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 ~26.3, *g* ~27.5, *r* ~27.7, *i* ~27.0, *z* ~26.2, *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

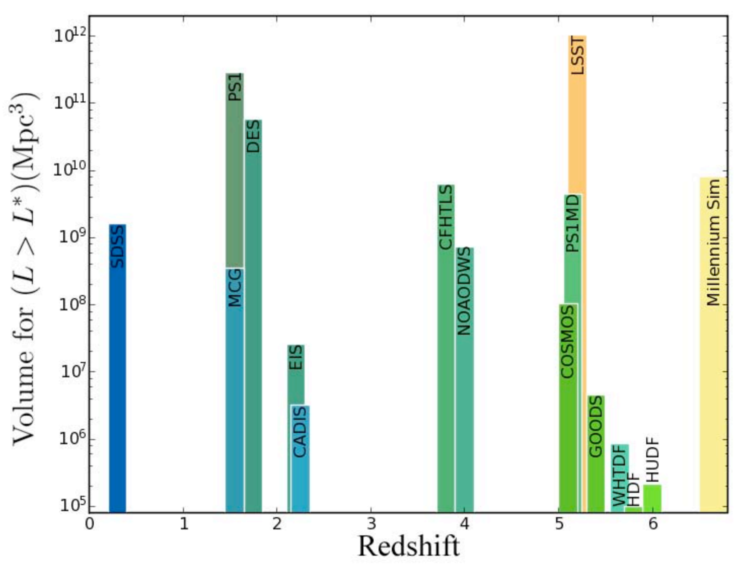


Fig. 1. Co-moving volume within which each survey can detect an L* galaxy ($M_B \sim -21$) assuming a typical Lyman break galaxy spectrum. LSST encompasses ~ 2 orders of magnitude more volume than current or other near-future surveys.

