Large Synoptic Survey Telescope

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The LSST Galaxies Collaboration: Nearby Groups and Clusters

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LSST will contribute to a wide variety of studies of galaxies, ranging from the Local Group to z > 5. As part of the science-planning effort in the LSST Galaxies Collaboration, we explore some of the contributions it will make to studies of groups and clusters of galaxies in the nearby Universe. Co-added images over 10 years will provide multi-band photometry of galaxies down to very low surface-brightness limits both within clusters and in their surrounding environments. This will make it possible to explore in great detail trends of color, size, surface brightness, and morphology with local environment. LSST time-series data will provide an inventory of novae, Cepheids, and long-period variables in the nearest clusters and groups of galaxies -- both within galaxies and in between galaxies. Cepheid variables in late-type galaxies, and surface-brightness fluctuations in early-type galaxies, will provide tests of group membership and help to delineate the three dimensional structure in very nearby groups and surrounding filaments. For more distant groups and clusters, nova rates will provide statistical confirmation of cluster membership for low-surface-brightness galaxies that are much too faint for spectroscopic redshifts.

I. THE DWARF GALAXY CENSUS

The census of dwarf galaxies surrounding the Milky Way now extends to absolute magnitudes -1.5 (Geha *et al.* 2008). There is a huge gap between this and the faint end of the SDSS or 2dFRS luminosity functions, which extend (at 50% completeness) to $M_R \sim -14.5$ (Blanton *et al.* 2005). Filling this gap are targeted surveys of nearby groups and clusters (e.g. Ferguson & Sandage 1991; Trentham *et al.* 2005). From these studies it is clear that the faint end of the luminosity function varies, or at least that the relative proportions of dwarfs to giants varies and that the morphology of the dwarfs depends on environment. However, given the sparse statistics of these surveys, and the extreme difficulty of measuring redshifts for low-surface-brightness dwarf galaxies, our understanding of the faint end of the luminosity function is still poor.

Low-mass halos are the first to collapse in hierarchical CDM models. A variety of physical processes influence their ability to cool and form stars. These include photo-ionization and heating from the first generation of stars, dissociation of molecular hydrogen, supernova winds, and ram-pressure stripping. Having a detailed census of low-luminosity galaxies as a function of environment should greatly improve our understanding of the relative importance of these processes.

DETECTION

Dwarf galaxies (dwarf spheroidals and dwarf ellipticals in particular) follow a relatively narrow size-magnitude relation. Nearby dwarfs will have larger sizes for their apparent magnitudes than the typical background galaxy. To get a rough indication of how well LSST can detect such low-surface-brightness galaxies, we have used the radius–absolute-magnitude relation from Woo et al. 2008 to compute radii versus apparent magnitudes (Fig 1).

These galaxies will appear against a sea of faint background galaxies. Figure 2 shows a simulation of dwarf galaxy images, assuming 50 LSST visits per band in *g,r*, and *i*, obtained in dark conditions. Dwarf galaxies with a range of distances and absolute magnitudes have been inserted into the images.

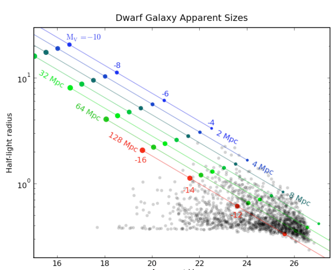

Figure 1 — The colored points and lines show the half-light radii for dwarf galaxies as a function of magnitude for distances ranging from 2 to 128 Mpc computed from the scaling relation of Woo et al. 2008. The grey points show the sizes of typical background galaxies measured from the simulation in Fig. 2. A dwarf galaxy with M_v= -4 should be visible and distinguishable from the background out to ~ 4 Mpc; a dwarf with M_v= -14 at 128 Mpc will be larger than most of the background galaxies of the same apparent magnitude.

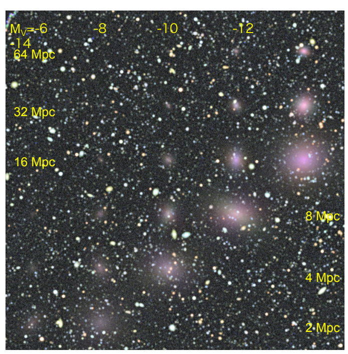

Figure 2 — Dwarf spheroidal galaxy visibility. Dwarfs of various distances and absolute magnitudes have been inserted into a simulated LSST image. The simulation is for 50 visits (1500s) each in dark time with *g,r,i*. The background image is from the GOODS survey, convolved with a 0.7" PSF with appropriate noise added. Sizes and colors for the dwarfs are computed from the size-magnitude and mass-metallicty relations of Woo *et al.* 2008 assuming a 10 Gyr old population.

