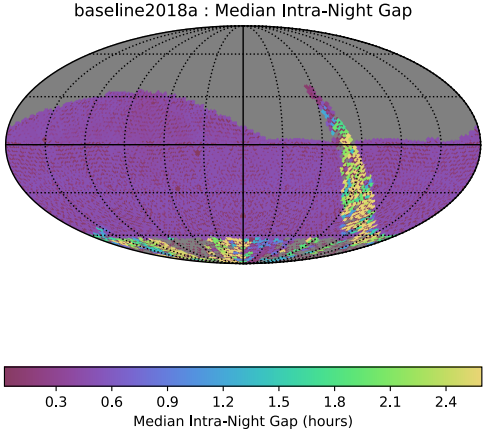


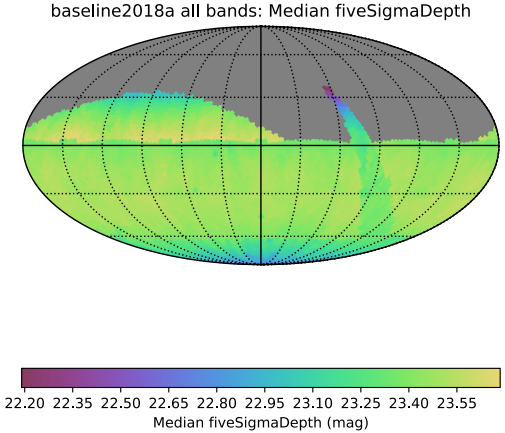
Rubin Observatory

LSST Survey Strategy baseline2018a/b





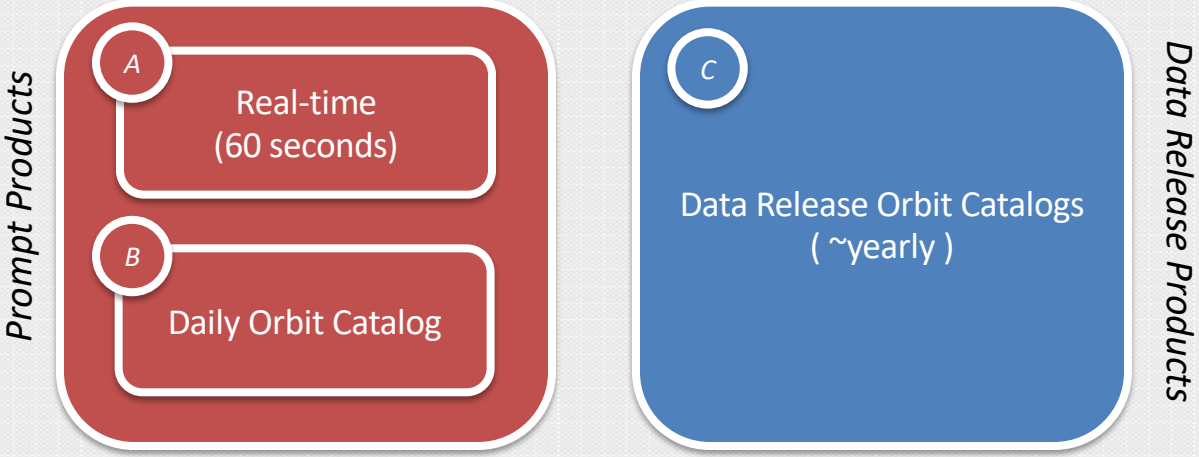




Solar System Data Products

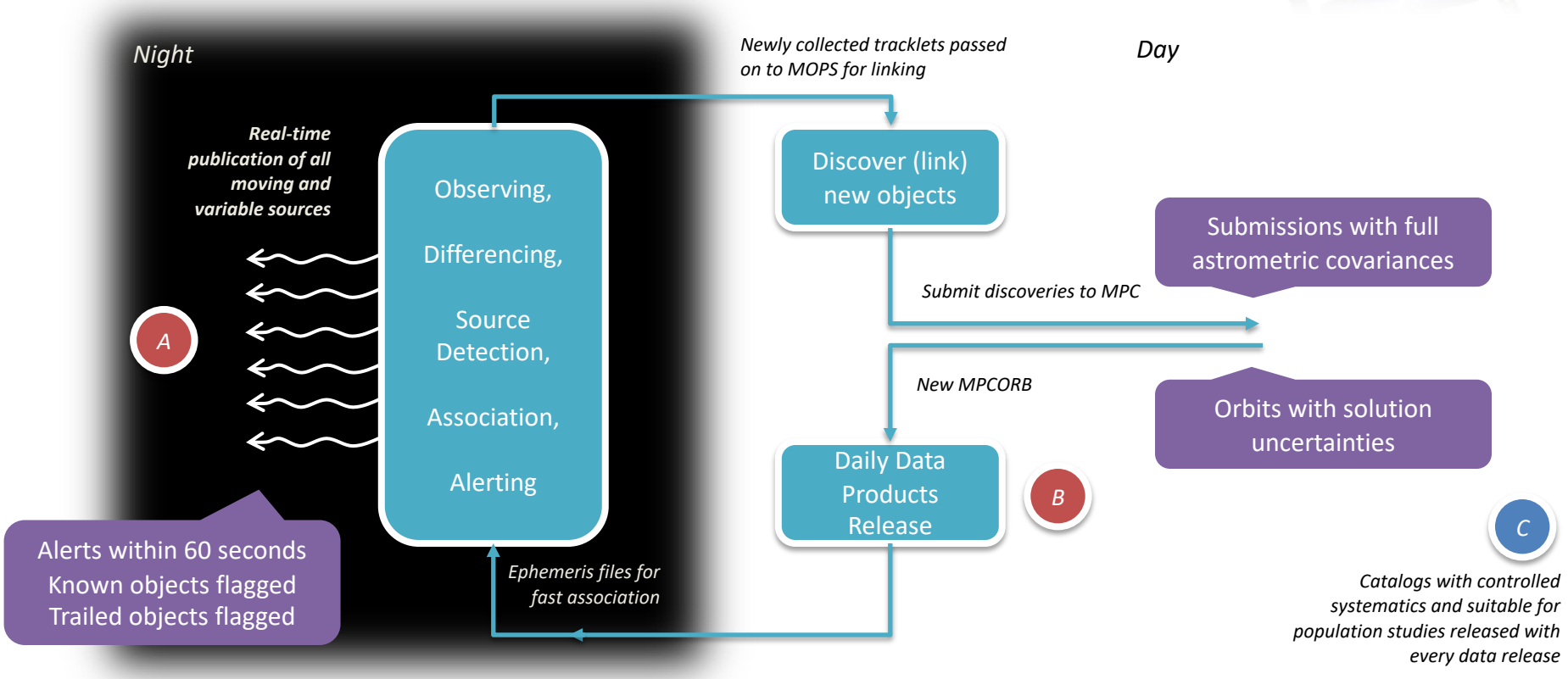
Over the past two years we've undertaken a major redesign, guided by collaboration input, of what products the LSST will deliver to enable Solar System science.

We will provide three kinds of Solar System-specific products:



See the handout (http://ls.st/Document-29545) for a one-page summary!

The 24-hr Solar System Processing Loop



See the handout at http://ls.st/Document-29545 for a one-page summary!

A. Prompt Products: Real-Time Alerts

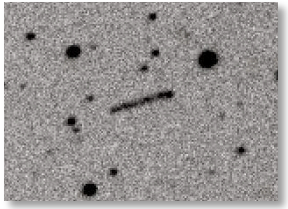
A. Real-time Alerts (>=2M SSO observations/night)	
Astrometry	±10 mas (bright; ±140 faint)
PSF flux	±10 mmag (bright end)
Aperture flux	±10 mmag (bright end)
Trailed source fit	Flux and on-sky motion for fast-moving (trailed) objects
Appearance characterization	Moments and extendedness of the object's 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

Within 60 seconds of observation

Measurements of all detections on difference images, including known and unknown SSOs.

Suitable for real-time discovery of trailed objects, and activity of known objects.



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

B. Prompt Products: Daily Catalog of Solar System Objects

B. Daily Solar System Products (>= 5.5M objects)	
Orbits	Computed by the MPC
Light-curve characterization	Period, light curve shape, other features
Absolute magnitude estimates	Estimates of (H, G12) in u,g,r,i,z,y bands
MOID	Minimum Orbit Intersection Distance to Earth
Extendedness indicators	Is/was the object comet-like in its appearance.

