Large Synoptic Survey Telescope

Mapping the Solar System with the LSST

Z. Ivezic (University of Washington) M. Juric (Princeton University), R. Lupton (Princeton University), A. Connolly (University of Pittsburg), J. Kubica (University of Pittsburg),   A. Moore (University of Pittsburg), A. Harris (Space Science Institute) , T. Bowell (Lowell Observatory), G. Bernstein (University of Pennsylvania), C. Stubbs (Harvard University)

The currently considered LSST cadence, based on two 10 sec exposures, may result in orbital parameters, light curves and accurate colors for over a million main-belt asteroids (MBA), and about 20,000 trans-Neptunian objects (TNO). Compared to the current state-of-the-art, this sample would represent a factor of 5 increase in the number of MBAs with known orbits, a factor of 20 increase in the number of MBAs with known orbits and accurate color measurements, and a factor of 100 increase in the number of MBAs with measured variability properties. The corresponding sample increase for TNOs is 10, 100, and 1000, respectively. The LSST MBA and TNO samples will enable detailed studies of the dynamical and chemical history of the solar system. For example, they will constrain the MBA size distribution for objects larger than 100 m, and TNO size distribution for objects larger than 100 km, their physical state through variability measurements (solid body vs. a rubble pile), as well as their surface chemistry through color measurements. A proposed deep TNO survey, based on 1 hour exposures, may result in a sample of about 100,000 TNOs, while spending only 10% of the LSST observing time. Such a deep TNO survey would be capable of discovering Sedna-like objects at distances beyond 150 AU, thereby increasing the observable Solar System volume by about a factor of 7. The increase in data volume associated with LSST asteroid science will present many computational challenges to how we might extract tracks and orbits of asteroids from the underlying clutter. Tree-based algorithms for multihypothesis testing of asteroid tracks can help solve these challenges by providing the necessary 1000-fold speed-ups over current approaches while recovering 95% of the underlying asteroids.

The Potential of LSST for Solar System Studies

LSST, with its unprecedented power for discovering moving objects, will make a giant leap forward in the studies of the dynamical and chemical history of the Solar system. LSST will improve the available data in several ways:

1. A large increase (about a factor of ten) in the number of detected objects: LSST will detect over a million Solar system objects (see Figure 1, bottom left)
2. LSST will be complete for objects about a factor of three smaller than the completeness limit of existing surveys ($V \sim 24$, or roughly 100 m objects in the main asteroid belt, or a 1000 km object at 130 AU, see Figure 2, bottom right)
3. LSST will measure accurate colors for the majority of detected moving objects, thereby allowing studies of their surface chemistry, its evolution with time, and of dynamical (collisional) evolution (see Figures 3 and 4, top right)
4. Orbital parameters will be determined for practically all objects, thereby increasing the sample of objects with both orbital parameters and colors by over a factor of twenty compared to the current state-of-the art
5. The variability information, which carries important information about the physical state of an asteroid (e.g. solid body vs. a rubble pile, Pravec & Harris, 2000) will be available for the majority of objects, thereby increasing the sample size by over a factor of hundred. These new data will constrain the size-strength relationship, which is a fundamental quantity that drives the collisional evolution of the asteroid belt.
6. LSST will provide a highly complete (~90%) census of potentially hazardous asteroids to a small size limit (~300 m). There is a 1:30 chance that LSST will discover an asteroid larger than 300 m which will strike Earth in the next 1000 years (roughly the current limit for sufficiently accurate orbit prediction); note that this estimate reflects the chance that such an object indeed exists, and not the LSST completeness.

Fig. 1.— (right) **The Cumulative Counts of Main-belt Asteroids on the Ecliptic,** as measured by the SDSS for $r < 21.5$ (Ivezić et al. 2001), and extrapolated to $r = 24$ (this extrapolation is supported by a recent Subaru survey of 3 deg^2 which finds a density of 290 deg^{-2} for $R < 24.4$, Yoshida et al. 2003). Taking into account the ecliptic latitude distribution, shown in the insert, the effective sky area is ~6,000 deg^2, and implies that **LSST will discover and determine orbits for over a million main-belt asteroids.**

