Large Synoptic Survey Telescope

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End-to-end Tests of LSST Science Cases with Image Simulations: Rare Astrometric Targets and Ultra-faint Dwarf Galaxies

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The LSST is a multi-purpose observatory that will permit unprecedented exploration of a multitude of science topics and hundreds of individual science cases. These range from studies of asteroids in the Solar System to multiple probes of the nature of dark energy (LSST Science Book, Version 2.0, arXiv:0912.0201). The LSST Image Simulation framework provides an opportunity for a quantitative, end-to-end, test of feasibility of many of the proposed studies. Especially suitable are those that only require the capabilities currently present in LSST Data Management software stack, and can be tested with a relatively small number (tens to hundreds) of simulated visits. Here we present two such tests: the recovery of high proper motion astrometric targets based on realistic 10-year simulations of a single LSST sensor, and simulations of observations of four ultra-faint dwarf satellite galaxies embedded in a realistic Milky Way background. The results improve our understanding of the LSST software and the expected performance of the system, and expose areas of research needed to achieve particular science goals.

The LSST Image Simulation framework (ImSim; see poster by Peterson et al.) is a powerful tool used to test and validate the capabilities of LSST data management software well in advance of first light.

This same framework also provides an opportunity for quantitative end-to-end tests of many of the scientific studies proposed for LSST by, in effect, "doing science" with the simulations. Such experiments improve our understanding of LSST software and the expected performance of the system, as well as identifying areas of research needed to achieve particular science goals.

Astrometric Easter Eggs

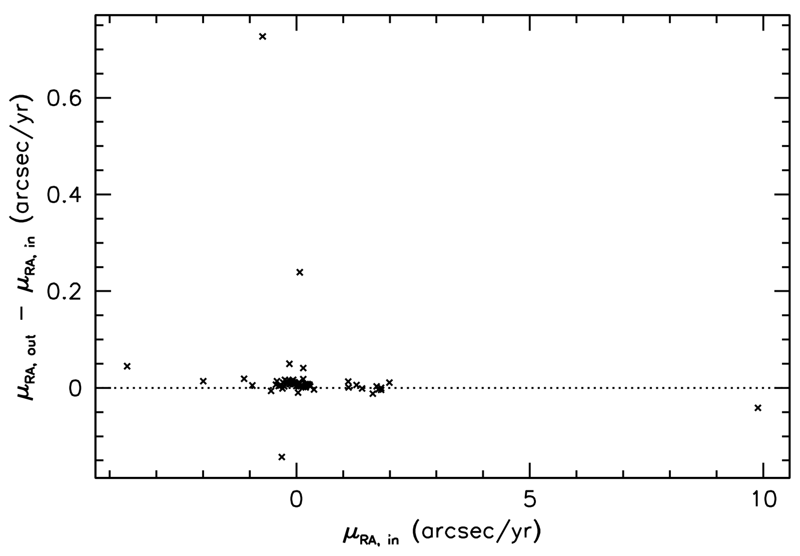
If they exist, LSST must not miss any large parallax or high proper motion objects. These are likely to be faint or very low-mass nearby stars that have gone undetected by existing surveys and are of considerable scientific value.

