Large Synoptic Survey Telescope

www.lsst.org

AGN Science with LSST

Robert R. Gibson[1], S. F. Anderson[1], D. R. Ballantyne[2], A. J. Barth[3], W. N. Brandt[4], R. J. Brunner[5], G. Chartas[6], P. Coppi[7], W. de Vries[8], M. Eracleous[4], X. Fan[9], A. G. Gray[2], R. F. Green[10], Z. Ivezic[1,11], M. Lacy[12], P. Lira[13], G. M. Madejski[14], J. A. Newman[15], G. T. Richards[16], D. P. Schneider[4], A. Seth[17], O. Shemmer[18], H. A. Smith[17], M. A. Strauss[19], E. Treister[20], D. E. Vanden Berk[21]

[1]University of Washington, [2]Georgia Tech, [3]UC Irvine, [4]Penn State, [5]University of Illinois, [6]College of Charleston, [7]Yale, [8]LLNL, [9]University of Arizona, [10]LBTO, [11]University of Zagreb, [12]NRAO, [13]Universidad de Chile, Chile, [14]SLAC National Accelerator Laboratory, [15]University of Pittsburgh, [16]Drexel University, [17]CfA, [18]University of North Texas, [19]Princeton, [20]Hawaii IfA, [21]St. Vincent College

The LSST survey will dramatically increase the number of known active galactic nuclei (AGN), cataloging over 10 million AGN across more than 20,000 square degrees of sky. Time-domain coverage, a hallmark of the LSST survey, will enable powerful new AGN selection criteria, including variability and the lack of proper motion, in addition to color-based selection in deep, coadded *ugrizy* (320—1050 nm) images. Most of the LSST sky will be observed about 1000 times over ten years, while AGN in "deep drilling" fields will receive intensive monitoring on time scales of minutes to years. Distinguishing traits of the LSST AGN survey include its coverage of the luminosity-redshift plane, its reach to high redshifts (with over 1000 AGN at z > 6.5), and the use of difference imaging to detect faint AGN surrounded by host galaxy emission or in crowded environments that challenge traditional photometry. LSST AGN will be used to determine the accretion history of supermassive black holes over cosmic time, the interaction of AGN with their evolving host galaxies and environments, the physics of AGN emission revealed by variability, and the relationship between AGN and dark matter through measurements of clustering at high redshifts. Multiwavelength analyses will benefit from matching LSST source identifications, redshifts, and light curves to archives and contemporaneous missions, and real-time LSST alerts will trigger follow-up observations. Simulated LSST images and archived SDSS Stripe 82 data are now being used to demonstrate the capabilities of the LSST AGN survey, with a current emphasis on evaluating metrics that select AGN based on their variability.

Identifying AGN

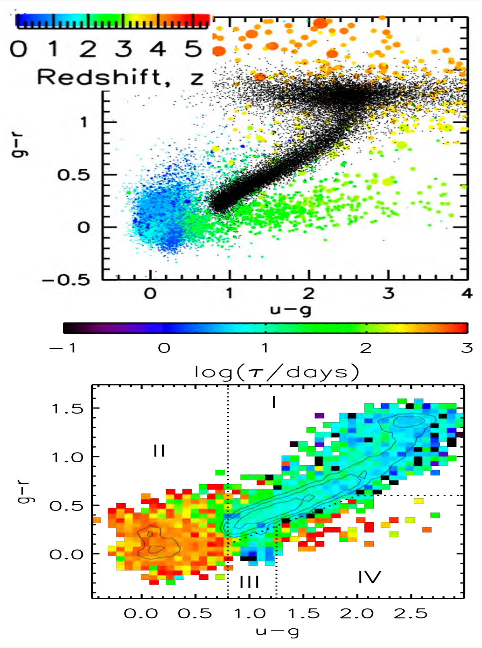
The LSST can select AGN from z~0-7.5 using a combination of methods.

Location in multi-dimensional color space has been widely used in the SDSS and other surveys to identify AGN candidates.

Lack of proper motion. Many color-space contaminants will move more than a few milli-arcseconds over the survey duration.

Multiwavelength matching using data from *Chandra*, *XMM-Newton*, *Spitzer*, *Fermi*, and other missions.