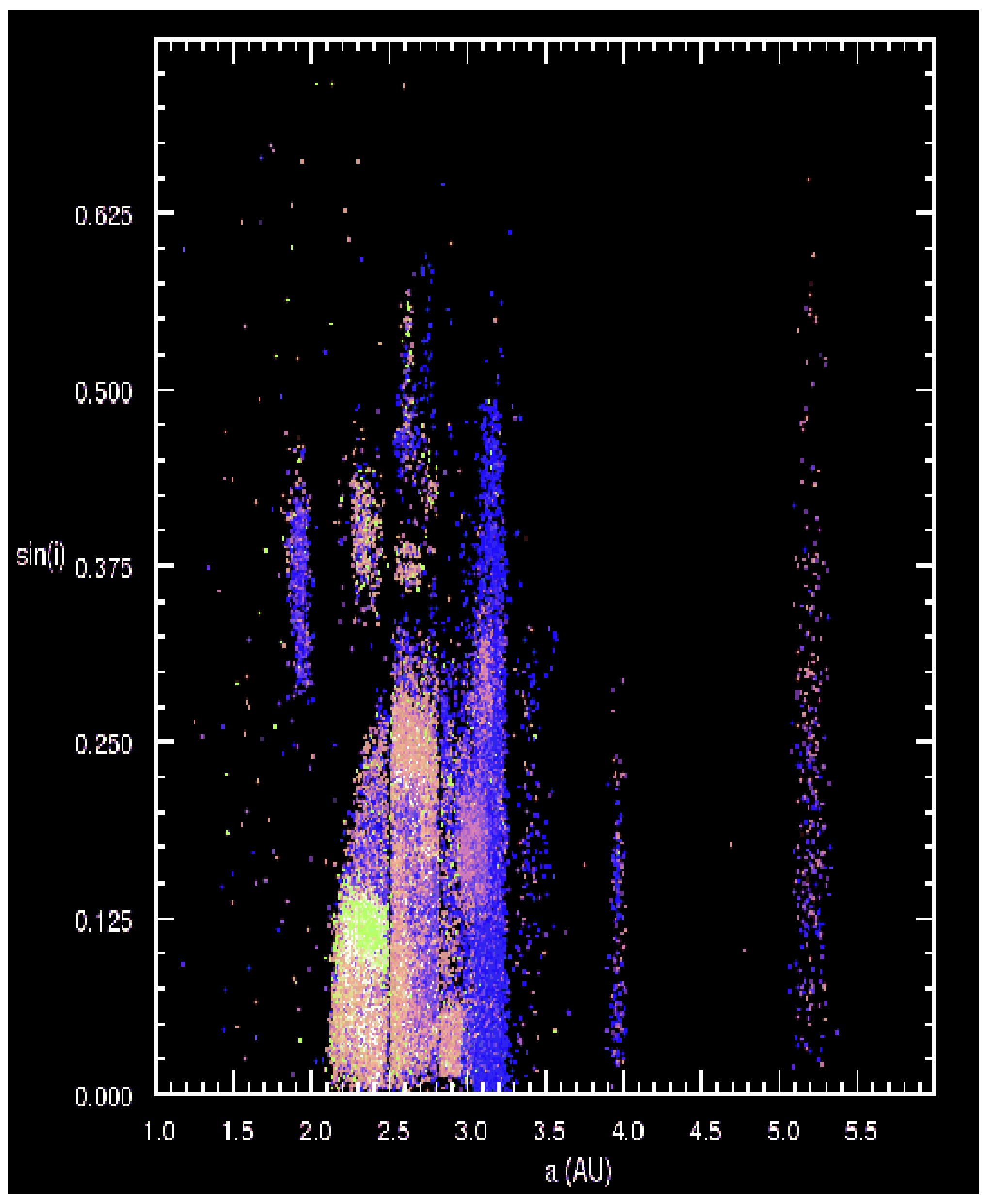


Fig. 3.— **A Map of the Solar System** The figure shows distribution of 43,000 asteroids from the SDSS Moving Object Catalog (see http://www.sdss.org/science/index.html) in the plane spanned by the orbital inclination and semi-major axis (approximately, the x axis is proportional to the distance from the Sun, and y axis is proportional to the distance from the orbital plane). The dots are colored according to their measured SDSS colors (Ivezić et al. 2002). Note the rich dynamical/chemical structure; e.g. distinctively colored clumps in the main asteroid belt ($2 < a < 3.5$), and a correlation between the color of Jupiter's Trojan asteroids ($a \sim 5.2$) and their inclination (Szabo et al. 2005, in prep.). **LSST will provide a sample over 20 times larger than shown in this figure, and will extend this map out to $a \sim 100$ AU.**