Daily Catalog of SSOs

A catalog of orbits and physical properties, refreshed daily.

The orbit solutions and designations will be obtained from the MPC. The physical properties (absolute magnitudes, light curves, extendedness characterization) will be computed from LSST data.

Details: SSObject and SSSource tables in http://ls.st/ouq

C. Data Release Products for Solar System Science

C. Solar System Data Release Products (every year)	
High-fidelity reprocessing	Catalogs derived from re-reductions of all survey data using improved calibrations and a single, well-characterized, software release. **A "gold" version of the daily catalog.**
The LSST Catalog of Solar System Objects	A catalog, suitable for population studies, of objects detected by LSST with orbits estimated using only LSST data.

Data Releases (annual)

LSST will reprocess all data once a year, releasing a well-characterized data release (DR).

The Solar System aspects of a data release include a "gold" version of the daily catalog, and a special "LSST-only" catalog of Solar System objects, suitable for population studies.

Solar System Science with LSST

Animation: SDSS Asteroids
(Alex Parker, SwRI)

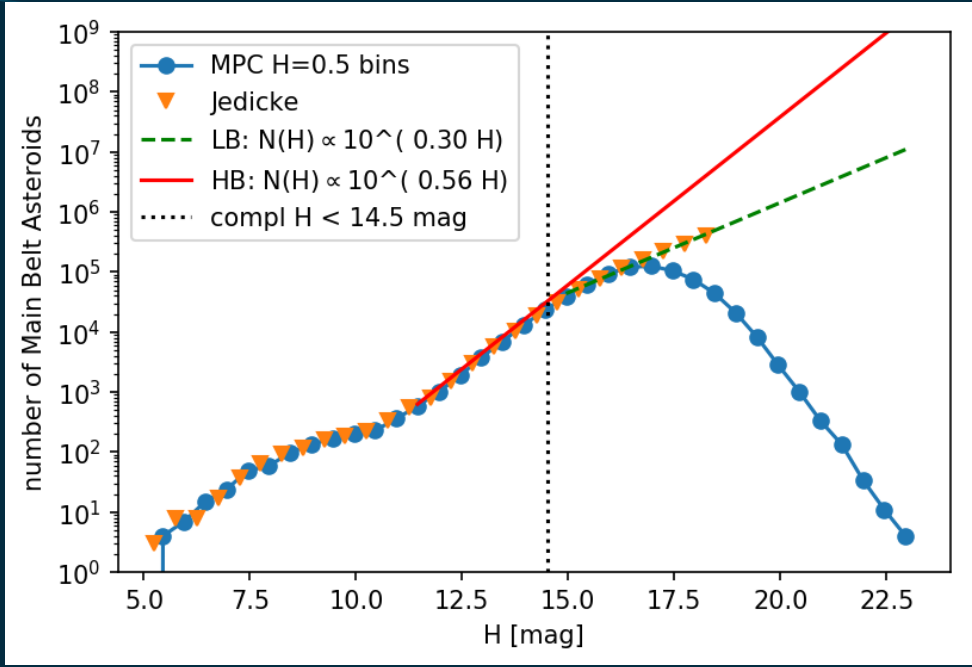
	Currently Known*	LSST Discoveries**	Typical number of observations+
Near Earth Objects (NEOs)	~22,000	200,000	(D>250m) 60
Main Belt Asteroids (MBAs)	~810,000	6,000,000	(D>500m) 200
Jupiter Trojans	~8000	280,000	(D>2km) 300
TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOs)	~3300	40,000	(D>200km) 450
Comets	~4000	10,000	?
Interstellar Objects (ISOs)	2	>10	?

Estimates: Lynne Jones et al.