Variability on timescales ranging from minutes to years. AGN can be identified from their distinctive pattern of optical variation in LSST light curves. The top figure to the right shows how (u-g, g-r) AGN colors change with redshift. AGN (colored points) overlap the stellar locus (black points) at several redshifts, complicating color-based selection. In the bottom figure (from MacLeod et al. 2010), SDSS Stripe 82 sources are color-coded by the time scale parameter, τ, from a Damped Random Walk model fit (Kelly et al. 2009, Kozlowski et al. 2010). Quasars (regions II and IV) have distinctly different time scale parameters from MS (region I) or RR Ly stars (region III).



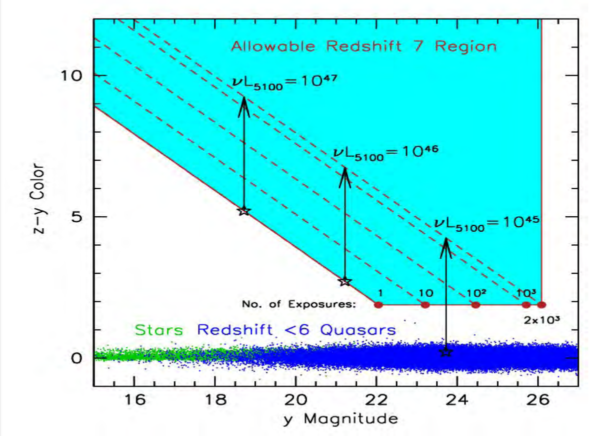
i	0.5	1.5	2.5	3.5	4.5	5.5	6.5	Total
16	666	597	254	36	0	0	0	1550
17	4140	4630	1850	400	54	0	0	11100
18	19600	28600	10700	1980	321	19	0	61200
19	68200	131000	53600	8760	1230	115	0	263000
20	162000	372000	194000	35000	4290	441	1	767000
21	275000	693000	453000	113000	14000	1380	34	1550000
22	336000	1040000	756000	269000	41200	3990	157	2450000
23	193000	1440000	1060000	476000	103000	10900	527	3280000
24	0	1370000	1360000	687000	205000	27400	1520	3660000
25	0	314000	1540000	888000	331000	60800	4100	3140000
26	0	0	279000	760000	358000	86800	7460	1490000
Total	1060000	5390000	5720000	3240000	1060000	192000	13800	16700000

Predicted Number of AGN in 20,000 deg^2 over 15.7<i<26.3 and 0.3<z<6.7 with M_i <= -20. The ranges in each bin are Δi=1 and Δz_{em}=1, except in the first and last bins where they are 0.8 and 0.7, respectively.

High-Redshift AGN

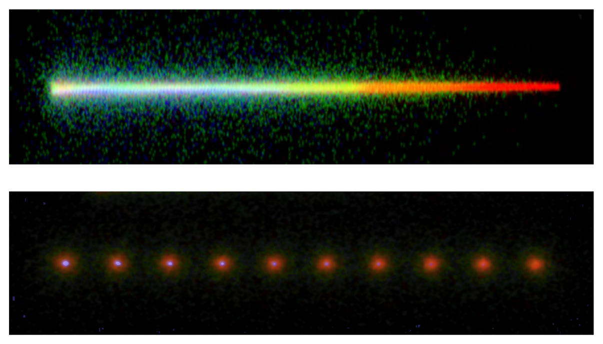
The LSST survey will identify over ~1000 AGN at z > 6.5 with optical luminosities down to 10^{44} erg s^{-1} that are *i*- and z-band dropouts. *y*-band dropouts detected by other observatories (e.g., in X-rays) will be candidates for even higher redshifts.

The LSST will be surveying an era when quasars were young, the Universe was finishing re-ionization, and black holes were growing rapidly. AGN components that are ubiquitous and stable at lower redshifts may be observed as they are forming (e.g., Jiang et al. 2010).



Redshift ~7 AGN candidates are defined to have 3σ *y*-band detections and 2σ *z*-band *non*-detections. The shaded space shows the candidate region in (*z-y, y*) space as a function of the number of exposures.