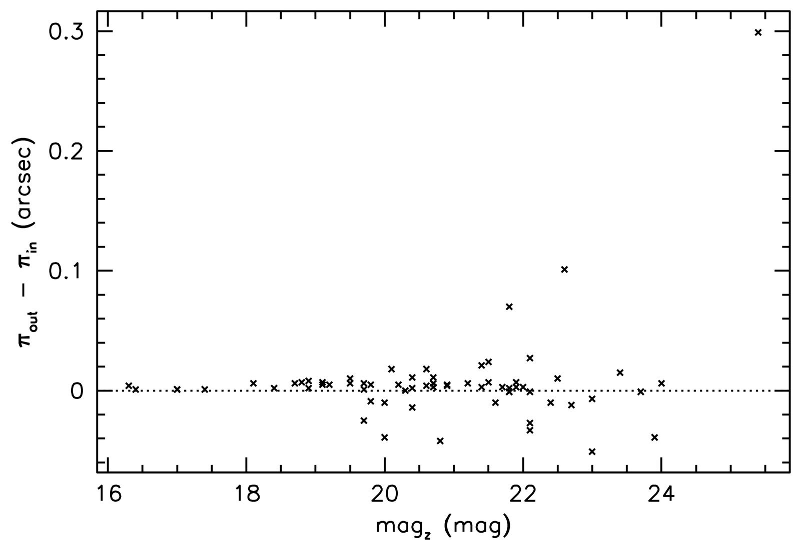
Since only a handful of such stars exist in the entire sky, they're unlikely to be generated and found in any single simulated visit. We've therefore inserted, by hand, 101 special fast-moving objects ("astrometric Easter eggs") into the ImSim star field (Raft 2,2; Sensor 1,1), and simulated them over 10 years with a realistic LSST cadence.

This served as a test of a large number of astrometric properties:

- Are there objects too big or too fast to find using normal software?
- Test systematic errors from refraction, details of cadence, etc.
- Test impact of correlations of hour angle, parallax factor in cadence.
- Compare data management (DM) and other processing and correlating algorithms.
- Test if we achieve accuracy levels mandated by the LSST Science Requirements Document.

The results are shown in figures to the right. **The top figure** demonstrates that existing LSST software is capable of finding and measuring even very high proper motion objects (10 arcsec/yr). **The bottom figure** shows the accuracy of parallax measurements and their dependence on magnitude; even at faint magnitudes, the high-parallax objects were reliably recovered (to ±2 mas for z<21 and ±4 mas for z<24 in isolated, high signal-to-noisesources; note that blended sources have larger uncertainties).





Streamlining Future Tests

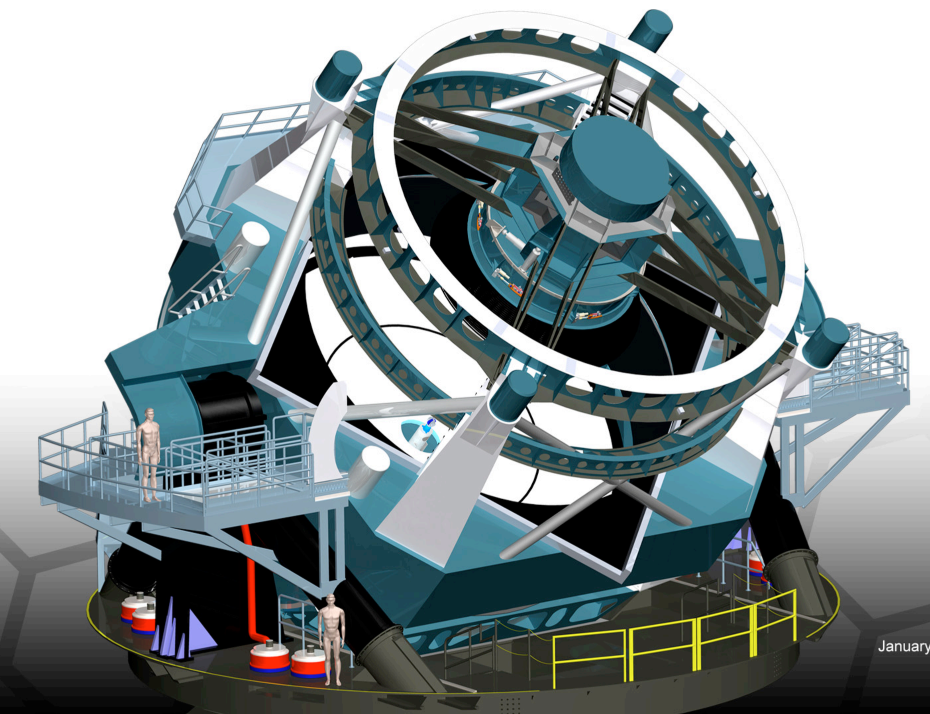
The simulations and analyses presented here are a result of work by the LSST Science Collaborations, the LSST Image Simulation team, and the Data Management team.

