Large Synoptic Survey Telescope

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Strong Gravitational Lensing with LSST

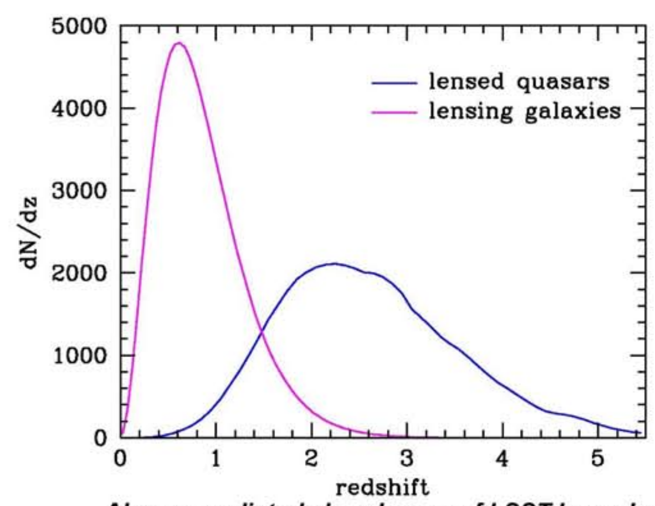
Philip J. Marshall[1], M. Bradac[2], G. Chartas[3], G. Dobler[4], A. Eliasdottir[5], E. Falco[6], C. D. Fassnacht[2], M. J. Jee[2], C. R. Keeton[7], M. Oguri[8], J. A. Tyson[2], LSST Strong Lensing Science Collaboration

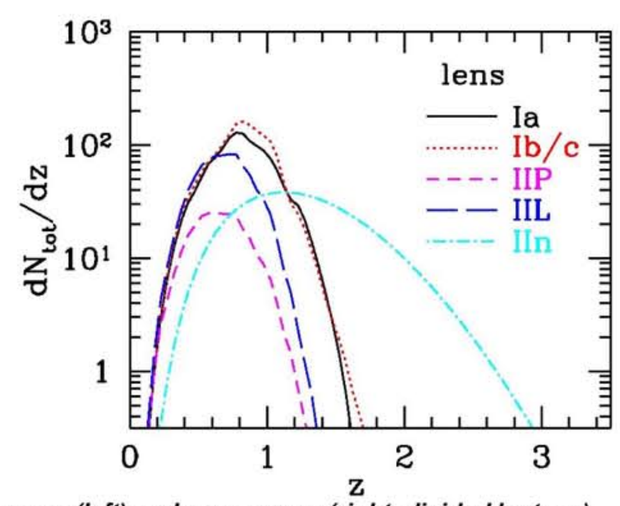
[1]Stanford Univ., [2]Univ. of California, Davis, [3]Pennsylvania State Univ., [4]Univ. of California, Santa Barbara, [5]Princeton Univ., [6]Harvard Smithsonian Center for Astrophysics, [7]Rutgers Univ., [8]National Astronomical Observatory of Japan

LSST will find more strong gravitational lensing events than any other survey preceding it, and will monitor them all at a cadence of a few days to a few weeks. We can expect the biggest advances in strong lensing science made with LSST to be in those areas that benefit most from the large volume, and the high accuracy multi-filter time series: studies of, and using, several thousand lensed quasars and several hundred supernovae. However, the high quality imaging will allow us to detect and measure large numbers of background galaxies multiply-imaged by galaxies, groups and clusters. In this poster we give an overview of the strong lensing science enabled by LSST, and highlight the particular associated technical challenges that will have to be faced when working with the survey.

Massive galaxy structure and evolution

Image separations in potentially 10^4 galaxy-scale strong lens systems enable accurate mass measurements; time variable sources (quasars and SNe) will provide time delays that constrain the density profile. Such a large sample can be sliced multiple ways, to probe the mass function of galaxies and its evolution, and to calibrate total and stellar mass to light ratios in both early and late-type galaxies. By focusing on the lensed sources, we will be able to construct samples of accurately-weighed galaxies selected essentially by their mass, out to the epoch (z=1-2) of massive galaxy formation.





