LSST Solar System Overview & Update

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Vera C. Rubin Observatory

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

A 10 year LSST survey starting in Oct. 2023

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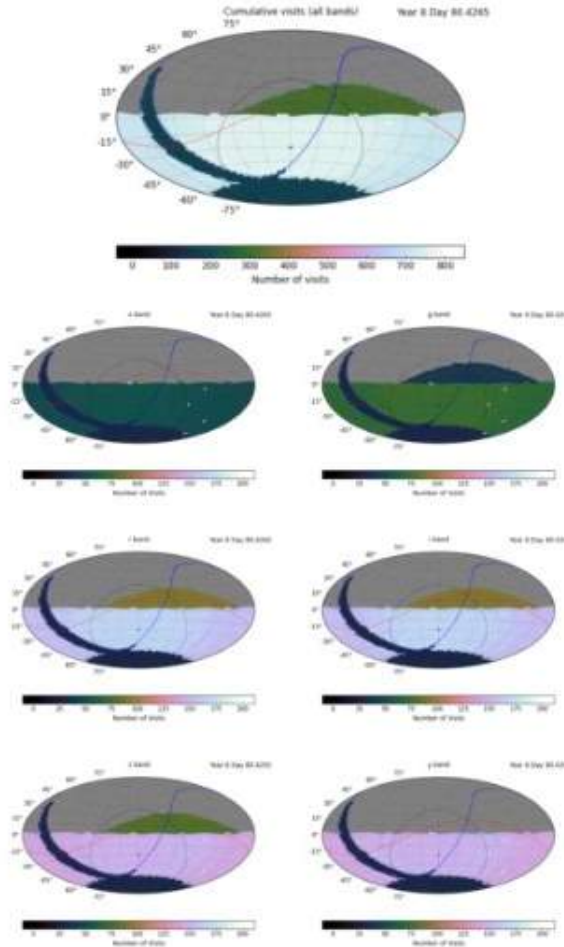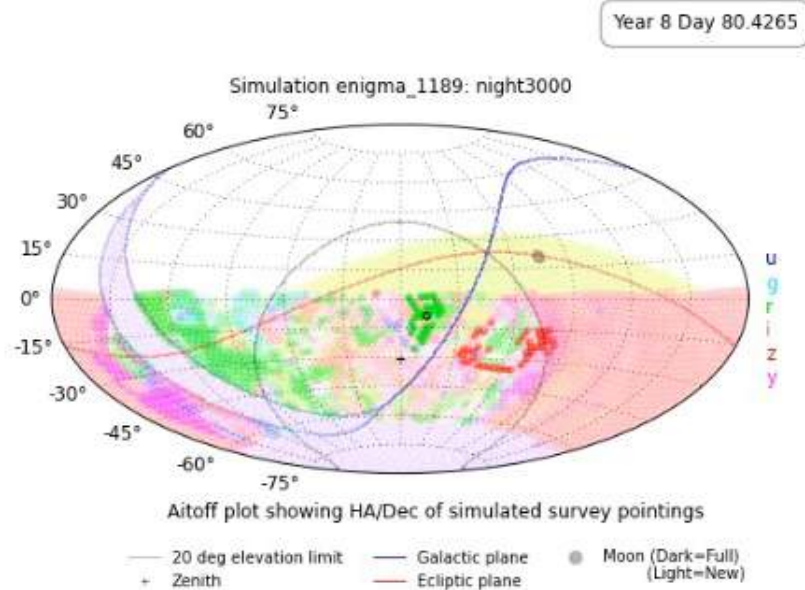1ms (rel), 10ms (abs)

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

Rubin Observatory, March 2021.

LSST Science Themes

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

Year 8 Day 80.4265

Simulation enigma_1189: night3000

Aitoff plot showing HA/Dec of simulated survey pointings

- 20 deg elevation limit
- Zenith
- Galactic plane
- Ecliptic plane
- Moon (Dark=Full) (Light=New)

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.