Other examples of such efforts include explorations of time variability of strongly lensed quasars and building template libraries of variable objects.

In the near future, we plan to introduce a streamlined and automated process by which Science Collaborations' members will be able to submit catalogs of special sources for inclusion in LSST image simulations. We will provide the necessary documentation and tools to prepare the input catalogs in the formats used by the Image Simulation team.

User-submitted catalogs will be merged with LSST's standard "universe model", and simulated and reduced as part of weekly data processing runs. The results (images and output catalogs) will be delivered back to the user who requested them.

We hope this will enable the community to test in detail the feasibility of their science cases for LSST, while providing the project with valuable feedback.



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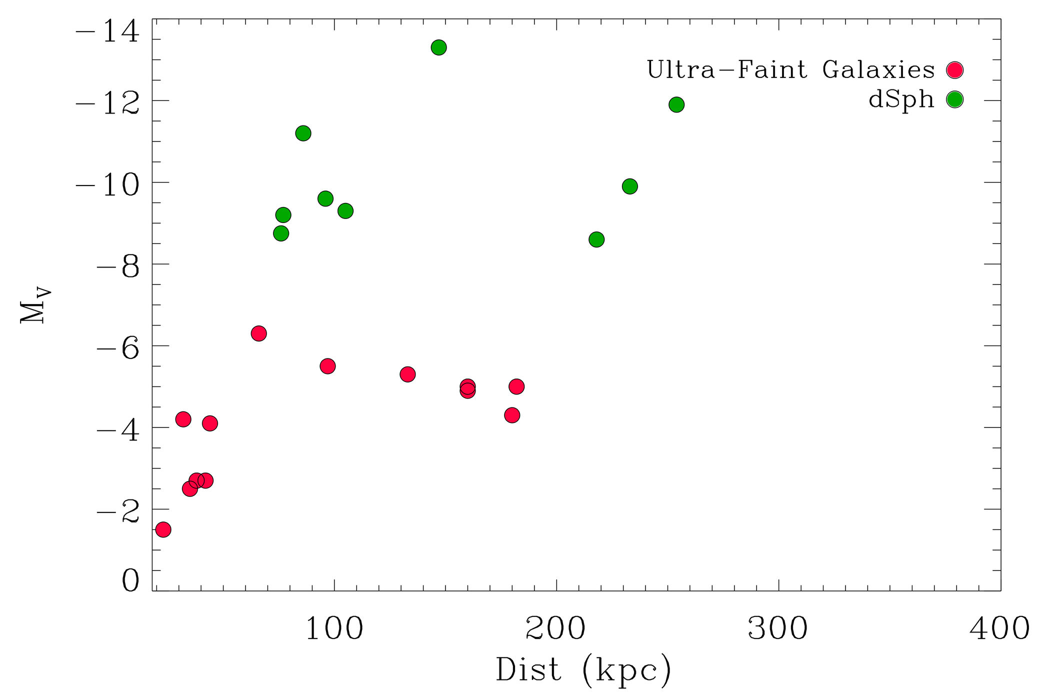
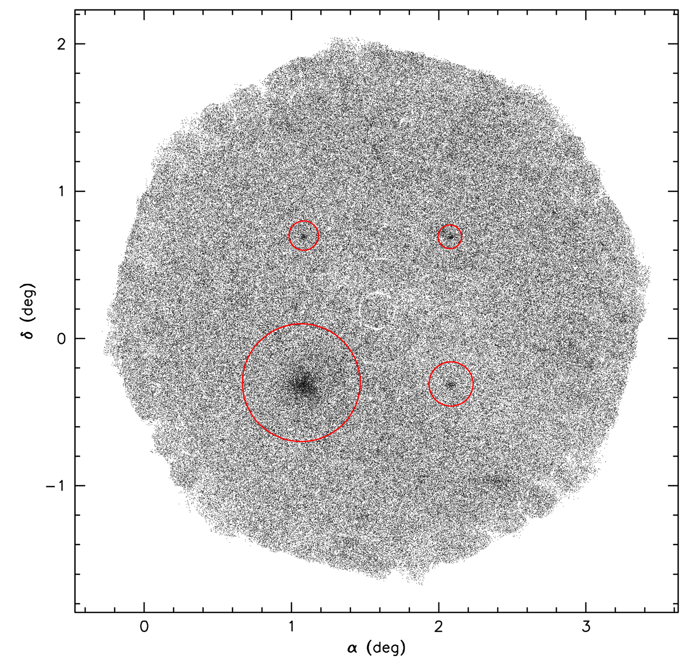
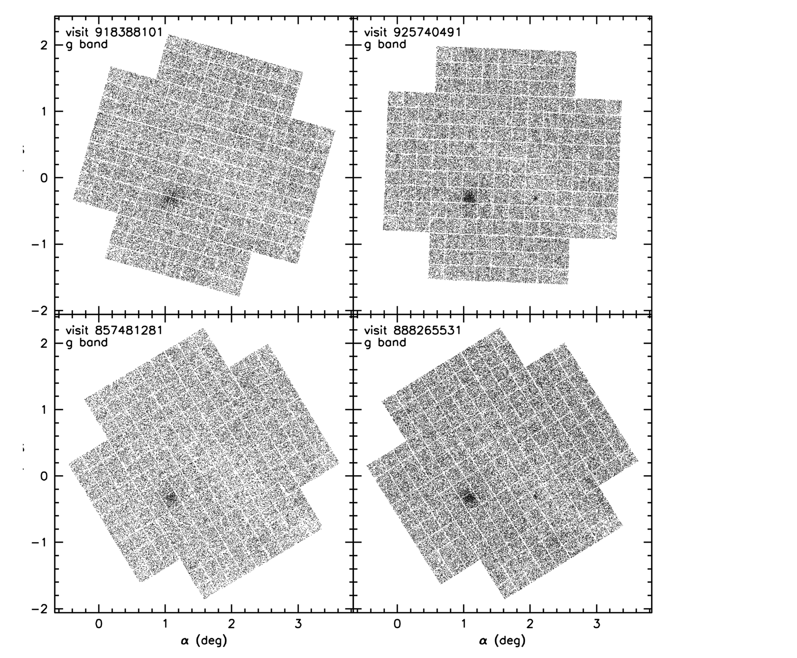
Ultra-faint Dwarf Galaxies