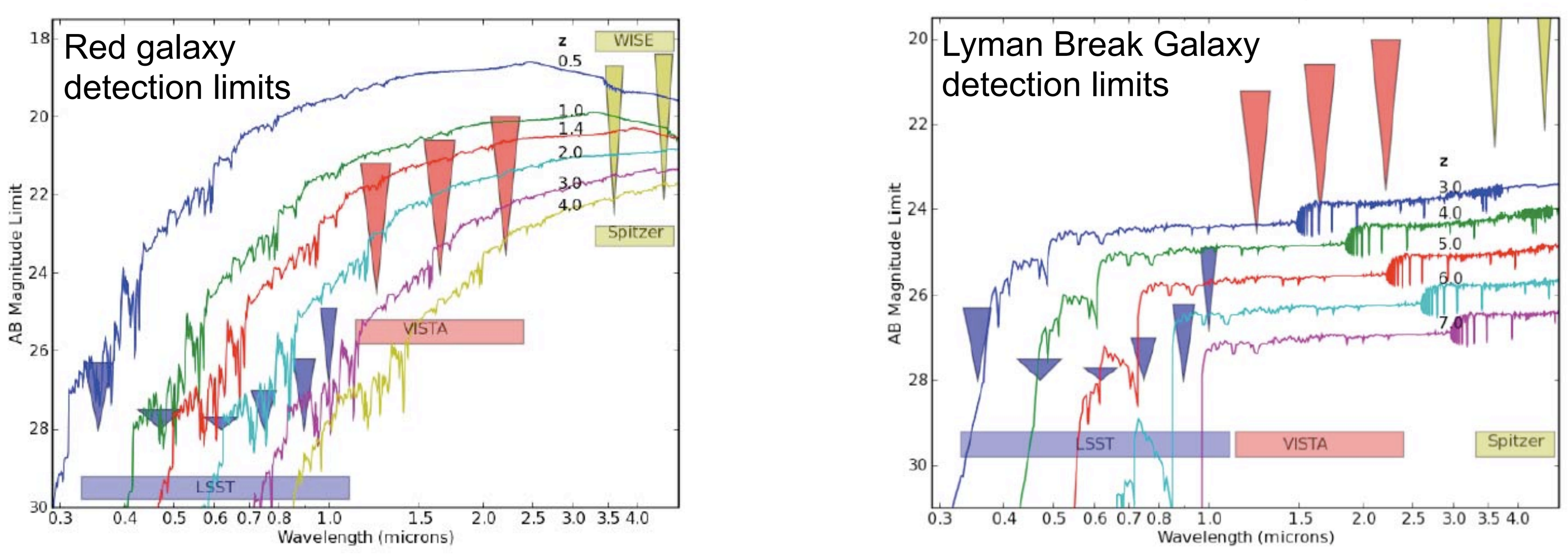


Fig. 2. ***Left:*** **The spectrum of a fiducial red galaxy as function of redshift** [Maraston 2005, Salpeter IMF, $Z_\odot$, z_{form}=10, τ_{SF}=0.1 Gyr, M_B=−20.5 at z=0]. ***Right:*** **The spectrum of a fiducial Lyman break galaxy as function of redshift** [Bruzual & Charlot 2003, Salpeter IMF, $Z_\odot$, 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 deg^2 (LSST; VISTA Hemisphere Survey; WISE all-sky survey). The bottom of the triangles show depth expected for deeper surveys with areas ~ tens of square 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.

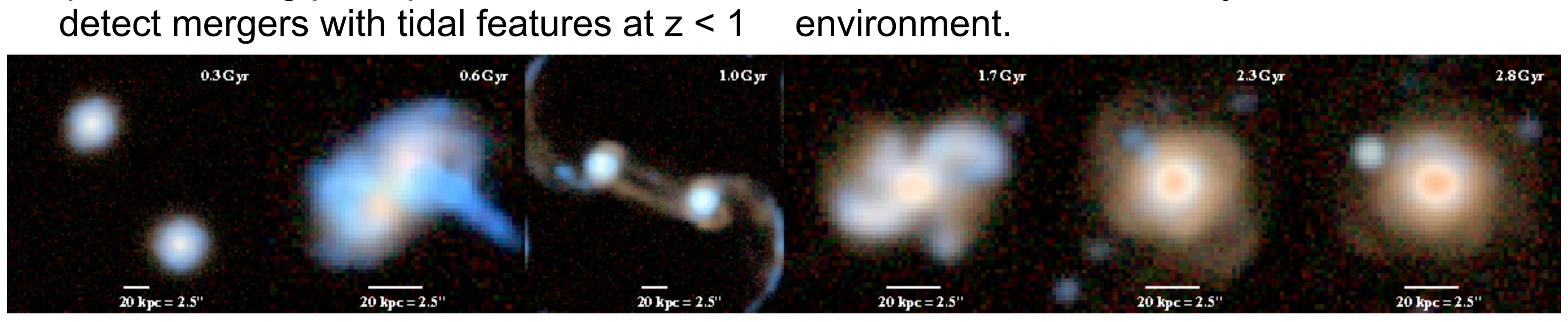
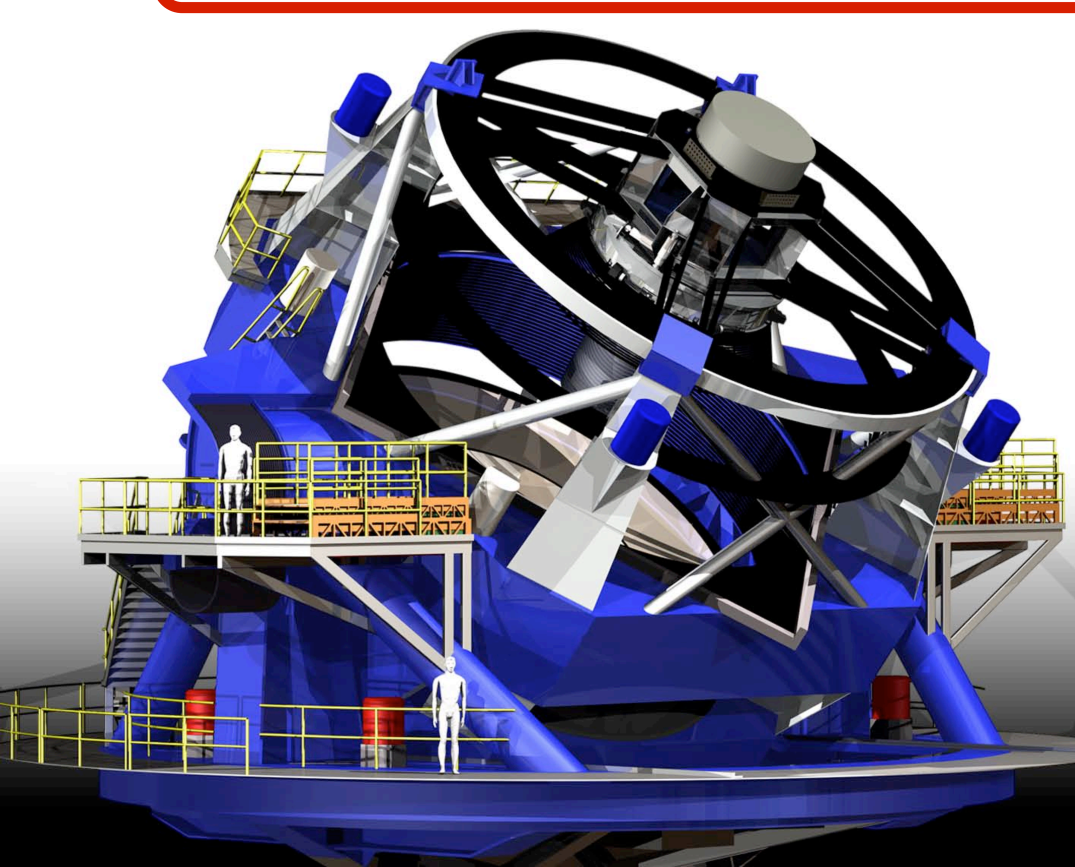