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

Data Products for Small Body Science

I. Real–Time Alerts within 60 sec

| 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

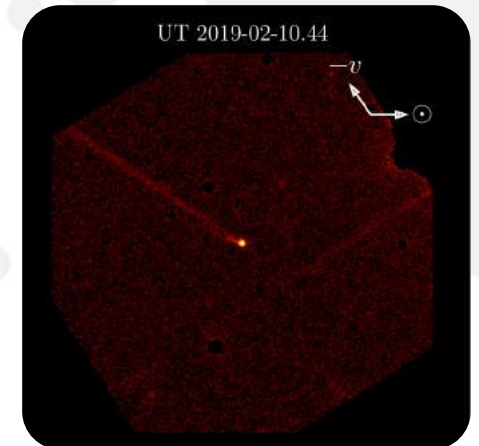*Details: DIASource tables in http://ls.st/oug*

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.

Allows us to monitoring ~0.5-1M small bodies for activity, each night.
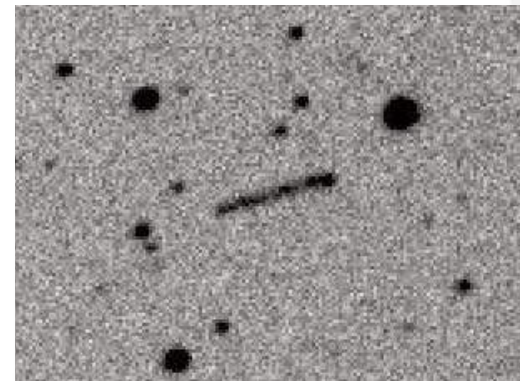
2014 MF6 (PHA), 60sec exposure, MPC Q62 (Guido, Howes & Nicolini)

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

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 (Earth)
Extendedness indicators	Is/was the object comet-like in its appearance?

A catalog of orbits and physical properties, recomputed 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.

The most up-to-date catalog of physically well-characterized small bodies in the Solar System.

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

III. High-Quality Data Release Catalogs

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.

LSST will reprocess all data once a year, publishing well-characterized and manually QA-ed data releases (DR).

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

We will also deliver the linking software, information about the selection functions, and metadata necessary to enable debiasing of the population.

Development Updates

> An extension of Holman et al. HelioLINC algorithm

> Prototype passed initial linking tests in February

> Paper is in the works (Eggl et al. in prep)

> Siegfried Eggl leaving for faculty position at UIUC (congratulations!)

> Ari Heinze coming to us from ATLAS.

Discovering Our Universe Together
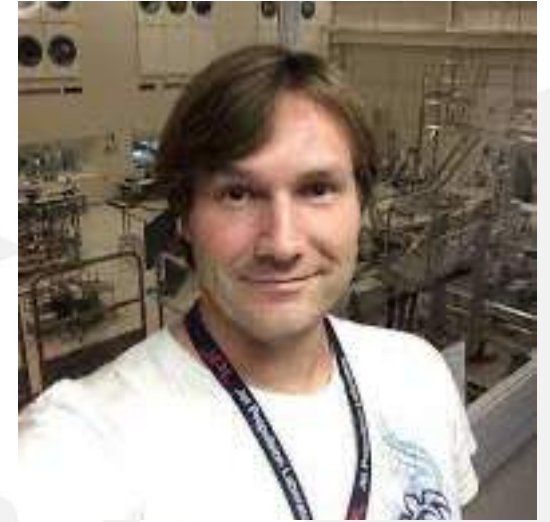
> Added a trailed source fitting algorithm to the stack
  - Estimates the centroid, flux, and on-sky motion vector for each object
  - https://github.com/lsst/meas_extensions_trailedSources

> Two different measurement techniques
  - Estimation from adaptive 2nd order moments
  - Veres et al. 2012 algorithm (simplified forward modeling)

> Finding that 2nd order moments are about as precise as Veres et al., at a fraction of the computational cost.

> Paper in the works (Langford et al.)