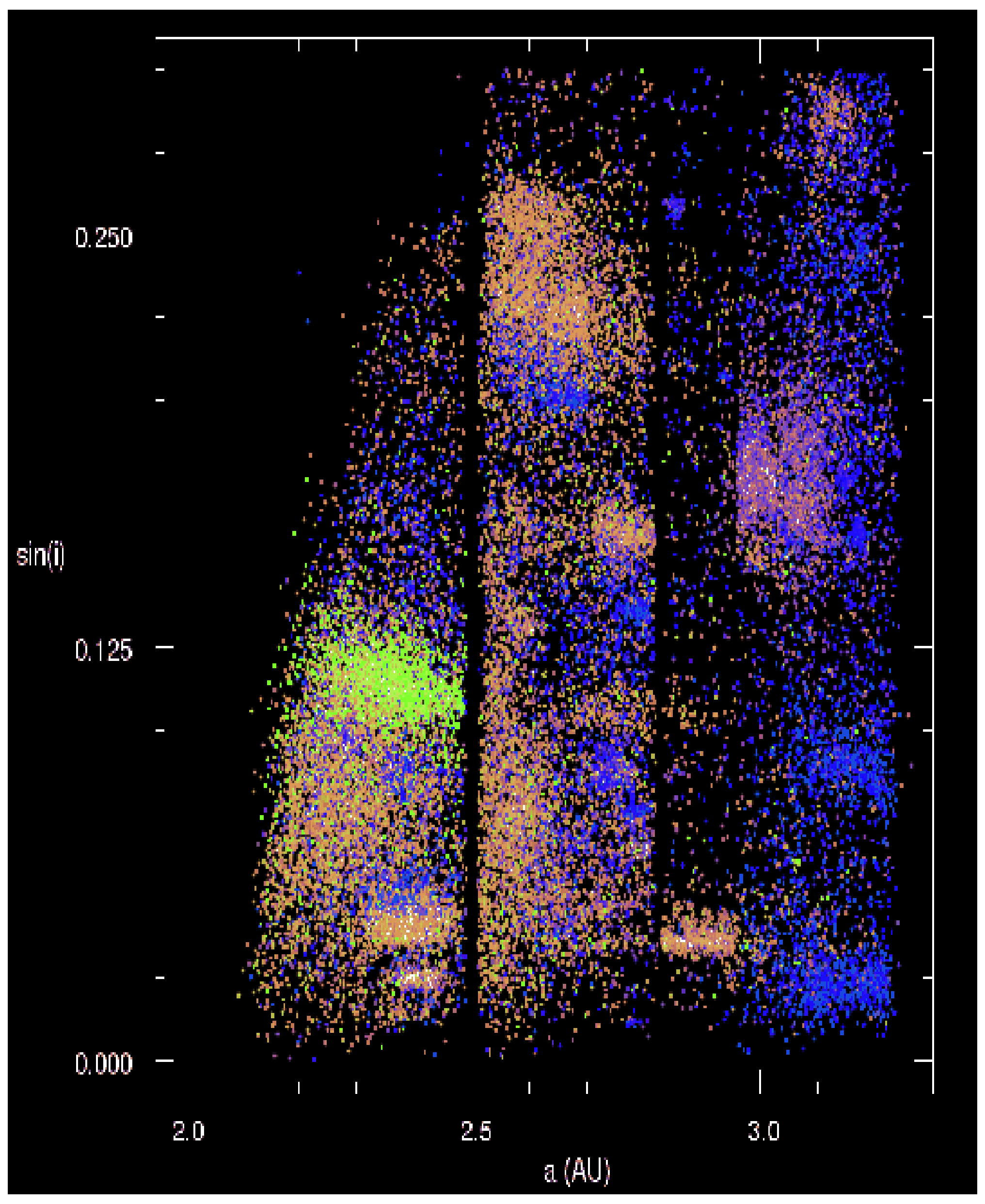