Fig. 5. A simulated *r-i-z* LSST image of a z~1 gas-rich equal mass disk merger (Lotz+ 2008). At t = 0.6 Gyr and 1.7 Gyr, strong blue distortions are visible on scales of a few arc-seconds. After the first pass (t = 1 Gyr), tidal tails are detectable at *i* < 27 mag per sq. arcsec. Faint shells, tidal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



References: Adelberger, K. L., et al. 2005a, ApJL, 620, L75; Adelberger, K. L., et al. 2005b, ApJ, 619, 697; Bahcall, N. A., et al. 2003, ApJ, 599, 814; Bouwens, R. J. et al. 2004, ApJL, 606, L25; Bouwens, R. J., et al. 2006, ApJ, 653, 53; Bruzual, G., & Charlot, S., 2003, MNRAS, 344, 1000; Bunker, A. J., et al. 2004, MNRAS, 355, 374; Calzetti, D., et al. 2000, ApJ, 533, 682; Coil, A. L. et al. 2008, ApJ, 672, 153; Davis, M. et al. 2003, SPIE, 4834, 161; Dickinson, M. et al. 2004, ApJL, 600, L99; Francke, H. et al. 2008, ApJL, 673, L13; Gwyn, S., 2009, http://www2.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/community/CFHTLS-SG/docs/cfhtls.html; Ilbert, O. et al. 2006, A&A, 457, 841; Ilbert, O. et al. 2009, ApJ, 690, 1236; Lee, K.-S., et al. 2006, ApJ, 642, 63; Lilly, S. et al. 2007, ApJS, 172, 70; Lotz, J. M., et al. 2008, MNRAS, 391, 1137; Malhotra, S. et al. 2005, ApJ, 626, 666; Maraston, C., 2005, MNRAS, 362, 799; Ouchi, M. et al. 2004, ApJ, 611, 685; Quadri, R. & Williams, R. 2009, arXiv:0910.2704; Sheth, R. K., & Tormen, G., 1999, MNRAS, 308, 119 ; Yan, H., & Windhorst, R. A., 2004, ApJL, 612, L93; Zehavi, I. et al. 2005, ApJ, 630, 1

Galaxies and their Dark Matter Halos

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.