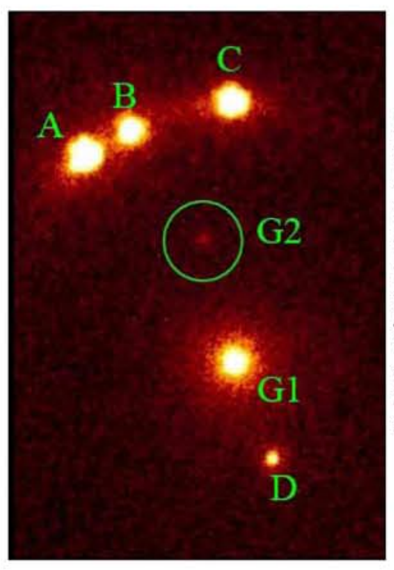
Above: predicted abundances of LSST lensed quasars (left) and supernovae (right, divided by type).

Lens Detection

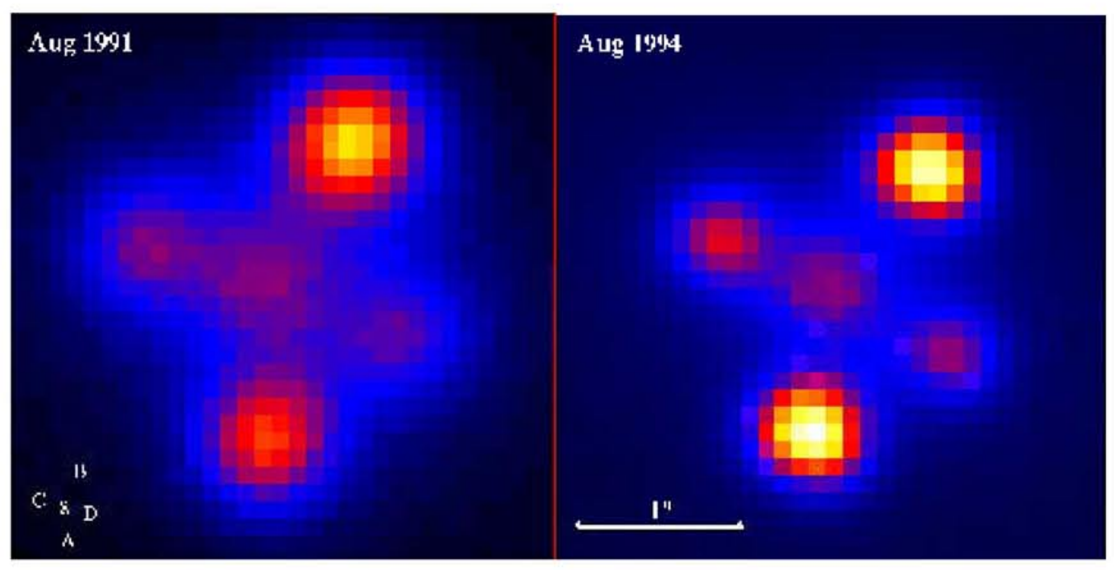
Multiply-imaged quasars will be found in the combined difference and stacked image source catalogs (few astronomical objects appear extended in difference imaging, Kochanek et al 2006), and the high resolution and u-band should make for a pure sample. Lensed supernovae can be spotted with a simple transient trigger. Detecting large numbers of lensed galaxies at high purity (such that follow-up is efficient) will be very difficult, given the incidence of confusing image plane structure (such as spiral arms, rings of star formation and so on). Even the first cut will require advanced deblending to enable meaningful database mining.