Ultra-faint dwarf galaxies: Since 2004, more than 25 dwarf galaxy companions to the Milky Way and M31 have been discovered that are less luminous than any galaxy known before. These "ultra-faint" dwarfs have absolute magnitudes of only -2 mag < M_V < -8 mag (L_V ~10^3 − 10^5 $L_\odot$, a range extending below the luminosity of the average globular cluster) and can be detected only as slight overdensities of resolved stars in deep, uniform imaging surveys.

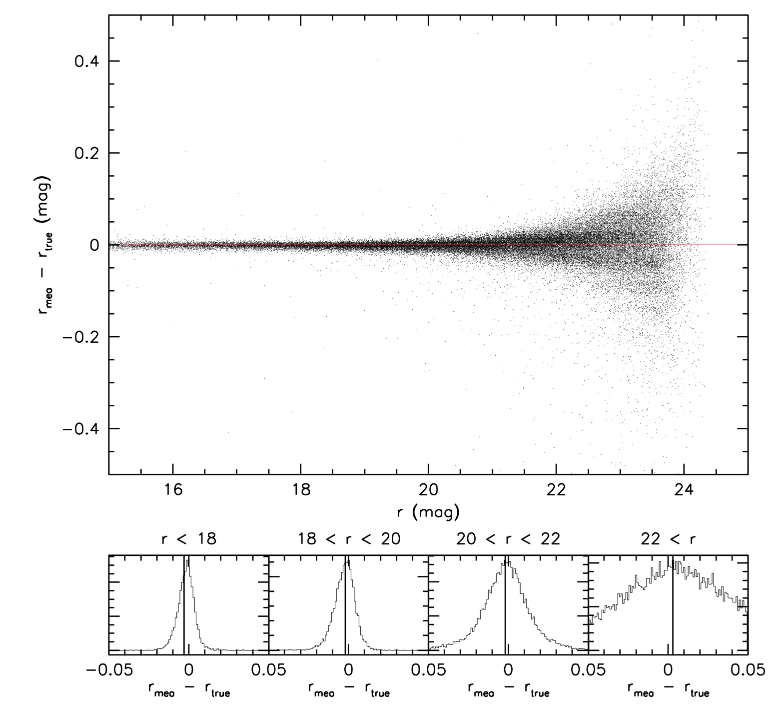
LSST should be able to detect them throughout the Milky Way's virial volume.