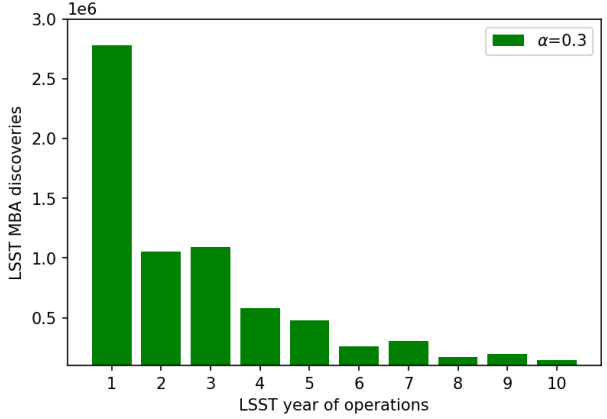
Expected Yields: Distributions

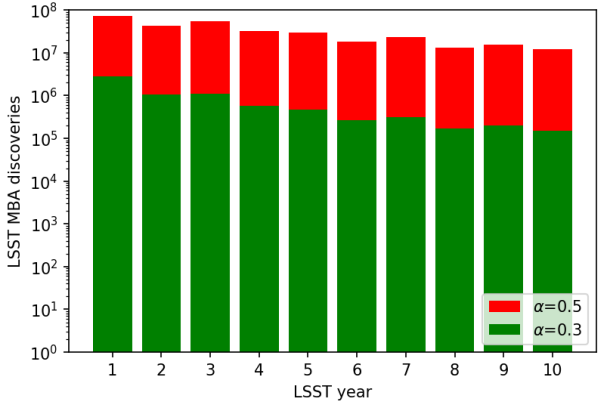
Main Belt Asteroids: N(H) + known object distribution (MPC, 03/2019)

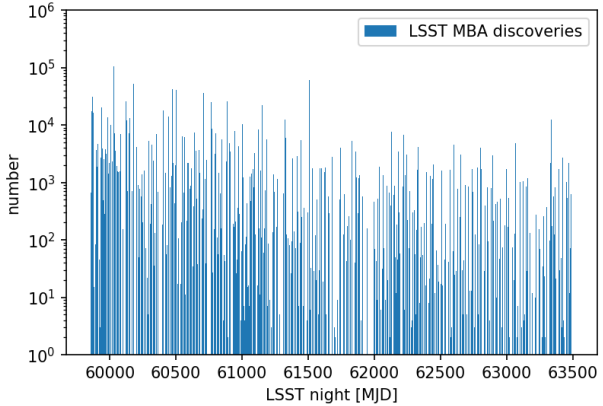
2 synthetic MBA populations:

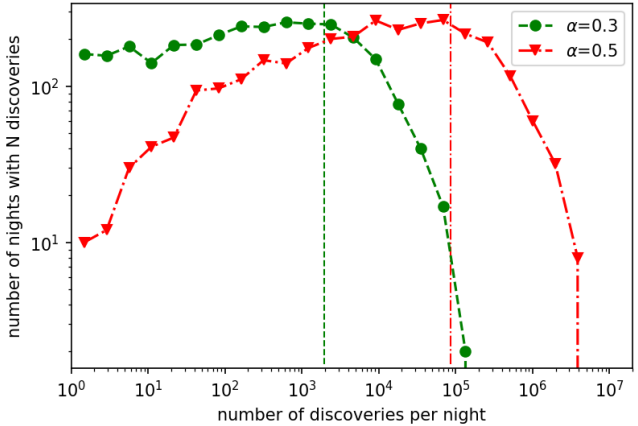


MBA Yields (baseline2018a/b)