Follow-up

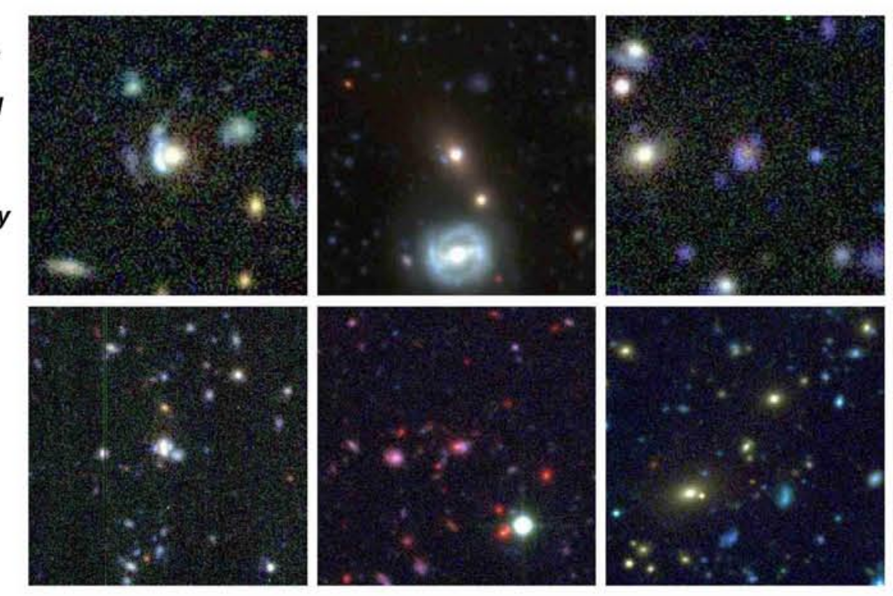
Physical masses (and cosmography) require lens and source redshifts, a potential follow-up bottle-neck. "Piggy-backing" on a galaxy redshift survey could pay dividends. Would photo-z's be good enough? Each time delay lens needs accurate, +/-few day time delay measurements: is the LSST cadence high enough? Are observing seasons long enough? Can we do without follow-up imaging at higher resolution?



Left: cusp configuration quad lens B2045, observed at high resolution in the K-band with AO at Keck. Satellite galaxy G2 partially explains the anomalously faint image B (McKean et al. 2007).



Above: long-term microlensing image flux variations in the Einstein Cross, Q2237+0305. (APOD image by Lewis, Irwin, et al., http://apod.nasa.gov/apod/ap961215.htm)