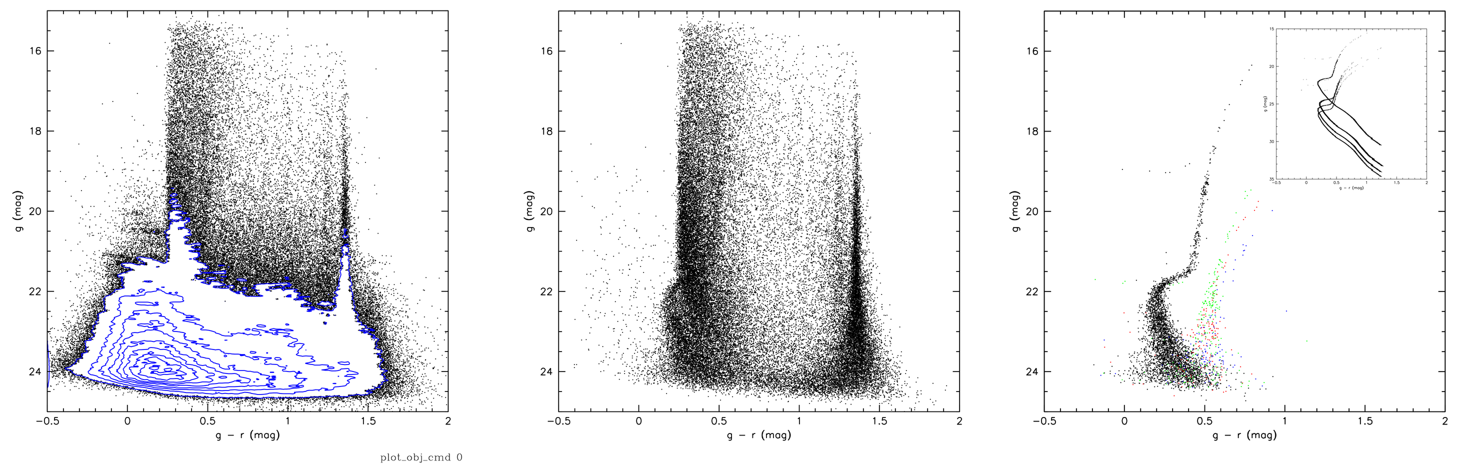


Top left: We inserted four mock galaxies into a single LSST field at distances of D = 44, 150, 225, 300 pc. The galaxies are analogs of Coma Berenices ultra-faint dwarf (King profiles with r_c=54pc, r_t=255pc, Σ_0=5.47; Munoz et al. 2010). A total of 12 visits were simulated (4 visits in each of the g, r and i bands), and reduced using the LSST Data Management software stack. The sources detected in each of the visits were associated to unique objects, shown as dots in the top left panel. The locations of the dwarf galaxies have been circled.

Top right: Four of the twelve simulated visits. The gaps show the boundaries of LSST's Camera rafts and sensors.



