The LSST-MPC Connection

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LSST: A Deep, Wide, Fast, Optical Sky Survey

8.4m telescope

18000+ deg²

10mas astrom.

r<24.5 (<27.5@10yr)

ugrizy

0.5-1% photometry

3.2Gpix camera

30sec exp/4sec rd

15TB/night

Imaging the visible sky, once every 3 days, for 10 years (825 revisits)

37 B objects

Slide Credit: Mario Jurić
What LSST Can Do

Finding Near Earth Asteroids

Credit: Jones et al. (2018)
What LSST Can Do
Explore the Origin of Main Belt Comets and Active Asteroids

Jewitt (2012)

Ki et al (2018). Adapted by Henry Hsieh
What LSST Can Do

‘Oumuamua - a messenger that reaches out from the distant past

Interstellar Object Discoveries

Credit: Bannister, et al. (2017)

Credit: NASA/JPL-Caltech

‘Oumuamua - a messenger that reaches out from the distant past

Credit: Drahos et al. (2018)

Credit: Bannister, et al. (2017)

Credit: Meech et al (2018)

Credit: Meech et al (2018)
What LSST Can Do

Explore the Origin of Sedna’s Strange Orbit and Test the Existence of Planet 9

Alignment of known distant orbits, with $q > 45$ au & $250 < a < 2000$ au. Orbits with $q > 60$ are shown in red.

Image Credit: S. Sheppard

Image Credit: R. Hurt/JPL-Caltech
It’s Really Coming! Science Operations Start in 2022
Next 3 years is the time to prepare!
## Expected LSST Yield

<table>
<thead>
<tr>
<th>Category</th>
<th>Currently Known*</th>
<th>LSST Discoveries**</th>
<th>Typical number of observations+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near Earth Objects (NEOs)</td>
<td>~20,000</td>
<td>200,000</td>
<td>(D&gt;250m) 60</td>
</tr>
<tr>
<td>Main Belt Asteroids (MBAs)</td>
<td>~650,000</td>
<td>6,000,000</td>
<td>(D&gt;500m) 200</td>
</tr>
<tr>
<td>Jupiter Trojans</td>
<td>~7000</td>
<td>280,000</td>
<td>(D&gt;2km) 300</td>
</tr>
<tr>
<td>TransNeptunian Objects (TNOs) + Scattered Disk Objects (SDOs)</td>
<td>~3000</td>
<td>40,000</td>
<td>(D&gt;200km) 450</td>
</tr>
<tr>
<td>Comets</td>
<td>~3000</td>
<td>10,000</td>
<td>?</td>
</tr>
<tr>
<td>Interstellar Objects (ISOs)</td>
<td>1</td>
<td>10</td>
<td>?</td>
</tr>
</tbody>
</table>

**Notes:**
- *ugrizy* photometry
- LSST Discoveries:
  - NEOs: ~20,000
  - MBAs: ~650,000
  - Jupiter Trojans: ~7000
  - TNOs + SDOs: ~3000
  - Comets: ~3000
  - Interstellar Objects (ISOs): 1
- Typical number of observations:
  - NEOs: ~200,000 (D>250m) 60
  - MBAs: 6,000,000 (D>500m) 200
  - Jupiter Trojans: 280,000 (D>2km) 300
  - TNOs + SDOs: 40,000 (D>200km) 450
  - Comets: 10,000
  - Interstellar Objects (ISOs): 10

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*Slide Credit: LSST Science book/Lynne Jones*
What is LSST project Providing

Solar System Data Products

Over the past year 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:

- **Prompt Products**
  - A: Real-time (60 seconds)
  - B: Daily Orbit Catalog

- **Data Release Products**
  - C: Data Release Orbit Catalogs (~yearly)

See the handout [http://ls.st/Document-29545](http://ls.st/Document-29545) for a one-page summary!
What is LSST project Providing

LSST Nightly/Daily Processing Loop

- Nightly/Daily Processing Loop
  - Observing
    - Real-time publication of all moving and variable sources
    - Ephemeris files for fast association
  - Newly collected tracklets passed on to MOPS for linking
  - Discover (link) new objects
  - Submit discoveries to MPC
  - New MPCORB
  - Daily Data Products Release
    - Catalogs with controlled systematics and suitable for population studies released with every data release


Slide Credit: Mario Jurić
Prompt Products: Real-Time Alerts

**A. Real-time Alerts (>=2M SSO observations/night)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astrometry</td>
<td>±10 mas (bright; ±140 faint)</td>
</tr>
<tr>
<td>PSF flux</td>
<td>±10 mmag (bright end)</td>
</tr>
<tr>
<td>Aperture flux</td>
<td>±10 mmag (bright end)</td>
</tr>
<tr>
<td>Trailed source fit</td>
<td>Flux and on-sky motion for fast-moving (trailed) objects</td>
</tr>
<tr>
<td>Appearance characterization</td>
<td>Moments and extendedness of the object’s image</td>
</tr>
<tr>
<td>Spuriousness score</td>
<td>Probability that the detection is an artifact</td>
</tr>
<tr>
<td>Nearby static objects</td>
<td>Information on adjacent objects (up to three)</td>
</tr>
<tr>
<td>MPC designation</td>
<td>Given for known objects</td>
</tr>
<tr>
<td>Predicted position and magnitude</td>
<td>Given for known objects</td>
</tr>
</tbody>
</table>

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.