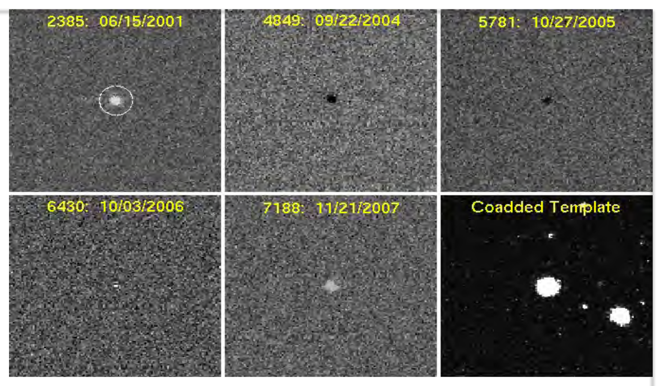
AGN Simulations



Top panel: simulated, false-color (*gri*) image of AGN at redshifts ranging from z = 0 to z > 6. *Bottom panel*: AGN emission weakening from *g* ~ 19 to *g* ~ 24 in ten copies of a *g* ~ 21 mag host galaxy at redshift z = 0.5. Backgrounds are not included in these images.

LSST Simulations (Connolly et al. 2010) are being developed to calibrate and test the LSST data-reduction pipelines. These simulations will also be used to characterize the completeness and efficiency of different methods of identifying AGN and measuring their characteristics. The simulations include realistic AGN light curves, star and galaxy catalogs, atmospheric models, and a detailed raytrace model of the telescope.

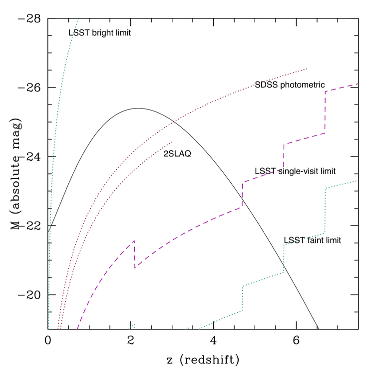
Difference Imaging



At right: *g*-band variability over 5 epochs in SDSS difference images from a quasar with mag *g* = 18.2 at redshift z = 1. A deep composite (bottom right) was subtracted from the SDSS image in each epoch to create the difference images shown in the first five panels.

Variability-based selection of AGN will be improved by the use of difference images. A deep, matched template will be subtracted from each new image to identify any sources that have changed significantly. This approach is particularly suited to AGN, because traditional photometry of fainter AGN is challenged by surrounding host-galaxy emission. Images can be rapidly matched and subtracted in the LSST pipeline, and sources detected in the images can immediately be flagged as variable, moving, and/or transient objects so that alerts can be issued for prompt follow-up. Light curves may be classified as AGN-like, supernova-like, or periodic. Tidal disruption candidates may also be identified in their host environments.

AGN Science



Luminosity function: The LSST survey will improve current measurements of the AGN luminosity function (LF) by increasing sample sizes, expanding coverage of the luminosity-redshift plane, and employing a variety of techniques to reliably identify AGN. In current models (e.g., Hopkins et al. 2007b), the bright end of the LF evolves from an era of rapid growth in the early Universe that "downsizes" at later times, while the faint end constrains duty cycles of AGN in sub-Eddington accretion phases. The figure shows current measurements of the evolution of the LF break luminosity L* (solid line) as a function of redshift, compared to the sensitivity of the SDSS (e.g., Richards et al. 2009), 2SLAQ (e.g., Croom et al. 2009), and LSST AGN surveys. The LSST survey probes the LF shape in the era of rapid black hole growth out to z ~ 6.

Clustering: Current studies of AGN clustering indicate that AGN typically reside in dark matter halos having redshift-independent masses out to z ~ 3 (e.g., Ross et al. 2009). If black hole masses are related to halo masses, then any luminosity-dependence in clustering will suggest accretion rates and duty cycles for AGN activity, and can be used to test models of AGN growth at higher redshift (Hopkins et al. 2007a). Close companions (galaxies or other AGN) will be examined for evidence of merger activity, and absorption features in follow-up spectra will reveal environmental characteristics of the intervening companion.

