Active-Galaxy Science with the Large Synoptic Survey Telescope

W.N. Brandt (PSU), S.F. Anderson (UW), D.R. Ballantyne (UA), A.J. Barth (UCI), R.J. Brunner (UI), G. Chartas (PSU), W. de Vries (Livermore IGPP), M. Eracleous (PSU), R.F. Green (UA), G. Madejski (SLAC), D.P. Schneider (PSU), O. Shemmer (PSU), H.A. Smith (CfA), P.S. Smith (UA), D.E. Vanden Berk (PSU) and the AGN Science Collaboration

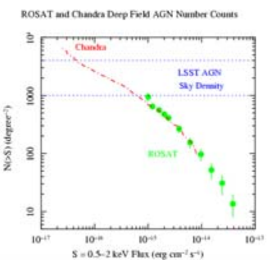
The Large Synoptic Survey Telescope (LSST) will provide great advances in our understanding of the demography and physics of active galactic nuclei (AGNs), owing to its unprecedented combination of solid-angle coverage, photometric and astrometric accuracy, sensitivity, broad wavelength coverage, and time sampling. Well-defined, large (20-80 million) samples of AGNs at 0 < z < 7.5 can be constructed via four approaches: location in color-color space, variability, lack of proper motion, and matching to multiwavelength data. The samples will allow studies of the AGN luminosity function and AGN clustering down to Seyfert luminosities out to z~6-7.5. The time baseline (usually hours-to-years), coupled with the large sample size, will produce a data set that can be used to address the physics of the AGN accretion process, allowing insights into the fueling of AGNs by stellar tidal disruptions and the lifetime of AGNs. Comparison of LSST data with archival X-ray and infrared fields will be the first stage of follow-up for more than a million AGNs, many of which will be heavily obscured.

AGN Selection and Yields

The LSST can select AGNs from z ~ 0-7.5 using four effective methods:

- Location in *ugrizy* color-color space. This has been a standard method of AGN selection in wide-field optical surveys, such as the Sloan Digital Sky Survey (SDSS).
- Lack of proper motion. The 3σ upper limit on proper motion for the full LSST survey will be a few mas per year.
- Variability on timescales ranging from minutes to years.
- Multiwavelength matching using data from *Chandra*, *XMM-Newton*, *Spitzer*, *GLAST*, and other missions.

In contrast to current wide-field optical surveys, the LSST will find moderate-luminosity, typical AGNs in the high-redshift universe. After 10 years of observations, the LSST should deliver AGN sky densities of ~ 1000-4000 deg^{-2}. This is competitive with the deepest pencil-beam multiwavelength AGN surveys to date, such as the Chandra Deep Fields. **The total LSST AGN yield should be ~ 20-80 million AGNs**, which is two orders of magnitude larger than the current AGN census.



AGNs at the End of the Dark Ages

The LSST can find many AGNs at the highest redshifts using color-selection methods. **About 200-1000 AGNs at z ~ 6.5-7.5 should be found as z-band dropouts** (i.e., detected only in the *y*-band). These AGNs will have optical luminosities down to ~ 10^{44} erg s^{-1}. By searching for X-ray sources that lack detections in any of the LSST filters, it should be possible to find AGNs at z > 7.5.

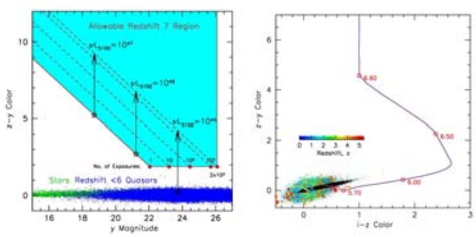
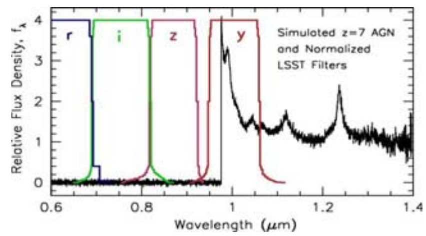


Fig. 1 - Left: LSST *z-y* vs. *y* color-magnitude diagram, showing the expected allowable region for redshift ~ 7 quasar candidates (cyan). The region limits are defined by the 3σ *y*-magnitude detection limits, and 2σ *z*-magnitude detection limits, as a function of the number of co-added 15 s exposures. An object is considered a redshift ~ 7 candidate if it is detected at the > 3σ level in the *y*-band, and does not exceed the *z* band 2σ detection limit. The *y*-magnitude detection limits reached in a given number of exposures are shown by red dots, and labeled by the number of exposures. The *y*-magnitudes and *z-y* color limits are shown for simulated redshift 7 quasars at three different 5100 Angstrom continuum luminosities. The open stars show the minimum *z-y* color limits required for a single 15 s exposure, and the ends of the arrows show the limits for 2000 exposures. A quasar at redshift 7 with an optical luminosity of 10^{45} erg s^{-1} can be detected in about 30 exposures, while quasars with optical luminosities exceeding 10^{46} erg s^{-1} can be detected in a single exposure. The expected *z-y* colors of stars (green) and redshift < 6 quasars (blue), based on results from the SDSS, are shown for comparison. The minimum *z-y* colors lie well above the star and low-redshift quasar color distributions. **Right:** Track of a quasar with an optical luminosity of 10^{46} erg s^{-1} on the *z-y* vs. *i-z* color-color diagram. Note that such quasars can be easily separated from the loci of stars (black) and lower redshift quasars (colored).



