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Solar System Science with LSST

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Abstract The Large Synoptic Survey Telescope (LSST) will provide a unique tool to study moving objects throughout the solar system, creating massive catalogs of Near Earth Objects (NEOs), asteroids, Trojans, TransNeptunian Objects (TNOs), comets and planetary satellites with well-measured orbits and high quality, multi-color photometry accurate to 0.005 magnitudes for the brightest objects. In the baseline LSST observing plan, back-to-back 15-second images will reach a limiting magnitude as faint as $r = 24.7$ in each 9.6 square degree image, twice per night; a total of approximately 20,000 square degrees of the sky will be imaged in multiple filters, with revisits about every 3 nights over several months of each year.

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1 Introduction

The Large Synoptic Survey Telescope (LSST) is a next-generation survey telescope which will image approximately 20,000 square degrees of sky down to $r = 24.7$ with a rapid observing cadence over a 10 year timespan. LSST is designed to satisfy four major science drivers:

(1) Understanding the nature of dark matter and dark energy
(2) Mapping the Milky Way
(3) Exploring the transient and variable optical sky
(4) Inventorying the Solar System.

LSST will doubtless also enable a broad range of unanticipated new scientific investigations, in a similar fashion as previous large surveys such as the Sloan Digital Sky Survey (SDSS; York et al. 2000), the Two Micron All Sky Survey (2MASS; Strutskie et al. 2006), and the Galaxy Evolution Explorer (GALEX; Martin et al. 2005).

In the area of planetary astronomy, LSST will provide massive catalogs of all classes of small moving objects within the Solar System. These catalogs will contain well-measured orbits and high-quality, multi-color photometry in *ugrizy* bands. Each object will be imaged multiple times within each night, within each lunation, and throughout a wide range of solar elongations. These observations will allow analysis of orbital distributions of each population to unprecedented small size limits, as well as analysis of color-color relationships between various classes of objects, lightcurve inversions and measurements of phase curves, leading to significant improvements in the understanding of physical properties of small bodies throughout the Solar System.

2 LSST Specifications

An evolving view of LSST specifications is available online in astro-ph/0805.2366 (Ivezic et al. 2008). The current design, optimized to meet the four main science drivers described above, includes a 9.6 sq degree field of view with a 0.2” per pixel plate scale (corresponding to a 3.2 Gigapixel camera). The primary mirror has a diameter of 8.4 m (6.5 m effective diameter), providing single visit 5σ limiting magnitudes of approximately $u = 23.9$, $g = 25.0$, $r = 24.7$, $i = 24.0$, $z = 23.3$, and $y = 22.1$. The telescope will be located at Cerro Pachon in northern Chile.

Simulations of the observing cadence are ongoing. In order to reach the required coadded limiting magnitudes in each band, the mean number of expected visits to field pointing within the LSST sky coverage will be 70, 100, 230, 230, 200 and 200 in u, g, r, i, z, and y, respectively. These visits will be spread throughout the ten year survey timespan. Each visit consists of a pair of 15 second exposures; each field pointing is visited twice within an hour in order to detect and identify quickly moving objects. On average, each field is revisited (twice) every 3 nights, throughout the window of visibility in each year, providing observations over a range of solar elongations.

Expected astrometric accuracy for individual LSST measurements is about 30 mas rms in each coordinate at $r = 23$ and 74 mas rms at $r = 24$. Expected photometric accuracy is 0.02 magnitudes at $r = 22$ for individual visits and 0.04 at $r = 23$. These levels of accuracy will be sufficient to provide high quality orbits, colors, rotation periods, and phase curves for vast numbers of Solar System objects.

3 LSST Inventory of the Solar System

The catalogs produced by LSST will include more than 80% of the potentially hazardous asteroids (PHAs) larger than 140m in diameter within the first 10 years of LSST operation (see Fig. 1, millions of main-belt asteroids (MBAs) and perhaps 20,000 TransNeptunian Objects (TNOs). MBAs could be detected down to size limits of 100 m and TNOs down to < 100 km in individual images. Proposed specialized deep observing sequences could easily detect TNOs down to 10's of km in diameter over a limited set of field pointings covering about 60 square degrees. These limits are illustrated in Fig. 2.

Observing fields over a wide range of ecliptic latitudes will provide improved characterizations of the inclination distribution of all classes of Solar System objects, but is particularly important for constraining the poorly understood relationship between various cometary families (Jupiter family comets, Halley type comets, and long period comets) and their source populations, which include the TNOs and inner and outer Oort cloud. Long period comets will be detected at larger distances than previously possible, constraining models of the Oort cloud and its formation. With the large number of objects expected in the catalogs, it will likely be possible to observe a pristine comet start outgassing on its first journey into the inner solar system.