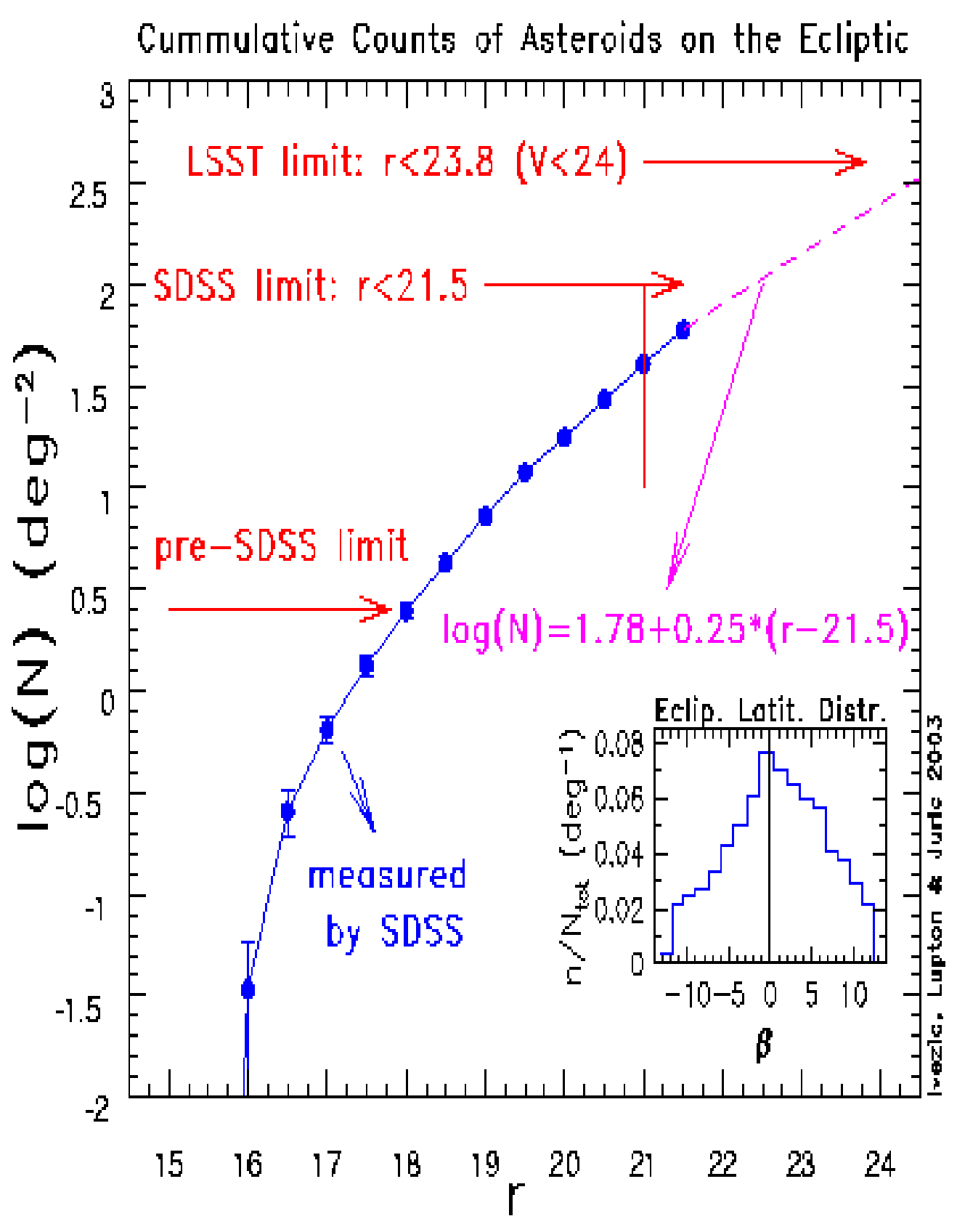