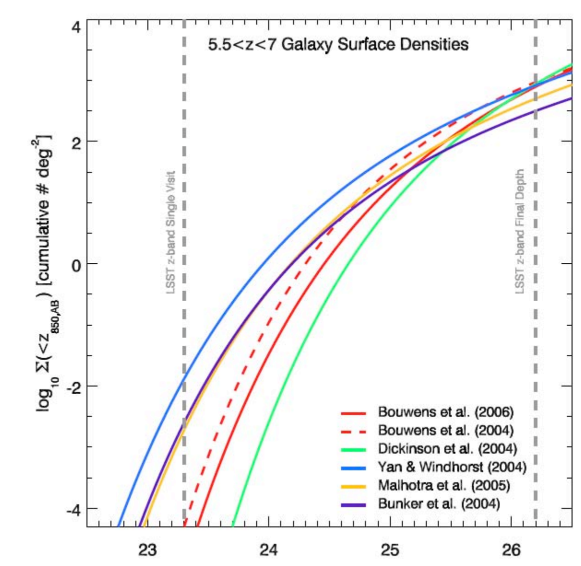


Fig. 3. LSST will greatly improve measurements of the bright end of the **z~6 LBG luminosity function**. The clustering of these rare objects will constrain the mass of their halos, and their association with z~6 quasars.

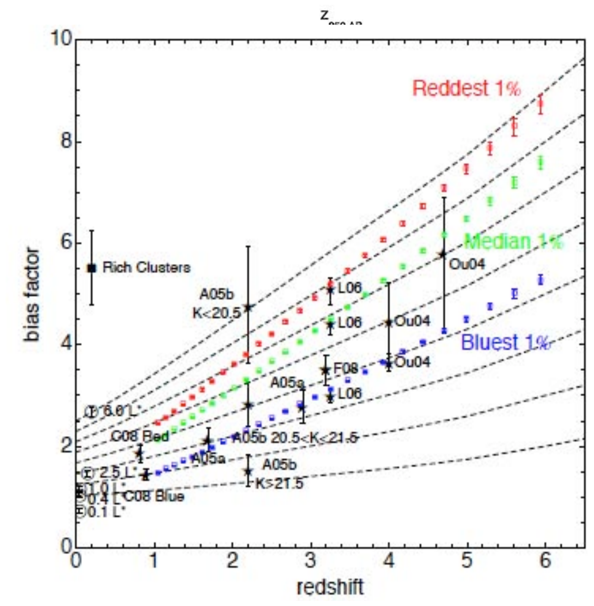


Fig. 4. **Evolution of galaxy bias v. redshift** for bluest 1%, reddest 1%, and median 1% of simulated LSST galaxy sample (blue, red, green points). Bias will be estimated from the angular two-point auto-correlation function ω(θ), and higher-order correlation statistics. Typical z~6 galaxies become massive 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).

Redshift Calibration with Tidal Pairs

How can we test LSST photometric redshifts without spectroscopy?

Close galaxy pairs with strong tidal features and no other companions have a high likelihood of physical association;
⇒ Δz_{phot} of each pair is a measure of redshift precision (Quadri+ 2009)

+ Biased towards challenging z_{phot} galaxies (star-forming, blue, dusty)
+ Tails detectable in full-depth LSST images out to z~1
+ Hundreds of pairs per LSST pointing

− Careful selection required to exclude false pairs
− Blending of very close pairs may give bad photometry, z_{phot}