Details: DIA Source tables in [http://ls.st/oug](http://ls.st/oug)

Slide Credit: Mario Jurić

2014 MF6 (PHA), 60sec exposure, MPC Q62 (Guido, Howes & Nicolini)
B. Daily Solar System Products (>= 5.5M objects)

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbits</td>
<td>Computed by the MPC</td>
</tr>
<tr>
<td>Light-curve characterization</td>
<td>Period, light curve shape, other features</td>
</tr>
<tr>
<td>Absolute magnitude estimates</td>
<td>Estimates of (H, G12) in u,g,r,i,z,y bands</td>
</tr>
<tr>
<td>MOID</td>
<td>Minimum Orbit Intersection Distance to Earth</td>
</tr>
<tr>
<td>Extendedness indicators</td>
<td>Is/was the object comet-like in its appearance.</td>
</tr>
</tbody>
</table>

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/oug

Slide Credit: Mario Jurić
## Data Release Products for Solar System Science

### 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.

### Table: C. Solar System Data Release Products (every year)

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-fidelity reprocessing</td>
<td>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.</td>
</tr>
<tr>
<td>The LSST Catalog of Solar System Objects</td>
<td>A catalog, suitable for population studies, of objects detected by LSST with orbits estimated using only LSST data.</td>
</tr>
</tbody>
</table>
The next 3 years are crucial in planning and preparation for LSST small body observations throughout the Solar System, and the science yield can be maximized with modest effort to develop predictive and analysis tools.
LSST Solar System Science Collaboration (SSSC)

Active objects Working Group (Lead: Mike Kelley): broadly consisting of all categories of activity in the minor planet populations: short period comets, long period comets, main belt comets, impact- or rotationally-generated active asteroids, etc

Community software/infrastructure development Working Group (Lead: Henry Hsieh): broadly consisting of people interested in helping build databases, software packages, etc to be used by the Solar System community on LSST data

Inner Solar System Working Group (Lead: Cristina Thomas): broadly consisting of the main belt, Mars/Jupiter Trojans, and Jupiter irregular satellites

NEOs (Near Earth Objects) and Interstellar Objects Working Group (Lead: Steve Chesley): broadly consisting of objects on orbits inward of or diffusing inward from the main belt as well as interstellar objects temporarily residing in the Solar System

Outer Solar System Working Group (Lead: Darin Ragozzine and Matt Holman): broadly consisting of KBOs, Centaurs, Oort cloud, Saturn/Neptune/Uranus Trojans, and Saturn/Neptune/Uranus irregular satellites

SSSC Co-Chairs:
David Trilling & Meg Schwamb

SSSC: UK Solar System POC
Wes Fraser

www.lsstsssc.org
LARGE SYNOPTIC SURVEY TELESCOPE SOLAR SYSTEM SCIENCE ROADMAP

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ABSTRACT

The Large Synoptic Survey Telescope (LSST) is uniquely equipped to search for Solar System bodies due to its unprecedented combination of depth and wide field coverage. Over a ten-year period starting in 2022, LSST will generate the largest catalog of Solar System objects to date. The main goal of the LSST Solar System Science Collaboration (SSSC) is to facilitate the efforts of the planetary community to study the planets and small body populations residing within our Solar System using LSST data. To prepare for future survey cadence decisions and ensure that interesting and novel Solar System science is achievable with LSST, the SSSC has identified and prioritized key Solar System research areas for investigation with LSST in this roadmap. The ranked science priorities highlighted in this living document will inform LSST survey cadence decisions and aid in identifying software tools and pipelines needed to be developed by the planetary community as added value products and resources before the planned start of LSST science operations.
A SOFTWARE ROADMAP FOR SOLAR SYSTEM SCIENCE WITH THE LARGE SYNOPTIC SURVEY TELESCOPE

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The 8.4-m Large Synoptic Survey Telescope (LSST) will provide an unprecedented view of the Solar System (Ivezić et al. 2008; LSST Science Collaboration et al. 2009). LSST will detect millions of asteroids and tens of thousands of distant Solar System bodies, within approximately 16 and 24.5 magnitudes (in r-band). Over a ten year period, most of these minor planets will receive hundreds of observations divided between 6 filters (ugrizy). What specifically LSST project will deliver for Solar System detections will soon be updated in the LSST Data Products Definition Document (DPDD; Jurić et al. 2013). A preliminary version of the new LSST Solar System data products schema is available at http://lsst/sd and http://lsst.org.

The LSST Solar System Science Collaboration (SSSC; http://www.lsstssc.org) produced a science roadmap (Schwamb et al. 2018) which outlines the collaboration’s highest ranked research priorities utilizing LSST. To achieve these science goals, the SSSC has identified crucial software products and tools that will be required but will not be provided by the LSST project. These will have to be developed by the SSSC and the broader planetary community. To spur this effort, we present below this list of LSST community software development tasks.

COMMUNITY SOFTWARE UTILITIES NEEDED DURING YEAR 1 OF LSST OPERATIONS

• Tools to extract cutouts from raw, reduced, and deep-stacked LSST images at locations where a specified orbit is predicted to appear, accounting for the uncertainty in the orbital parameters.

https://doi.org/10.3847/2515-5172/ab0e10

Schwamb et al. (2019,RNAAS)
More details can be found on the SSSC’s webpage

LSST Solar System Science Collaboration

Over its 10 year lifespan, the Large Synoptic Survey Telescope (LSST) could catalog over 5 million Main Belt asteroids, almost 300,000 Jupiter Trojans, over 100,000 NEOs, and over 40,000 KBOs. Many of these objects will receive hundreds of observations in multiple bandpasses. The LSST Solar System Science Collaboration (SSSC) is preparing methods and tools to analyze the data, as well as understand optimum survey strategies for discovering moving objects throughout the Solar System.