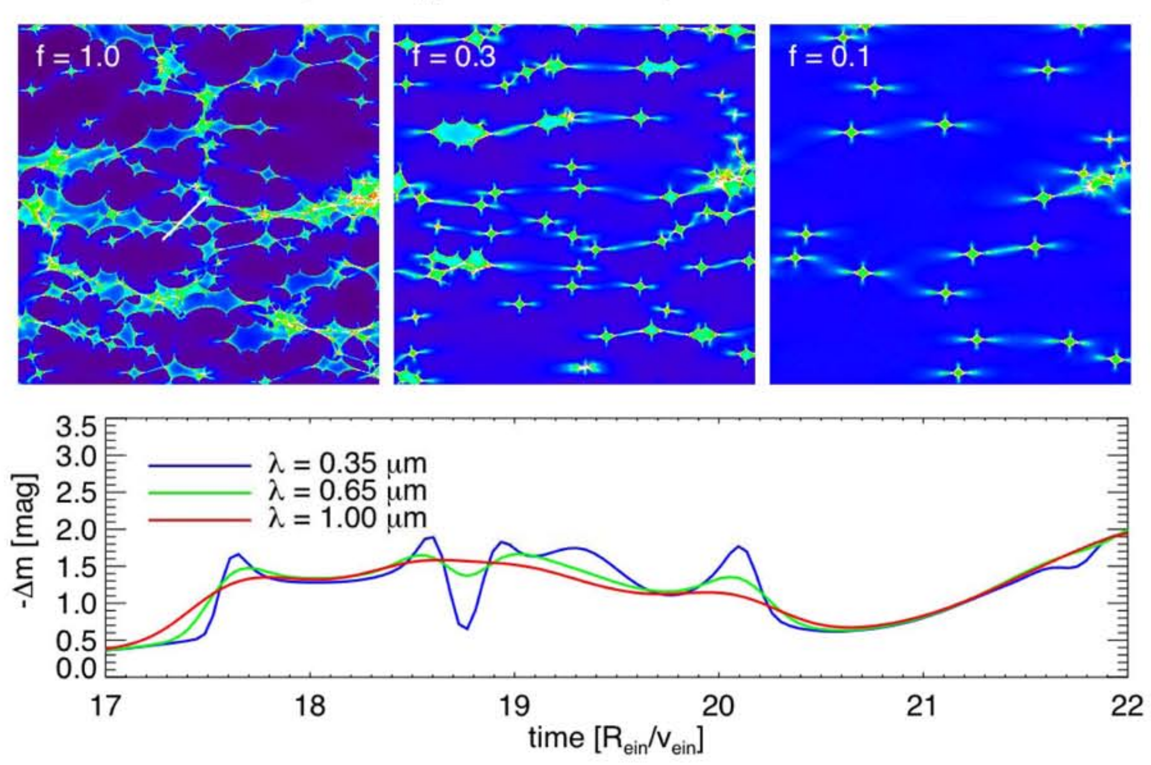


Right: 6 galaxy-galaxy strong lenses detected by chromatic image differencing in the CFHT legacy survey. (Color images: R. Cabanac and the SL2S collaboration.)

Dark Matter Subhalos

"Millilensing" by dark matter subhalos of mass 10^6-10^{10} $M_\odot$ (predicted in large numbers, Springel et al 2008) perturb the fluxes of point-like images in galaxy-scale lenses by tens of percent, and their positions by several to tens of milli-arcseconds: these "anomalies" can be identified and exploited by careful modeling (Dalal & Kochanek 2002). Strong lensing provides a unique opportunity to detect these mass clumps, test CDM predictions, and probe galaxy formation on the smallest scales. LSST will enlarge the current sample by ~100, allowing us to probe the mass function, spatial distribution, and density profiles of the subhalos, all as a function of redshift.

Below: modeling QSO microlensing. Moving the source across the caustics of a model starfield (stellar mass fraction f) allows lightcurves to be predicted and fit to the data. The accretion disk is smaller, and so appears more variable, in the bluer filters.



