Large Synoptic Survey Telescope

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Galaxy Evolution with LSST

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The key goal of the LSST Galaxies Working Group is to measure the multivariate properties of the galaxy population including trends with redshift and environment. This includes observed galaxy properties (luminosities, colors, sizes, and morphologies) as well as derived galaxy properties (stellar masses, ages, and star formation rates) and how the joint distribution of these galaxy properties depends on redshift and environment as measured on a wide range of scales. Galaxy formation is inherently stochastic, but is fundamentally governed by the statistical properties of the underlying dark-matter density field. Determining how the evolving multivariate galaxy properties and scaling relations depend on this density field, and on the distribution and evolution of dark matter halos, will connect the results of large surveys to theoretical models of structure formation and galaxy formation.

Galaxy Statistics: LSST Volume, Limits, Numbers

- full-depth LSST 5σ pt. source detection limits
  u ~26.1, *g* ~27.4, *r* ~27.5, *i* ~26.8, *z* ~26.1, *y* ~24.9 AB
- $>10^{10}$ galaxies detected to z ~ 6
- $>10^{9}$ galaxies detected at z > 2
- $>10^{7}$ galaxies detected at z > 4.5
- structural measurements and *ugrizy* photometry for 4×10^9 galaxies at z < 1.5

- dwarf galaxies detected to 4 Mpc at $M_V \sim -4$; to 128 Mpc at $M_V \sim -14$
- L* galaxies ($M_B \sim -21$) detected to z~5 over 10^{12} Mpc^3 co-moving volume (Fig. 1)

- 'deep drilling fields' will be ~10x deeper than standard LSST over ~10 LSST pointings with 5σ pt. source limits *ugriz* ~28.0, *y* ~26.8

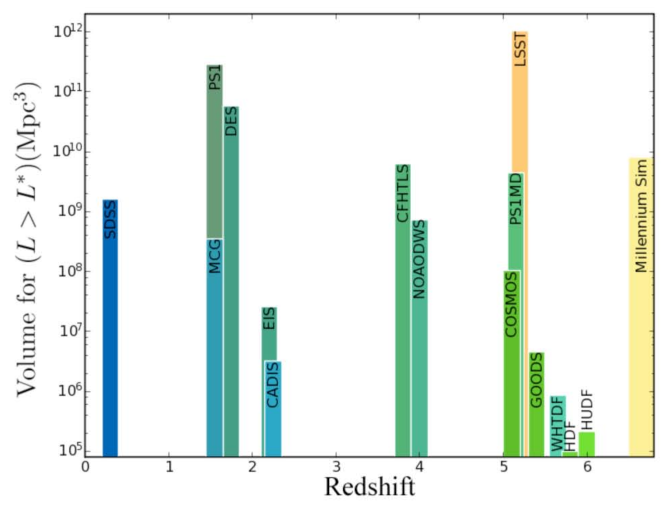


Fig. 1. Co-moving volume within which each survey can detect an L* galaxy ($M_B \sim -21$) assuming a typical Lyman break galaxy spectrum. LSST encompasses ~ 2 orders of magnitude more volume than current or near-future surveys.