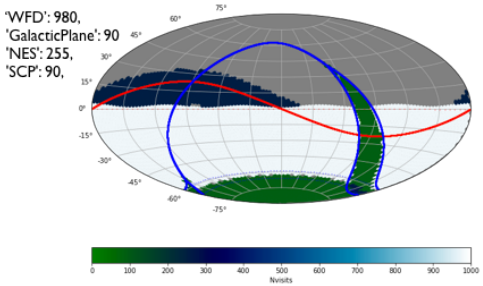


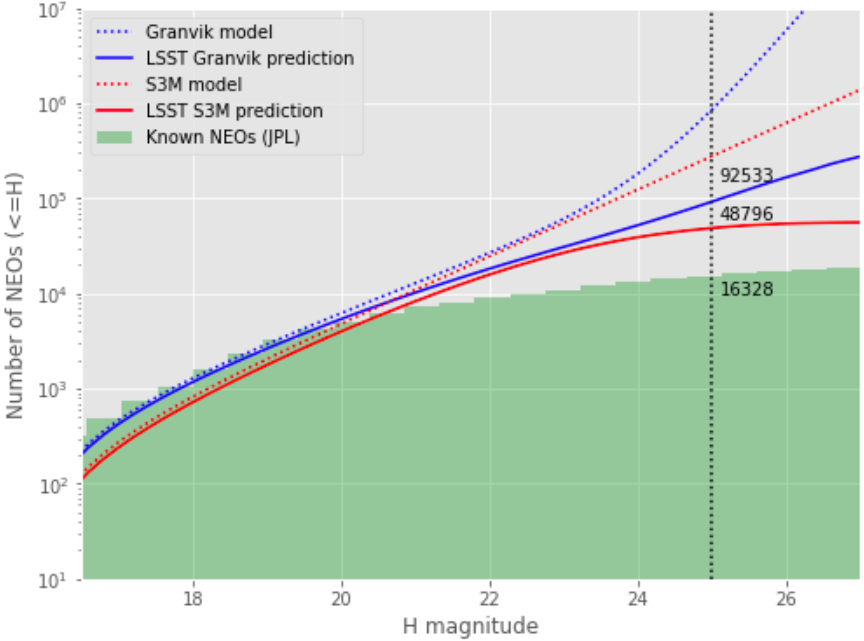






NEO Yields (baseline2018a/b)





In current baseline strategy, after 10 years:

- 50-100K NEOs @ H<25
- 250K @ H<27

S3M - Grav et al 2011; Granvik - Granvik et al 2018

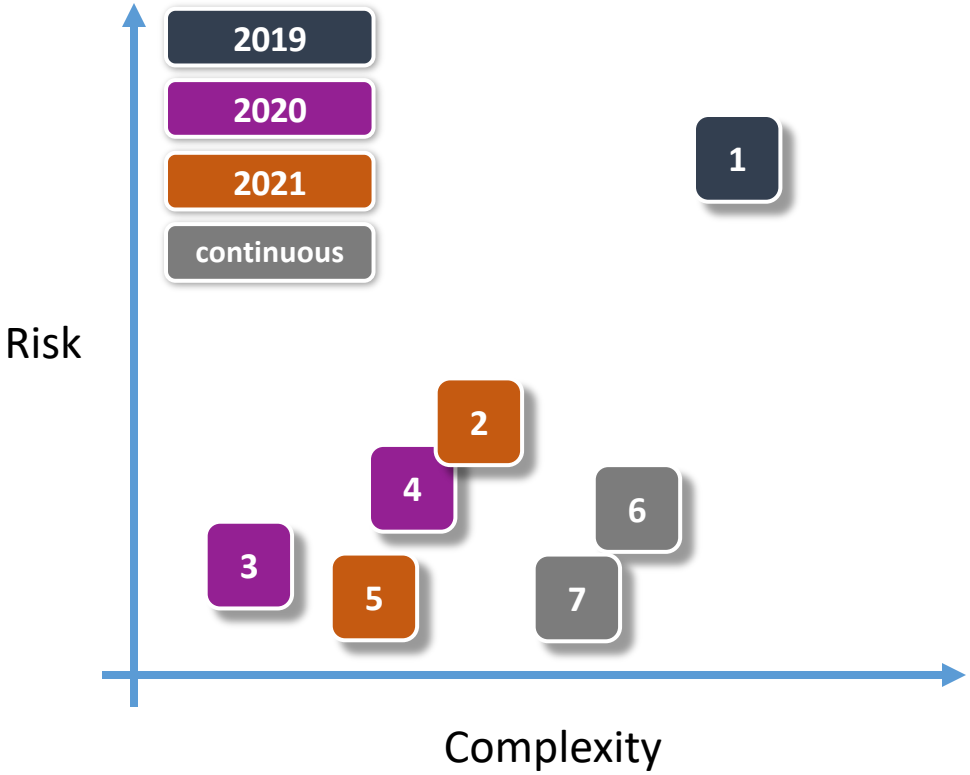
2019-2020 Dev Milestones

- Pytrax/Heliolinc tests
  - “Heliolinc 2” – an experimental pure-python implementation
- First version of the IOD/OD routines
- First end-to-end linking test (~40 deg^2; 70%+ recovery rates)
- Daily Data Products Release Pipeline early prototype
- Database Ingestion Prototypes

- Next 12 months
  - “Mock LSST” improvements, DDPR improvements
  - Attribution code
  - MPC submission code, Integration test with the MPC