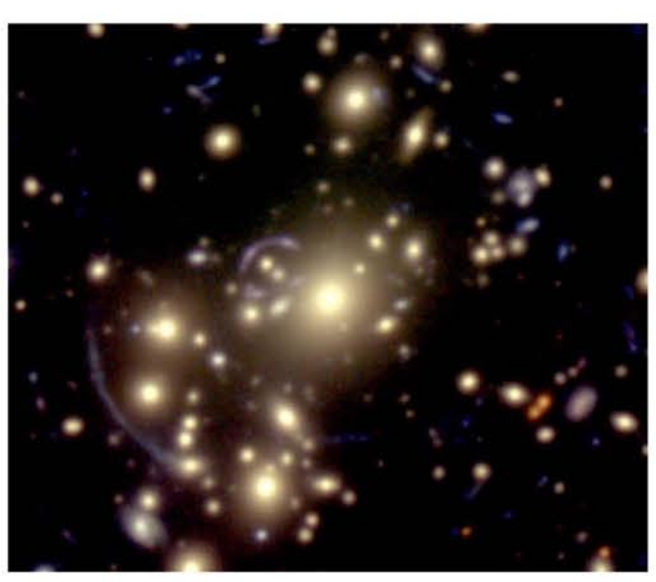
Coping with Microlensing

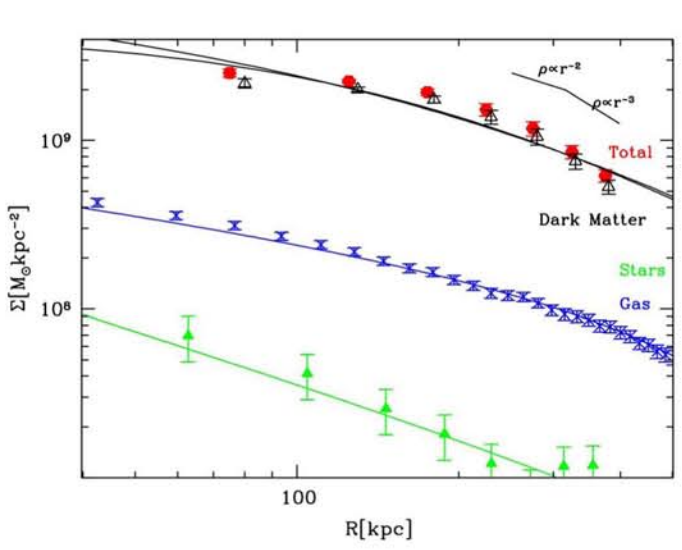
LSST monitoring of lenses will be essential to remove microlensing effects on the image fluxes - but what precision will remain, given the universal cadence planned? Modeling microlensing by brute force simulation of caustic crossings (Kochanek 2004) is robust but computationally intensive - and only gets more so as the light curve lengthens. The radio-loud subsample could be followed up with radio snapshots or IR imaging. How expensive will this follow-up be? One exciting prospect is to investigate anomalous fluxes of quadruply-imaged SNe: when they fade, can the perturber be seen in deep, high resolution images of the SN host galaxy arcs and Einstein rings? For the dust analysis, chromatic variability, intrinsic and microlensing-induced, can be studied (Mosquera et al. 2009). Will it matter that the different filter data are not taken simultaneously?

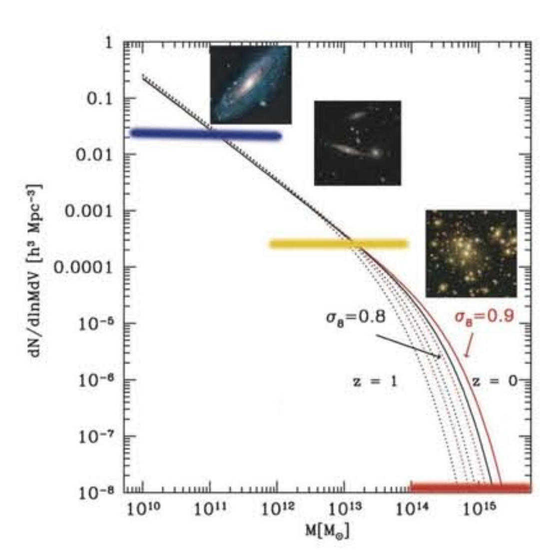
Dust in Lens Galaxies

Strong gravitational lenses provide multiple independent sight-lines per system, allowing the differential dust extinction curve of the lens galaxy to be deduced (Nadeau et al. 1991). The combined LSST sample of several thousand lensed quasars and supernovae enables extensive studies of the extinction properties of high redshift galaxies as a function of galacto-centric radius, and probes the evolution of dust with redshift and galaxy type. For the lensed SNe, the dust emission of the lensing galaxy can be measured once the SN has faded, making it possible, for the first time, to do a comparative study of dust extinction and dust emission in galaxies outside the Local Group.

SDSS lensed QSOs. Note the reddened inner images in the left two panels, and the benefit of seeing the lens galaxy light (right). The LSST image quality is expected to be a factor of 2 higher than SDSS.