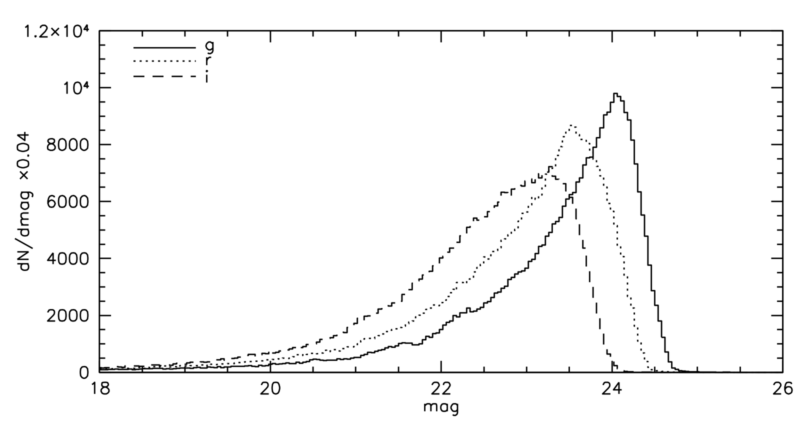
Above: The accuracy of LSST photometry. We have cross-matched the objects detected in simulated visits to the input ("truth") catalogs, and compared measured vs. true magnitudes for point sources. The current DM pipeline produces 2 mmag of bias and about 7 mmag RMS scatter at bright magnitudes. While not yet at the required levels, this is sufficient to test the capability to detect and characterize ultra-faint dwarf galaxies.



Above: The *g-r* vs. *g* color-magnitude diagrams of objects detected in the twelve simulated visits. In dense regions of CMD space, individual dots have been replaced by contours for greater clarity.

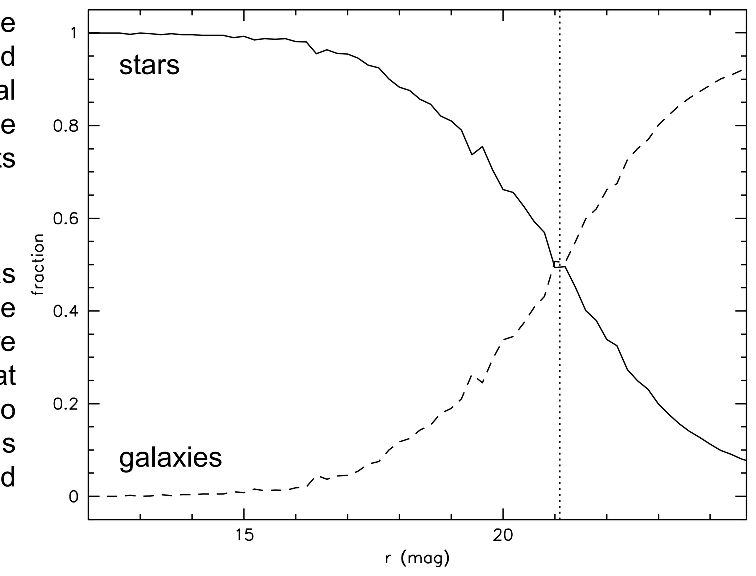
The panel to the left shows the CMD for all 397451 detected objects. At faint magnitudes, it is clearly dominated by galaxies. In the middle panel, we only show the stars, assuming perfect star/galaxy separation. The Galactic main sequence turnoff (MSTO) at *g-r~0.3* and the M-dwarf plume at *g-r~1.4* become clear. An additional main sequence, belonging to the closest ultra-faint dwarf (at *D=44pc*) is also apparent, with the MSTO around *g~22* mag.

Finally, on the right panel we show only the stars belonging to inserted dwarf galaxies, with the inset showing the input CMDs. The main sequence and the RGB of the dwarf at *D=44*pc are clearly visible, as is the RGB of the *d=150*pc dwarf.



Towards more realistic tests: The figures shown above use pre-existing knowledge about which object is a star and which is a galaxy. This information will be unavailable in real observations. Instead, star-galaxy separation will have to be inferred based on the morphology of an object and its spectrophotometric properties.

The figure to the left shows the total number of objects as a function of apparent magnitude in the simulated field, while the **figure to the right** shows the fraction of objects that are stars (solid) and galaxies (dashed line). It is clear that reliable star-galaxy separators will be needed if LSST is to discover distant and faint dwarf galaxies. The simulations such as the one presented here can be used to test and validate different approaches to star-galaxy separation.



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