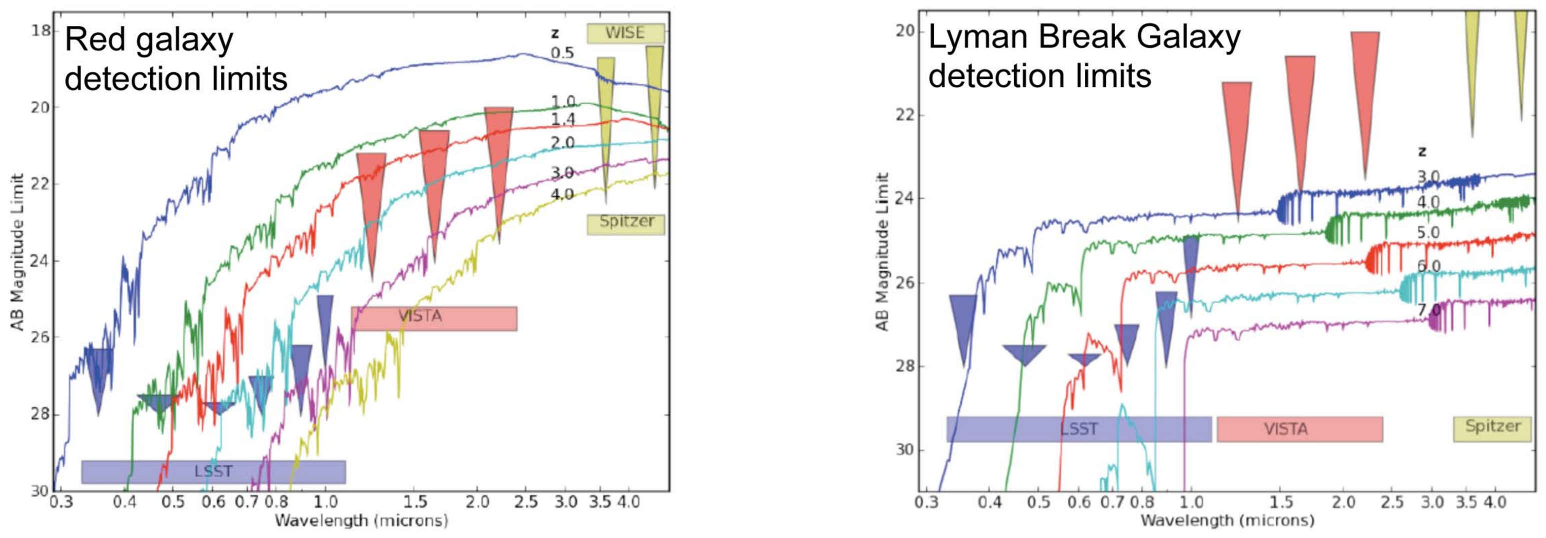


Fig. 2. *Left:* The spectrum of a fiducial red galaxy as function of redshift [Maraston 2005, Salpeter IMF, $Z_\odot$, $z_{form}=10$, $\tau_{SF}=0.1$ Gyr, $M_B=-20.5$ at z=0]. ***Right:* The spectrum of a fiducial Lyman break galaxy as function of redshift** [Bruzual & Charlot 2003, Salpter IMF, $Z_\odot$, age=0.2 Gyr, constant SFR, Calzetti+ 2001 dust with $E_{(B-V)}=0.14$, normalized to L* at each redshift]. Magnitude limits are shown in optical for LSST (blue triangles), NIR for VISTA (red triangles), and mid-IR for WISE/Spitzer (yellow triangles). The top of the triangles show typical depth of wide surveys with areas ≥ 20,000 sq. degrees (LSST; VISTA Hemisphere Survey; WISE all-sky survey). The bottom of the triangles show depth expected for deeper surveys with areas ~ tens of sq. degrees (LSST deep drilling fields; VISTA VIDEO survey; Spitzer SWIRE).

Galaxy Sizes, Structures, and Mergers

- PSF ≤ 0.7" will allow galaxy size, bulge/disk ratio measurement at z < 0.6
- μ_{limit} ~ 27 mag per sq. arcsec in *riz*; will detect mergers with tidal features at z < 1
- $>10^8$ tidal tail mergers, $>10^6$ 'dry' mergers ⇒

will measure sizes, structure and merger rate vs. redshift, luminosity, color, environment.

