# Sorcha: A Solar System Survey Simulator for the Legacy Survey of Space and Time

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## Statement of Need

The upcoming Legacy Survey of Space and Time (LSST) at the Vera C. Rubin Observatory (Bianco et al., 2022; Ivezić et al., 2019; LSST Science Collaboration et al., 2009) is expected to revolutionize solar system astronomy. Unprecedented in scale, this ten-year wide-field survey will take ~2 million exposures split between 6 filters while also discovering and monitoring millions more solar system objects than are currently known (Fedorets et al., 2020; Grav et al., 2016; Hoover et al., 2022; Ivezić et al., 2019; Jones et al., 2009, 2018; Kurlander et al., 2025; LSST Science Collaboration et al., 2009; Murtagh et al., 2025; Schwamb et al., 2018; Shannon et al., 2015; Silsbee & Tremaine, 2016; Solontoi et al., 2010; Vereš & Chesley, 2017). This wealth of new information surpasses any survey to date in its combination of depth, sky coverage and sheer number of observations. The LSST will enable planetary astronomers to probe the dynamics and formation history of the solar system on a scale never before attempted. However, all astronomical surveys are affected by a complex set of intertwined observational biases, including observational strategy and cadence, limiting magnitude, instrumentation effects and observing conditions. The small body discoveries from an astronomical survey therefore provide a biased and distorted view of the actual underlying population. To help address this, survey simulators have emerged as powerful tools for assessing the impact of observational biases and aiding in the study of the target population. Open-source survey simulators have long been used in smaller population-specific surveys such as the Canada–France Ecliptic Plane Survey (CFEPS, Jones et al., 2006; Kavelaars et al., 2009; Petit et al., 2011) and the Outer Solar System Origins Survey (OSSOS, Bannister et al., 2016, 2018; Lawler et al., 2018) to forward model the effects of biases on a given population, allowing for a direct comparison to real discoveries. However, there is no commonly-used package available already suitable for the job of handling future petabyte solar system discovery surveys. The CFEPS and OSSOS survey simulators are specifically designed for their bespoke surveys. The scale and tremendous scope of the LSST requires the development of a new tool capable of handling the scale of the Rubin Observatory's LSST and all solar system small body populations.

Probing the orbital/size/brightness distributions and surface composition in each of the solar system's small body reservoirs is the top science priority in the Rubin Observatory LSST Solar System Science Collaboration (SSSC) Science Roadmap (Schwamb et al., 2018). In order to perform these detailed population studies, one must account for all the survey biases (the complex and often intertwined detection biases: brightness limits, pointing, cadence, on-sky motion limits, software detection efficiencies) in the discovery survey (see Lawler et al., 2018 for a more detailed discussion). The SSSC's Software Roadmap has identified a solar system survey simulator as one of the key software tools that must be developed in order to achieve the collaboration's top science goals (Schwamb et al., 2019). A survey simulator takes an input model small body population and outputs (biases the population to) what LSST should have detected by utilizing the LSST pointing history, observation metadata, and Rubin Observatory Solar System Processing (SSP) pipeline's detection efficiency so one can compare those simulated LSST detections to what was actually found by Rubin Observatory.

# Summary

`Sorcha` is a multipurpose, open-source solar system survey simulator for the LSST. Its modular design and configuration file allows each simulation to be finely customized by the user for their specific needs. `Sorcha` was designed to work at the large scale demanded by the large data rate from the LSST, and simulations can be run on high-performance computing clusters or on a researcher's laptop/desktop machine. The simulator can be used to facilitate predictions before the LSST begins science operations and to achieve a wide range of science goals when the LSST solar system discoveries are available.

Built in Python to be flexible, easy-to-use, and applicable to all solar system small body populations, `Sorcha` runs on the command line, ingesting files which describe the input population and the input survey. To predict the position of millions of solar system objects over ten years and over ~billion observations in a reasonable timescale, `Sorcha` makes use of an ephemeris generator (described in Holman et al., 2025) powered by ASSIST (Holman et al., 2023), an open-source Python and C99 software package for producing ephemeris-quality integrations of solar system test particles using the the IAS15 (15th-order Gauss-Radau) integrator (Rein & Spiegel, 2015) within the REBOUND N-body integrator package (Rein & Liu, 2012) to model the motion of the particles under the influence of gravity. `Sorcha` also makes use of a per-module randomization approach, as described in (Schwamb et al., 2024), allowing for deterministic random number generation during testing regardless of the order in which modules are executed. Additionally, in order to facilitate the use of customizable, community-built classes to describe cometary activity or light-curve modulation effects, `Sorcha` provides abstract base classes from which custom implementations can inherit, allowing a high level of customization of the code without requiring the user to modify the source code directly.

`Sorcha` is expected to be a key community tool for solar system science with the LSST. The software package has already enabled predictive work to be made ahead of the start of the LSST, with predictions made of the overall yield of new the asteroid and trans-Neptunian object discoveries (Kurlander et al., 2025) and of centaurs: a class of small, icy bodies that orbit the Sun on giant planet-crossing paths (Murtagh et al., 2025). We expect that future

upgrades to Sorcha will include adding the capability to simulate past well characterized wide-field discovery surveys in addition to the LSST.

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