Fig. 4.— **The Dynamical-Chemical Correlation for Main-belt Asteroids** Similar to the figure to the left, except that here proper inclination and semi-major axis (which remove perturbations caused by planets and thus better reveal dynamical clustering than observed orbital elements) are shown for 33,000 asteroids from the SDSS Moving Object Catalog, which have proper orbital elements computed by Milani & Knežević (1992). The clusters of points are asteroid dynamical families, proposed to represent remnants of larger bodies destroyed in collisions (Hirayama 1918). The SDSS data provide strong support for this hypothesis because families exhibit strong color segregation, suggesting a common origin. **LSST will extend this map to a three times smaller size limit, and will also provide structural information by measuring light curves for each object.**



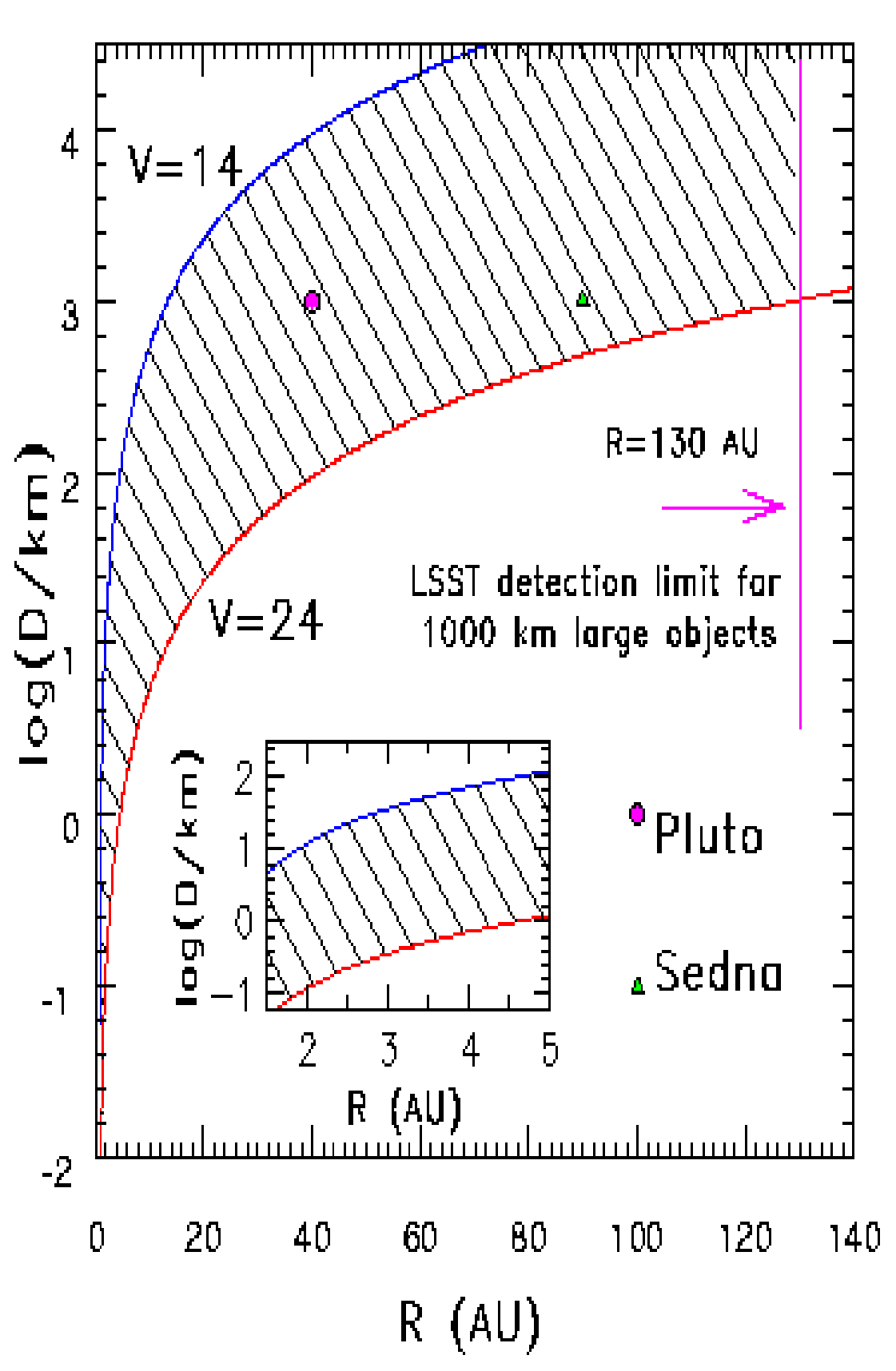


Fig. 2.— **The size range of the Solar system objects which LSST will detect** will be limited by detector saturation ($V \sim 14$, blue curve) and the faint limit ($V \sim 24$, red curve). LSST will be capable of discovering a $D \sim 1000$ km object as distant as 130 AU, and will detect objects as small as 100 m at the inner edge of the main asteroid belt (see the insert). Currently, **little is known about the outer regions of the Solar System that LSST will explore**; however, the recent discovery of Sedna suggests that the true edge of the Solar system may be much further than the orbit of Pluto (see the symbols).

REFERENCES

Hirayama, K. 1918, *Groups of asteroids probably of common origin*, AJ, 31, 185

Ivezić, Ž. *et al.* 2001, *Solar System Objects Observed in the Sloan Digital Sky Survey Commissioning Data*, AJ, 122, 2749

Ivezić, Ž. *et al.* 2002, *Color Confirmation of Asteroid Families*, AJ, 124, 2943

Milani, A. & Knežević, Z. 1992, *Asteroid proper elements and secular resonances*, Icarus, 98, 211

Pravec, P. & Harris, A.W., 2000, *Fast and Slow Rotation of Asteroids*, Icarus, 148, 12

Yoshida, F., *et al.* 2003, *Size and Spatial Distributions of Sub-km Main-belt Asteroids*, PASJ, 55, 701

The University of Arizona
Tucson Arizona
University of Washington
NOAO
Illinois
University of Illinois at Urbana-Champaign
Brookhaven National Laboratory
Research Corporation
UC Davis University of California, Davis
SLAC
Johns Hopkins University