Multiwavelength: The LSST will add new value to existing multiwavelength archives and will provide near-simultaneous optical photometry for sources observed by contemporaneous missions in other wavebands. Radio, infrared, and X-ray observations will be used to study blazars, star-forming galaxies, and obscured AGN in LSST catalogs. Ten-year light curves will reveal the temporal evolution of broad-band spectra and will allow alerts to be generated for follow-up in interesting cases such as dramatic changes in strongly-absorbed AGN spectra, potential "state changes" in accretion modes, or outbursts that permit spectral mapping of the intervening IGM at high S/N.

Variability: Relations between AGN variability properties and luminosity, redshift, rest-frame wavelength, time scale, color, and radio-jet emission will be defined with overwhelming statistics over a wide range of parameter space. With spectroscopic follow-up, these relations may be extended to include black hole masses and accretion rates. Luminosity- and color-evolution will be measured for individual sources to constrain accretion models that were previously tested against ensembles of AGN (e.g., Vanden Berk et al. 2004). "Deep drilling" fields will intensively monitor AGN over minutes to years for ~100 deg^2 of sky. Efficient strategies will also be required to identify and follow up on serendipitous discoveries of AGN with unanticipated temporal properties.

Examples of transient phenomena: The LSST is predicted to observe each year over 130 tidal disruption events in which a star is torn apart by the gravitational force near the supermassive black hole. These events may be used to detect smaller black holes and may release detectable gravitational waves. Binary AGN, orbiting with a parsec-scale separation, may produce periodic bursts that can be monitored by the LSST. Supermassive black hole mergers, detected by their gravitational wave signals, may also be localized and monitored.

Lensing: The LSST will monitor ~4000 AGN lensed into multiple images. (See the LSST strong lensing poster here at AAS.) "Microlensing" events, in which stellar-mass objects gravitationally magnify the emission from an accretion disk, will also be observed. The resulting multi-band light curves will depend on accretion disk structure and size scales, and can therefore be used to study accretion physics and black hole demographics over a wide range of luminosities and redshifts. See the LSST strong lensing poster in this session.

Education and Outreach

AGN survey points of contact:

- **High redshifts** when the Universe was young and very different
- Powerful energy output as the **first giant black holes** feed and grow
- A **delicate balance** between small (AGN) and large (galactic) scales
- The **environments where AGN are triggered** and thrive
- Searching for visual **signatures of AGN activity** across the Universe

Educational LSST projects, using *prototype* data sets (such as simulations or SDSS Stripe 82) can be generated now. Possible examples include:

- Searching for AGN by their colors and light curve properties. How do AGN differ from stars, SNae, and galaxies?
- Mapping out the cosmic web of known AGN and comparing it to galaxy maps
- Generating movies showing how our images of AGN and galaxies change as a function of redshift and galaxy properties

Multi-Mission Synergy

The 10-year LSST AGN survey will:

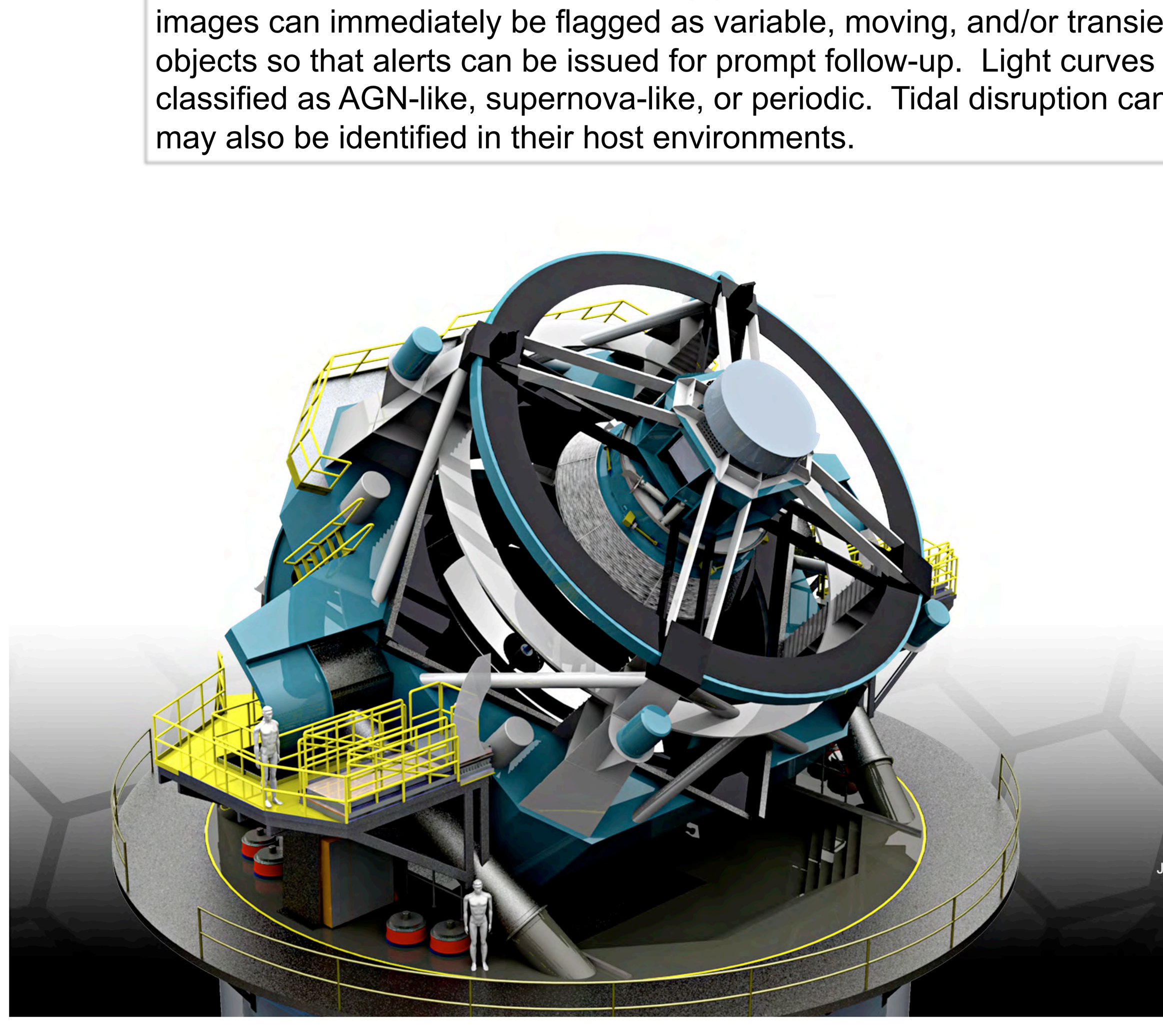
- **Complement multiwavelength data** from *Chandra, XMM-Newton, Spitzer*, HST, WFIRST, EUCLID, WISE, and other observatories.
- **Provide 10-year light curves** for sources across the southern sky.
- **Monitor sources to trigger** state-based observations; LSST can efficiently monitor an *ensemble* of sources to select one of many candidates for targeting.
- **Follow up** on sources detected by other missions, including gravitational wave detectors, as part of its natural cadence.
- **Preserve its own 10-year archive** for subsequent missions.

References

Connolly, A. J. et al. (2010), SPIE, 7738, 53
Croom, S. M. et al. (2009), MNRAS, 392, 19
Hopkins, P. F. et al. (2007a), ApJ, 662, 110
Hopkins, P. F. et al. (2007b), ApJ, 654, 731
Jiang, L. et al. (2010), Nature, 464, 380
Kelly, B. C. et al. (2009), ApJ, 698, 895
Kozlowski, S. et al. (2010), ApJ, 708, 927
LSST Science Book, arXiv:0912.0201
MacLeod, C. L. et al. (2010), arXiv:1009.2081
Richards, G. T. et al. (2009), ApJS, 180, 67
Ross, N. P. et al. (2009), ApJ, 697, 1634
Vanden Berk, D. E. et al. (2004), ApJ, 601, 692

See the **LSST Science Book** for more examples of LSST AGN Science.

Email contact for R. Gibson: `rgibson@astro.washington.edu`



January 2011

LSST is a public-private partnership. Design and development activity is supported in part by the National Science Foundation. Additional funding comes from private gifts, grants to universities, and in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.