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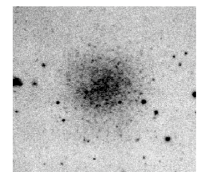


DISTANCES

For dwarfs that are too faint for spectroscopy, surface-brightness fluctuations (Fig. 3) can provide an indication of the distance. This can be used to confirm cluster or group membership, or can be used as part of the criteria for high-resolution follow-up observations with HST or JWST.

Figure 4 shows the absolute magnitude limits, limiting distance moduli, and expected number of galaxies for which LSST can determine a surface-brightness fluctuation magnitude to a precision of 0.5 mag.

For nearby star-forming dwarfs, LSST-detected Cepheids can also be used for distance estimates.

Figure 3 — Surface-brightness fluctuations in a dE galaxy in the Leo I group at 10 Mpc from Flint et al. 2001. This is a 10-min I-band exposure from Keck in 0.5" seeing. (Reproduced from ApJ. Supp.)

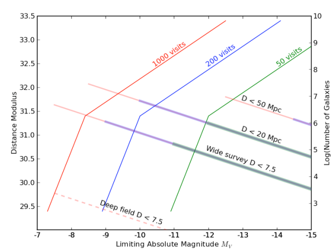


Figure 4 — LSST Surface-brightness fluctuations. The curves moving upwards to the right show distance modulus vs. absolute magnitude for SBF determination to a precision of 0.5 mag for 50, 200, and 1000 *r*-band visits. This is derived by scaling from the realistic image simulations of Mieske, Hilker & Infante 2008. These simulations include the effects of photon statistics, resolution and image size. The curves moving upwards to the left show the expected number of galaxies in a 20000 square-degree survey (solid lines) or a 10 square-degree deep-drilling field with 1000 visits (dashed line near the bottom). Numbers are based on the luminosity function of Croton *et al.* (2005).

II. STREAMS, DIFFUSE LIGHT, AND INTRACLUSTER STARS

Mergers and interactions over time should strip stars from galaxies, forming tidal tails and streams that eventually disperse into a diffuse stellar halo interspersed between the galaxies in groups and clusters (Fig 5). For halos more massive than ~ $10^{13} M_\odot$, more than 10% of the light should come from intra-group stars.

With control over sky-level fluctuations provided by multiple exposures in different observing conditions, and the possibility of extensive calibrations and modeling of scattered light, LSST should be capable of providing a systematic survey of low-suface-brightness diffuse features around nearby galaxies.

Studies of diffuse light with LSST will include detection and characterization of individual streams, as well as stacking experiments with groups and clusters (after masking galaxies to much fainter limits than possible with SDSS).

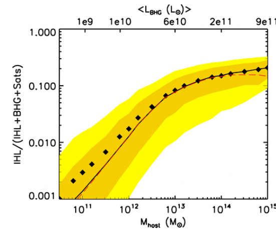


Figure 5 — Fraction of the total stellar mass expected to reside in intra-halo light (IHL) as a function of the total (dark-matter + baryonic) mass of the host halo, from Purcell *et al.* (2007). (Reproduced from ApJ.)

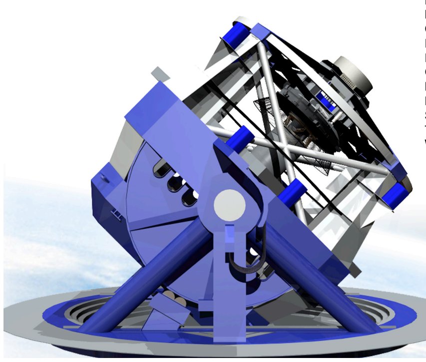
NOVAE

Novae will provide a powerful way to probe diffuse light. Shara (2006) estimates that LSST will obtain good light curves and hence distance estimates for ~50 "tramp" novae per year within 40 Mpc if the diffuse stellar mass is 10% of the stellar mass in galaxies.

It is interesting to contemplate putting one of the LSST "deep drilling" fields on a nearby cluster of galaxies. Consider the Fornax Cluster for example (distance 19 Mpc). The total stellar mass is ~$2.3 \times 10^{11} M_\odot$. If 10% is in intra-cluster light, we can expect 23 intra-cluster novae per year. Observing 9 out of 12 months for 10 years would yield 172 intra-cluster novae.

CONCLUSIONS

LSST offers tremendous promise for exploring the faint, low-surface-brightness parts of the nearby universe. In the very nearby universe (< 5 Mpc), we expect dSph galaxies as faint as M_V = -4 to be detectable and distinguishable from background objects. Based on an extrapolation of the field-galaxy luminosity function (Croton *et al.* 2005) the LSST wide survey should reveal ~10^5 dwarf galaxies with M_V < -9 and distance D < 7.5 Mpc, which will be revealed as local by virtue of surface-brightness fluctuations. Low-surface brightness streams and intra-group stars will be revealed both in diffuse light and by intra-cluster novae.



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