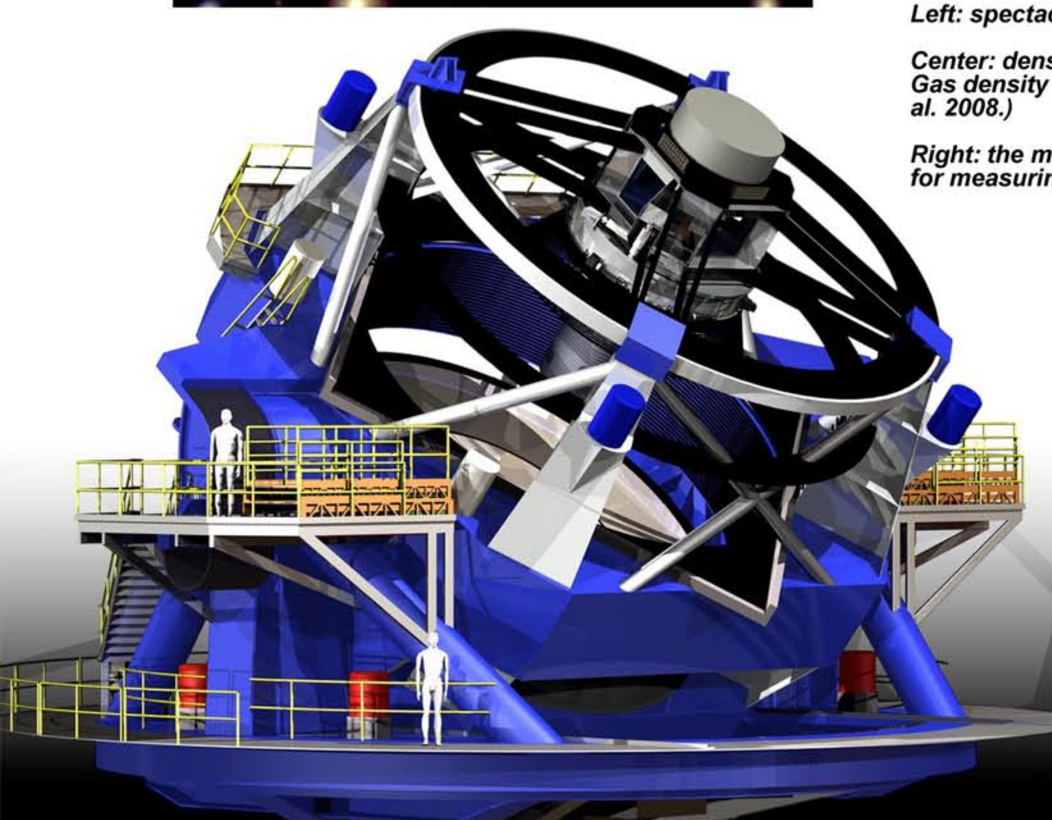
Left: spectacular lensing cluster A1703., observed at LSST resolution with Subaru.

Center: density profile measurement in massive cluster RXJ1347, from a strong + weak lensing analysis. Gas density is from a fit to the Chandra X-ray surface brightness and temperature. (Data from Bradac et al. 2008.)

Right: the mass function of collapsed objects, from galaxies to clusters. Accurate cluster masses are vital for measuring cosmological parameters, and the sensitivity is highest at the high mass end.

Dark Matter and Dark Energy with Clusters of Galaxies

Strong lensing has an important role to play in cluster physics studies; meanwhile, the cluster mass function is one of the four most promising dark energy probes (Albrecht et al. 2006). LSST will detect and measure ~1000 strong-lensing clusters, in which the combination of both weak and strong lensing data will allow us to reconstruct the mass distribution from the inner cores (~10kpc) to the clusters' outskirts (~1Mpc) with better than 10% accuracy. This high-fidelity mass profile will provide opportunities to better test the CDM-predictions such as the profile concentration (and its relation to halo mass and redshift), the halo ellipticity, and the substructure mass function. These lensing masses will also provide critical calibration of concurrent or future optical, weak lensing, X-ray or SZ samples, and provide information on dark and baryonic matter interactions by studying the departure from the theoretical scaling relations. Strong lensing data will reduce the uncertainty in the cluster mass function where it is most needed, at the high mass end.



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Modeling the Cluster Sample

Clusters can be detected either by their weak lensing shear peaks, or their optical richness. Therefore, understanding both selection functions will be critical in constructing cluster mass functions. In addition, identification of strongly lensed sources, which can be iteratively improved by mass modeling, needs to be automated (crowd-sourced?) in order to study ~1000 clusters. Modeling one thousand clusters to high accuracy will be a challenge. Improved numerical simulations (both dark and baryonic matter) will be needed to fully exploit the significant observational improvements LSST offers, both for studies of cluster structure and cosmology with the mass function.

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