Discovering Our Universe Together

MPC Data Exchange Challenge #1

Ran a successful initial integration test with the Minor Planet Center (October 2020)

Made mock, full-size, submissions for the first three weeks of the LSST survey (ADES PSV format). **A typical night early in the LSST will bring 17,000 new discoveries.**
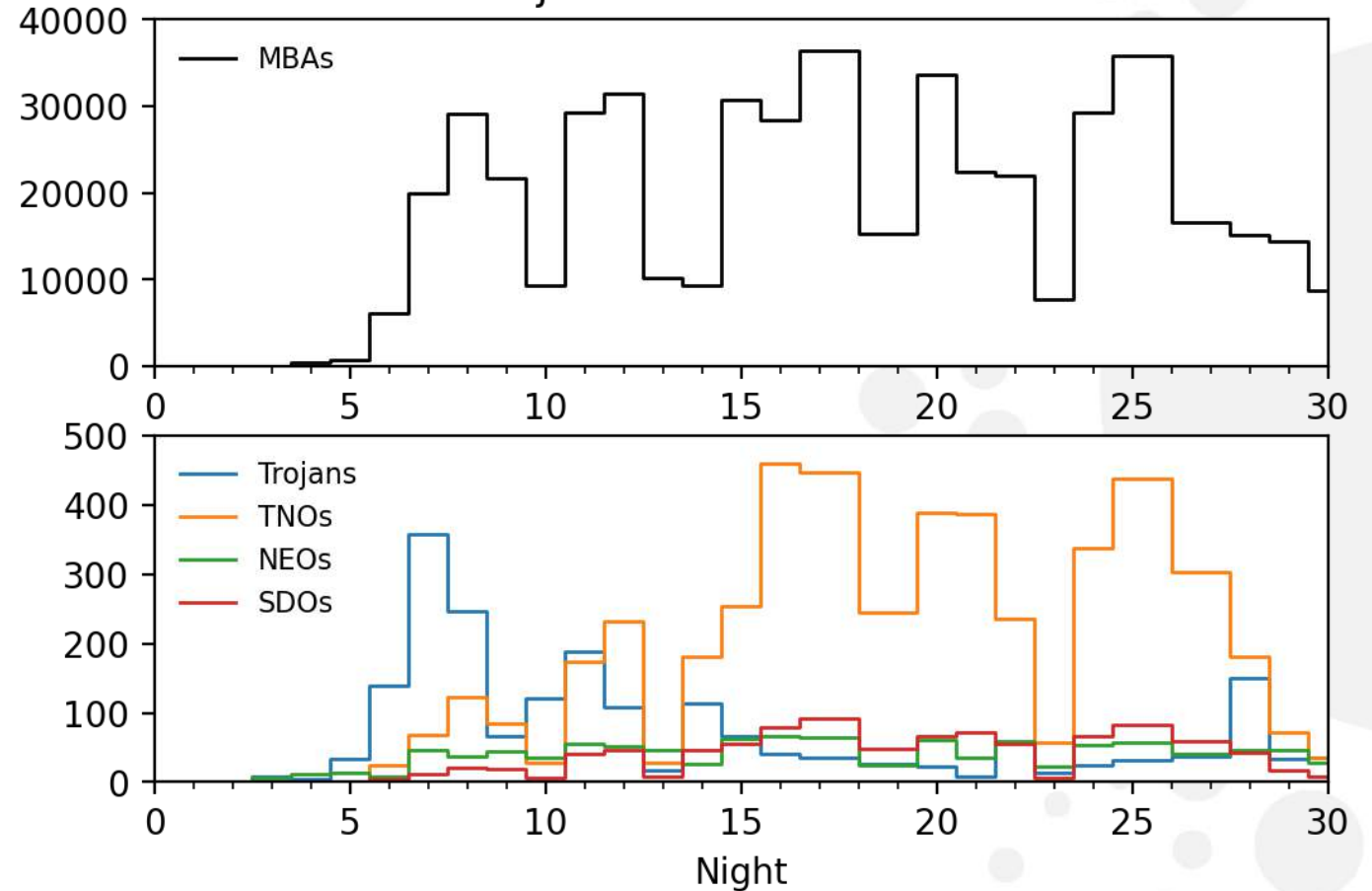
The MPC accepted and manually processed the submissions, through to the generation of a new MPCORB catalog. **The process took approximately 4 hours.**

No architectural bottlenecks identified; assuming MPC capacity is enlarged as expected no significant problems.