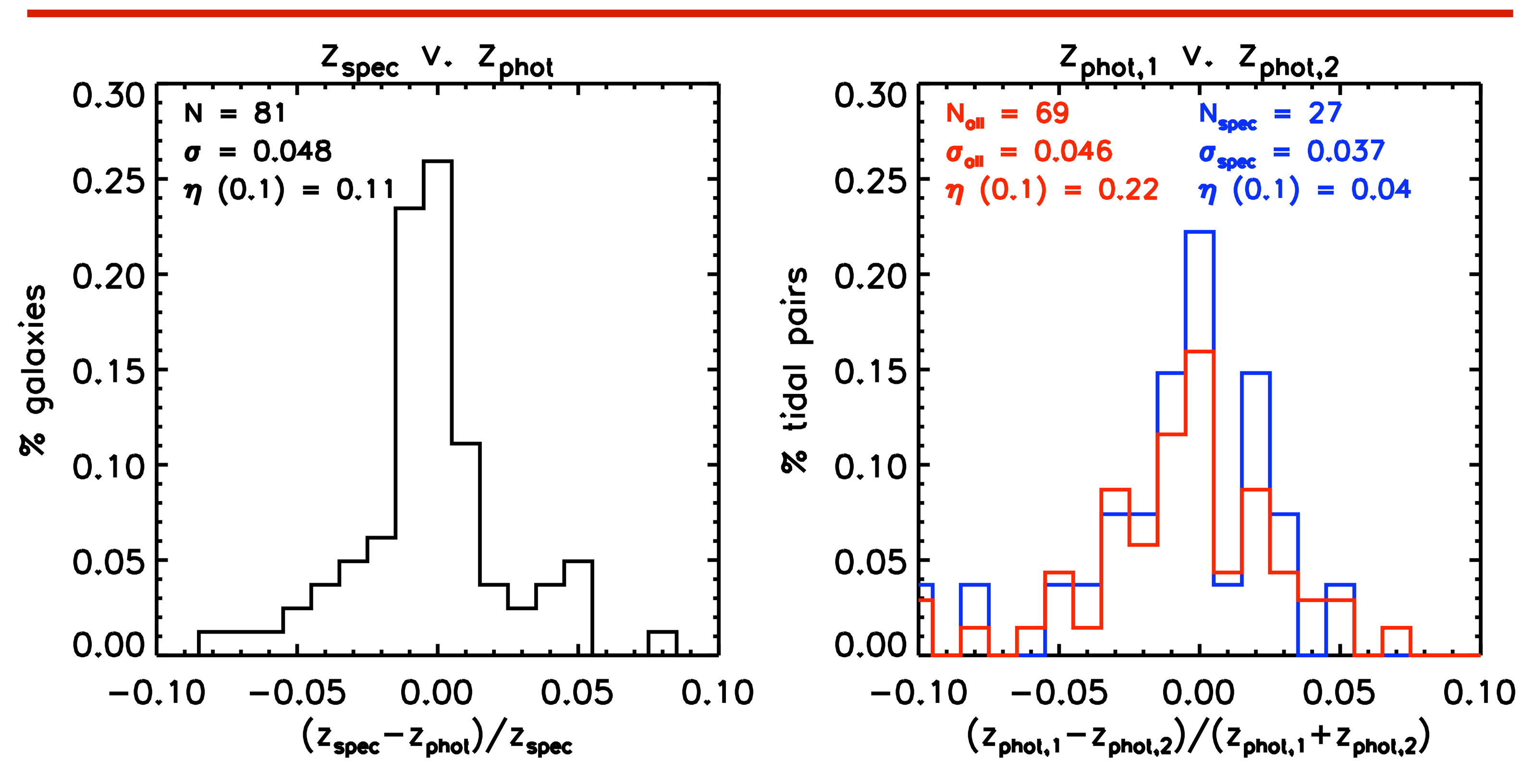


Fig. 6. 69 isolated tidal pairs (138 galaxies) at z<1 were selected from CFHTLS* Deep *i* images (Gwyn 2009) and matched to public z_{phot} (Ilbert+ 2006, 2009) and z_{spec} (Davis+ 2003, Lilly+2007) catalogs. ***Left:*** $\mathbf{Z_s}$ **v.** $\mathbf{Z_p}$ **for Tidal Galaxies**. 81/138 have spectroscopic redshifts; $\sigma[(z_p-z_s)/z_s)]$ = 0.048, and catastrophic error rate η = 11% (where$|(z_p-z_s)/z_s| \geq 0.1$). ***Right:*** $\mathbf{Z_{p1}}$ **v.** $\mathbf{Z_{p2}}$ **for Tidal Pairs**. The distribution of $(z_{p1}-z_{p2})/(z_{p1}+z_{p2})$ for all 69 tidal pairs (red), and for 27 spectroscopically-confirmed tidal pairs (blue). $\sigma[(z_{p1}-z_{p2})/(z_{p1}+z_{p2})] \sim \sigma[(z_p-z_s)/z_s)] \sim 0.05$, and is similar for both spectroscopically-confirmed pairs and full sample at 0.1 and -0.1. However, η is higher (22%) for full sample due to false pair contamination.

* Based on observations obtained with MegaPrime/MegaCam, a joint project of CFHT and CEA/DAPNIA, at the Canada-France-Hawaii Telescope (CFHT) which is operated by the National Research Council (NRC) of Canada, the Institut National des Science de l'Univers of the Centre National de la Recherche Scientifique (CNRS) of France, and the University of Hawaii. This work is based in part on data products produced at the Canadian Astronomy Data Centre as part of the Canada-France-Hawaii Telescope Legacy Survey, a collaborative project of NRC and CNRS.

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