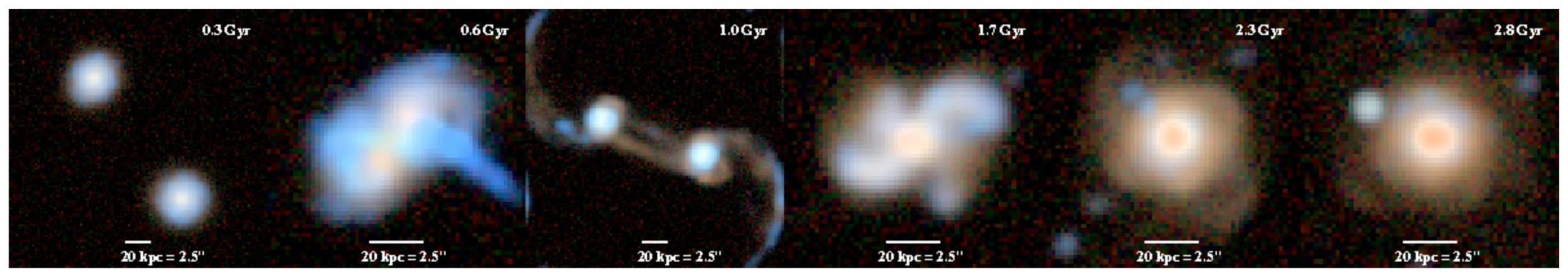
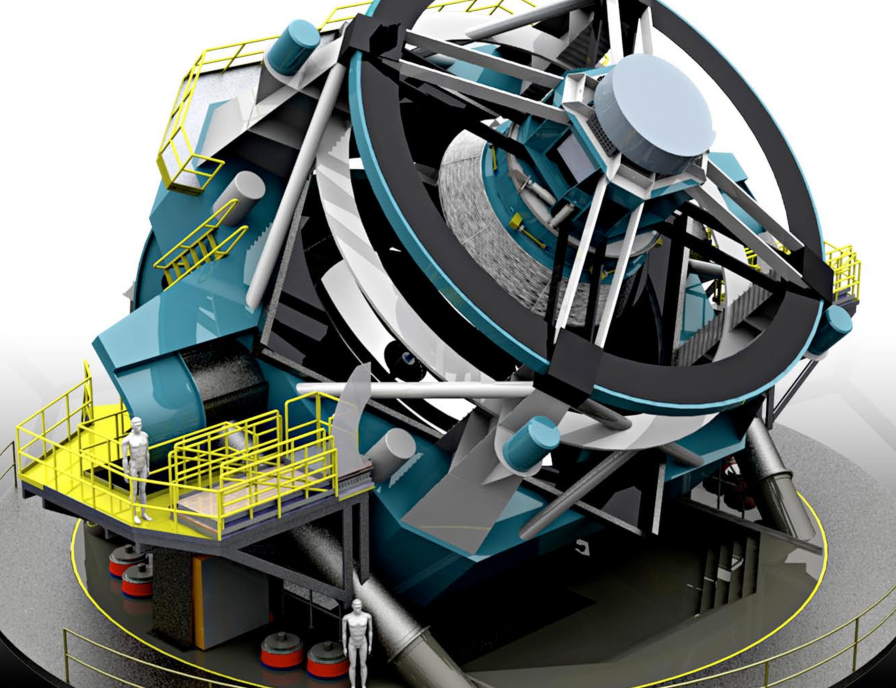


Fig. 5. A simulated *r-i-z* LSST image of a z~1 gas-rich equal mass disk merger (Lotz+ 2008). At t = 0.6 Gyr and 1.7 Gyr, strong blue distortions are visible on scales of a few arc-seconds. After the first pass (t = 1 Gyr), tidal tails are detectable at *i* < 27 mag per sq. arcsec. Faint shells, tidal features, and blue tidal dwarfs will be apparent at full LSST depth for up to a Gyr after the final merger (t = 2.3-2.8 Gyr).



Galaxies and their Dark Matter Halos

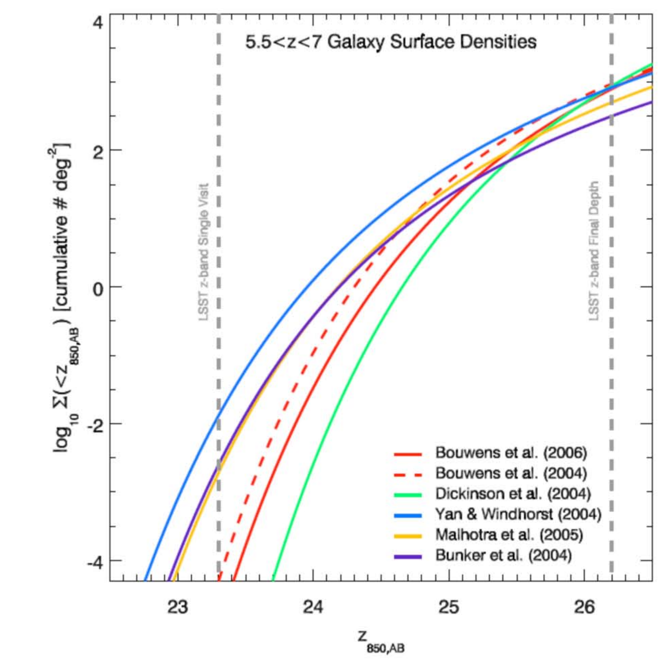


Fig. 3. LSST will greatly improve measurements of the bright end of the **z~6 LBG luminosity function**. The clustering of these rare objects will constrain the mass of their halos, and their association with z~6 quasars.

Measuring the spatial clustering of dark matter halos hosting galaxies over wide range of cosmic time will allow us to trace the evolution of galaxy populations from one epoch to another by identifying their progentior/descendent relationships.