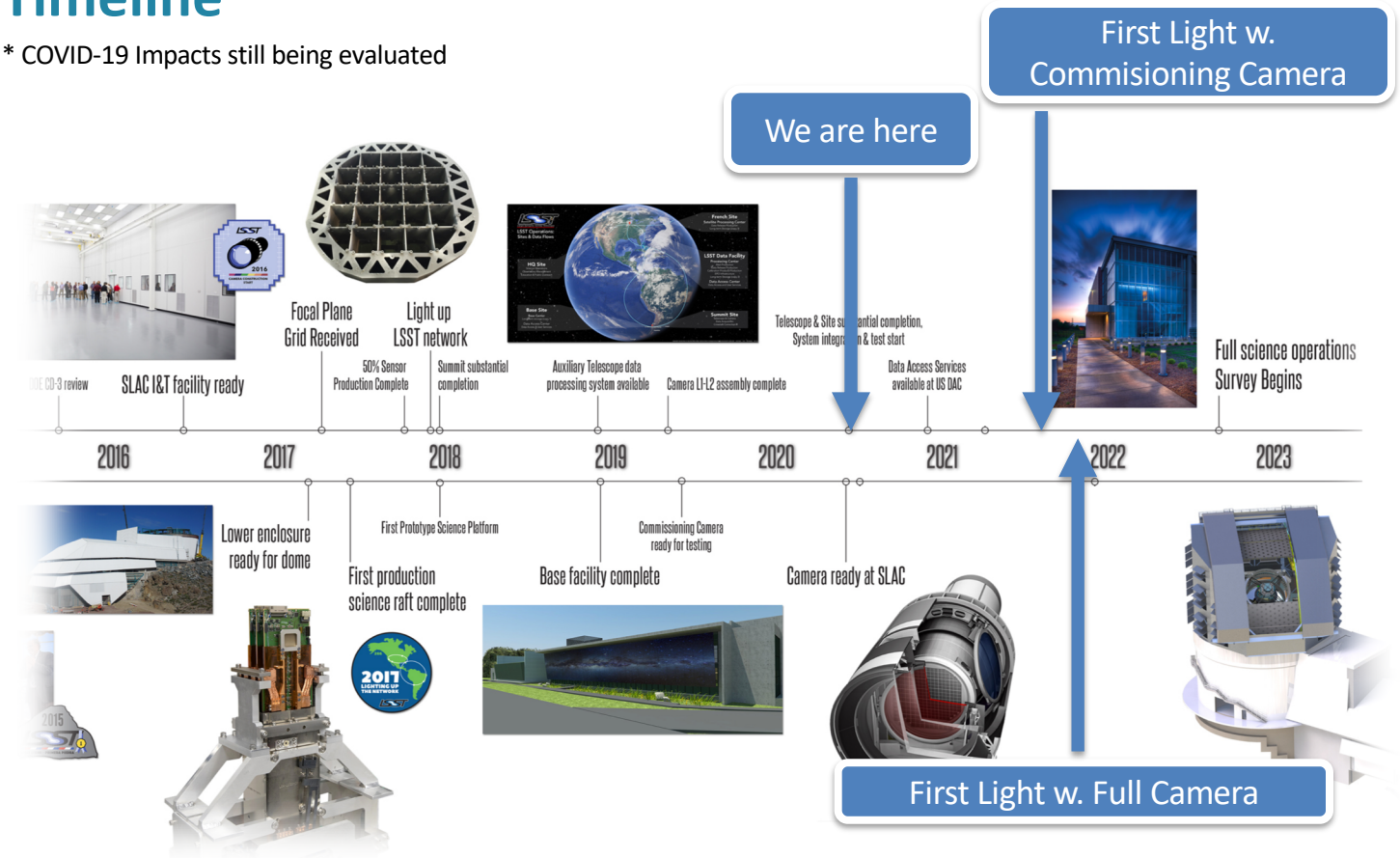
Development: Complexity / Risk Matrix

1. Linking
2. Precovery
3. Attribution
4. Submission
5. Daily Production
6. Monitor & Control
7. Q.A.



Timeline*

* COVID-19 Impacts still being evaluated



https://www.lsst.org/about/timeline

First light is a ~year away

Commissioning begins in ~1.5yrs

Operations start in <2.5 years.