Discovering Our Universe Together

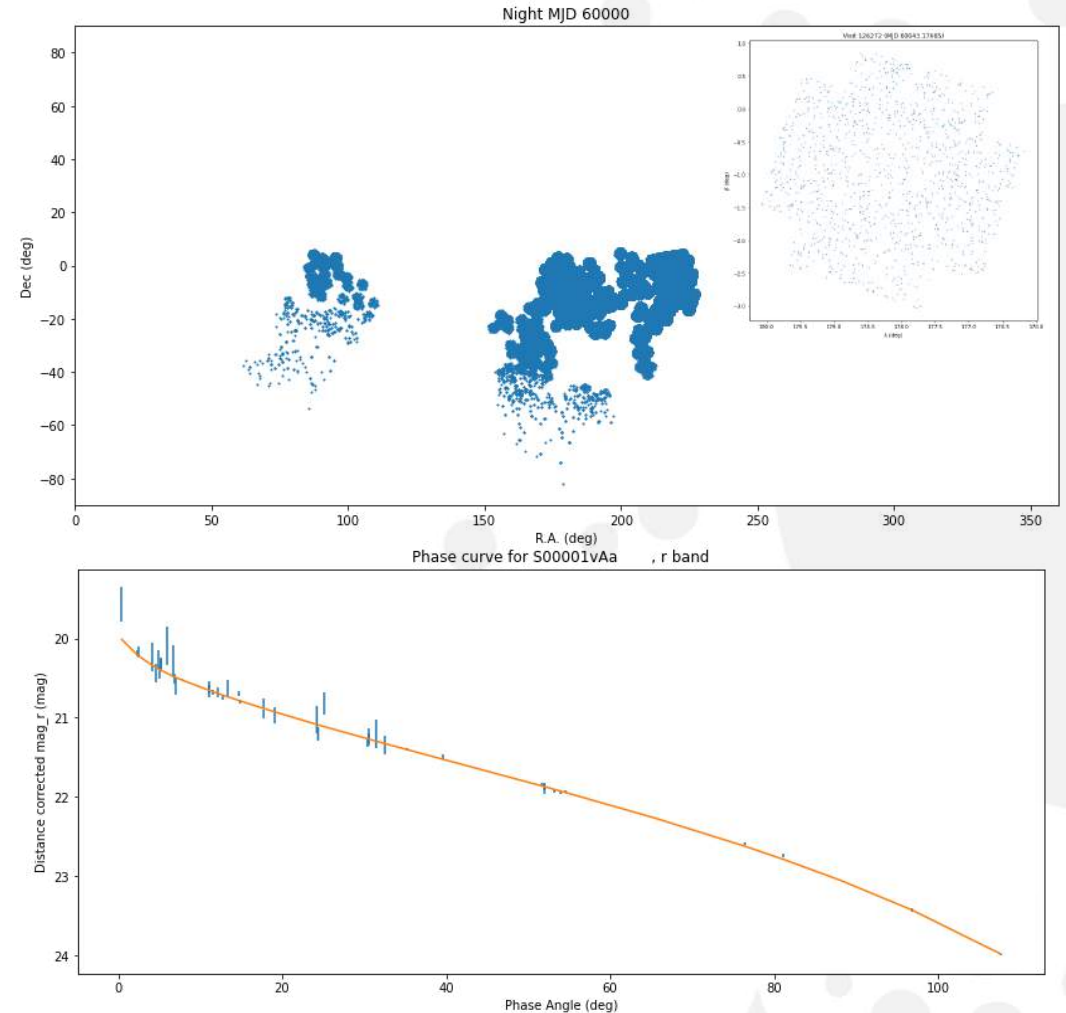# New Simulations

> Full 10yr dataset (~1Bn measurements)

> All SS* tables (SSObject, SSSource, MPCORB)
   - SSObject: prototype Daily Data Products Pipeline

> New cadence (baseline 1.7)

> Realistic magnitude, astrometry errors

> Absolute magnitude fits (H, G system)

> Using the same chosen technology (PostgreSQL)

> Community-developed pipeline including software from Naidu, Fedorets, +Rubin's SSO team and UW Solar System Group's most excellent band of undergrads (Cornwall, Berres, Chernyavskaya, Langford)

Discovering Our Universe Together

Onto the JupyterHub!

https://sssc.dirac.institute