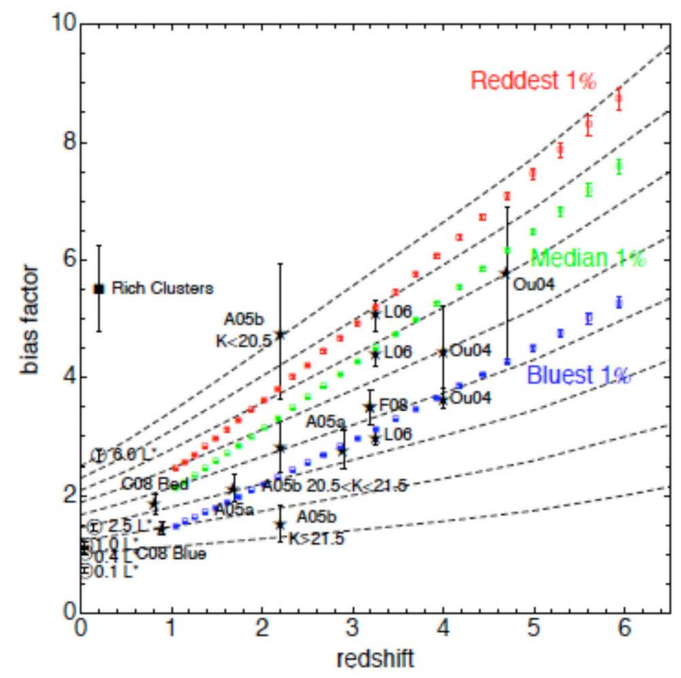


Fig. 4. Evolution of galaxy bias v. redshift for bluest 1%, reddest 1%, and median 1% of simulated LSST galaxy sample (blue, red, green points). Bias will be estimated from the angular two-point auto-correlation function ω(θ), and higher-order correlation statistics. Typical z~6 galaxies become massive z~2 galaxies, while blue z~6 galaxies become typical z~2 galaxies. The dashed lines are evolutionary tracks predicted by Sheth-Tormen conditional mass function. Black points are literature estimates of galaxy bias: z~0 galaxies from Zehavi+ 2005; rich cluster galaxies from Bahcall+2003; z~1 galaxies from Coil+ 2008 (C08); z~2 galaxies from Adelberger+ 2005a, 2005b (A05a, A05b); z~3 LBGs from Francke+ 2008 (F08), Lee+ 2006 (L06); z>4 LBGs from Ouchi+ 2004 (O04).

Large Data Analysis Challenges and Mutlivariate Studies

The vast amount of LSST data will require novel data analysis techniques. Key to galaxy studies will be:

- **Deblending**: reconstructing galaxies when either well resolved or blended with other sources.
- **Multivariate analysis:** construction of luminosity functions, n-point correlation functions, etc. and their dependence on environment and redshift (or, conversely, bias as a function of redshift and galaxy properties, see Fig. 4).
- **Cross-survey correlation:** Combining LSST survey data, at least in limited areas such as the deep drilling fields, with radio, IR and X-ray surveys will allow improved determination of parameters such as star-formation rate, dust temperature and mass, and AGN accretion rate. X-ray data in particular will be important for determining the AGN fraction (and correspondingly helping to remove obscured AGN as a source of outliers in these analyses). The planned mission eRosita and proposed mission WFXT would detect ~ 10^4 and 10^5 normal galaxies and ~ 10^6 and 10^7 AGN, respectively. XMM-Newton and Chandra are spending an increasing fraction of their time on very large projects and surveying LSST deep drilling fields will likely be proposed and could reach detection limits corresponding to NGC 6240 (a ULIRG/merger with a binary AGN) at z ~ 2.

To address these challenges the LSST galaxies team will be proceeding by:

- Analyzing mock catalogs from end-to-end simulations based on the Millenium galaxy simulation and models of the LSST telescope and operations (*see Krughoff poster*)
- Consultation with the LSST Astroinformatics collaboration on the use of advanced statistical techniques, e.g., data mining techniques for dimensionality reduction and outlier detection/rejection, and the use of Virtual Observatory tools for cross-survey correlations (*see Borne et al. poster*).
- After the start of operations, using deep drilling fields as a "primer" for the analysis of the shallower survey data
- Community-based computing strategies, such as the "Galaxy Zoo" to allow the public to help classify sources and identify mergers and irregular galaxies that will be problematic for deblending algorithms.

References:
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