Within the asteroid belt, derivation of proper elements for main belt and Trojan asteroids will allow ever more resolution of asteroid families and their size-frequency distribution, as well as the study of the long-term dynamics of the individual asteroids and the asteroid belt as a whole. With the high precision astrometry produced by LSST, masses for the largest 100 or so asteroids can be estimated from the perturbation of other asteroid orbits.

High-quality multi-color *ugrizy* data obtained for a substantial fraction of objects can be used to establish relationships between different populations of small bodies, such as irregular satellites and asteroid or TNO classes. Trends in color and dynamical history can be constrained. This will also enable taxonomic classification of asteroids and enable estimates of asteroid diameter with rms uncertainties of 30%.

With the addition of light-curve information, rotation periods and phase curves can be measured for large fractions of each population, leading to new insight on physical characteristics. Photometric variability information, together with sparse lightcurve

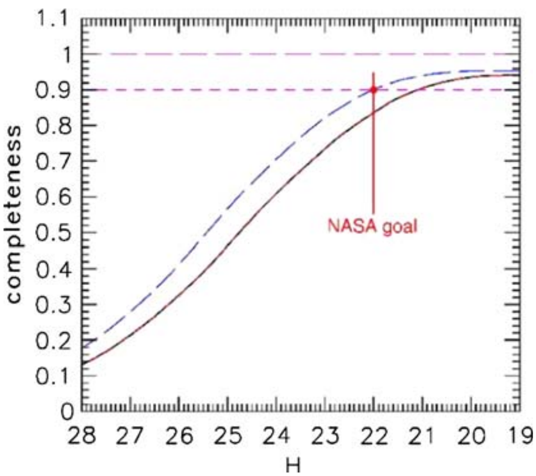

Fig. 1 Completeness of the LSST survey for PHAs brighter than a given absolute magnitude; H = 22 mag is equivalent to a typical 140 m asteroid. The lower solid curve indicates the completeness reached in a 10-year baseline survey. The upper dashed curve results from spending 15% of the observing time in an NEO optimized mode and running the survey for 12 years, meeting the 90% completeness level for 140 m objects mandated by the US Congress. Adapted from (Ivezic et al. 2008)

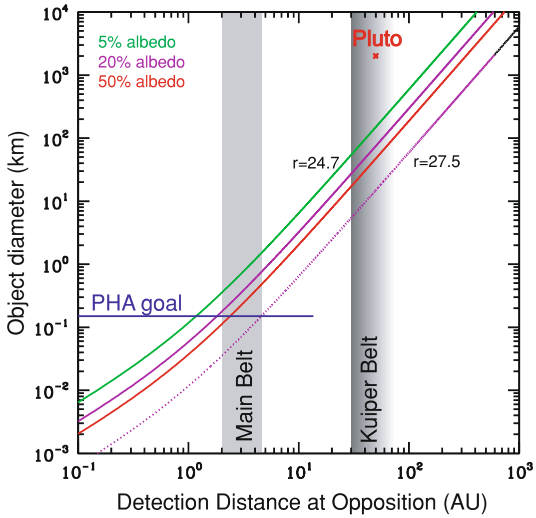

Fig. 2 LSST detection limits for solar system objects near opposition, for various albedos and the typical LSST single-visit limiting magnitude of $r = 24.7$. Proposed deep observing sequences could reach $r = 27.5$ and detect TNOs down to 10's of km in diameter. Adapted from (Jones et al. 2007)

inversion, will allow spin state and shape estimation for up to two orders of magnitude more objects than presently known. This will leverage physical studies of asteroids by constraining the size-strength relationship, which has important implications for the internal structure (solid, fractured, rubble pile) and in turn the collisional evolution of the asteroid belt. Similar information can be gained for other solar system bodies.

4 Conclusion

By providing comprehensive catalogs, including data on colors and photometric variability, on small bodies throughout the Solar System, LSST can bring our understanding of these populations together into complete picture. Rare or previously unknown classes of objects can be fully characterized. Size distributions for NEOs, MBAs, Trojans, Centaurs, TNOs and comets can be compared down to unprecedented small size limits, looking for comparable or unexplained breaks in these size distributions. Color relationships of different populations can be used in addition to orbital distributions to help constrain models of the formation of the Solar System. Physical characteristics which influence the orbital evolution of asteroids can be understood and accounted for. The inventory of the small bodies produced by LSST will provide a significant step forward in understanding the formation and evolution of the Solar System.

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