AGN Variability Studies

We use a parameterized description of AGN variability from the SDSS (extrapolated to fainter apparent magnitudes) to estimate the fraction of AGNs that may be detected as significantly variable by the LSST. We assume that the 10σ detection limit in a single-epoch LSST image is *i* ~ 24, and calculate the magnitude difference at which only 1% of the non-variable stars will be flagged as variable candidates due to measurement uncertainty. The probability that the single-band rms magnitude difference of an AGN will exceed this value - and will therefore be flagged as a variable candidate - depends upon redshift, luminosity, observed time interval, and the number of observing epochs.

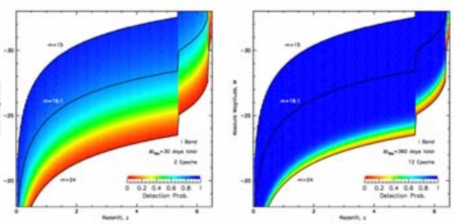
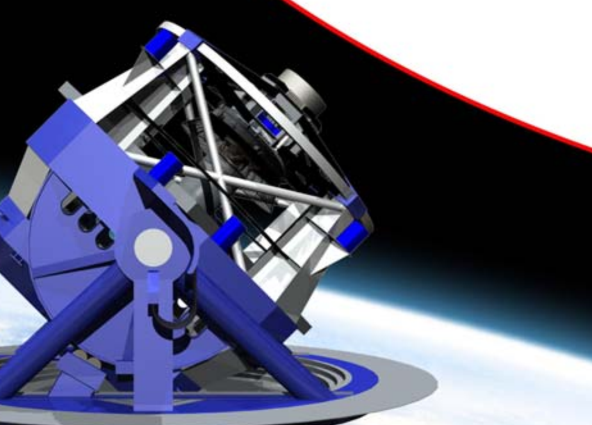


Fig. 2 – The probability of detecting an AGN as variable as a function of redshift and absolute magnitude. **Left:** Two epochs separated by 30 days. **Right:** 12 epochs spanning 360 days. Nearly all of the AGNs between the limiting apparent magnitudes would be detected as variable after 1 year.

Even with only two epochs separated by 30 days, a large fraction of AGNs will be detected as variable objects. The fraction of AGNs detected depends strongly on absolute magnitude at each redshift. After 12 epochs with a total time lag of 360 days, **nearly all of the AGNs to a limiting apparent magnitude of ~ 24 will be detected as variable**. The detection fraction will increase as the number of epochs increases, and the use of all six bands will improve the detection fraction even further.

Stellar Tidal Disruptions

Transient outbursts from galactic nuclei are likely caused by inevitable fueling events of nuclear supermassive black holes when a star, planet, or gas cloud is tidally disrupted and partially accreted. The LSST will greatly extend the limited current studies of such events and will provide a definitive determination of the rate of optical outbursts throughout the Universe. It will explore promising "discovery space" by looking for outbursts with lower luminosities, higher redshifts, and different timescales. Outburst rates will be constrained as a function of galaxy type and nuclear activity. Furthermore, LSST data processing will enable rapid identification of nuclear outbursts, so that **intensive spectroscopic and multiwavelength follow-up studies will be possible while the event is in progress**. Aside from their innate interest, these LSST results will be relevant to the planning of missions such as the Black Hole Finder Probe and LISA.



LSST is a public-private partnership. Design and development activity is supported by in part the National Science Foundation under Scientific Program Order No. 9 (AST-0551161) and Scientific Program Order No. 1 (AST-0244680) through Cooperative Agreement AST-0132798. Portions of this work are supported by the Department of Energy under contract DE-AC02-76SF00515 with the Stanford Linear Accelerator Center, contract DE-AC02-98CH10886 with Brookhaven National Laboratory, and contract W-7405-ENG-48 with Lawrence Livermore National Laboratory. Additional funding comes from private donations, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.

Brookhaven National Laboratory, California Institute of Technology, Columbia University, Google, Inc., Harvard-Smithsonian Center for Astrophysics, Johns Hopkins University, Kavli Institute for Particle Astrophysics and Cosmology - Stanford University, Las Cumbres Observatory Inc., Lawrence Livermore National Laboratory, National Optical Astronomy Observatory, Princeton University, Purdue University, Research Corporation, Stanford Linear Accelerator Center, The Pennsylvania State University, The University of Arizona, University of California at Davis, University of California at Irvine, University of Illinois at Urbana-Champaign, University of Pennsylvania, University of Pittsburgh, University of Washington