Large Synoptic Survey Telescope

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AGN Science with the LSST

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Although the numbers of known quasars and active galactic nuclei (AGN) have grown considerably in the past decade, a vast discovery space remains to be explored. LSST will fill the gaps by producing a sample of at least 10 million optically-selected AGNs that will span more than a factor of 1,000,000 in luminosity, and will allow detection of ~1000 AGN beyond a redshift of 7. Utilizing a combination of colors, photometric variability, and lack of proper motion, this large-area AGN survey will dwarf the largest current samples by more than an order of magnitude. Each LSST region will receive ~1000 visits, allowing variability to be explored on timescales from minutes to a decade. The ground-breaking combination of area, depth, and cadence will allow for significant new AGN (and other related transient) science. LSST will break the luminosity-redshift degeneracy inherent to shallower flux-limited samples and provide unprecedented quantification of the optical AGN luminosity function. Such statistical studies will help define the demographics and accretion history of supermassive black holes with cosmic time, and relate these to the formation and evolution of galaxies. LSST will discover sufficient numbers of faint, high-redshift AGN to enable clustering measurements that will place important constraints on models for the relationship between AGN and the dark matter distribution. LSST will also investigate multi-wavelength phenomena, with its power coming from the ability to compare with both wide-area and pencil-beam surveys at other wavelengths. The former is important for investigations of rare objects, the latter for probing intrinsically more numerous, but undersampled populations. In short, LSST will produce transformative results in our understanding of AGN fueling mechanisms, the physics of accretion disks, the contribution of AGN feedback to galaxy evolution, the cosmic dark ages, and science based on the use of AGN as background sources.

Introduction

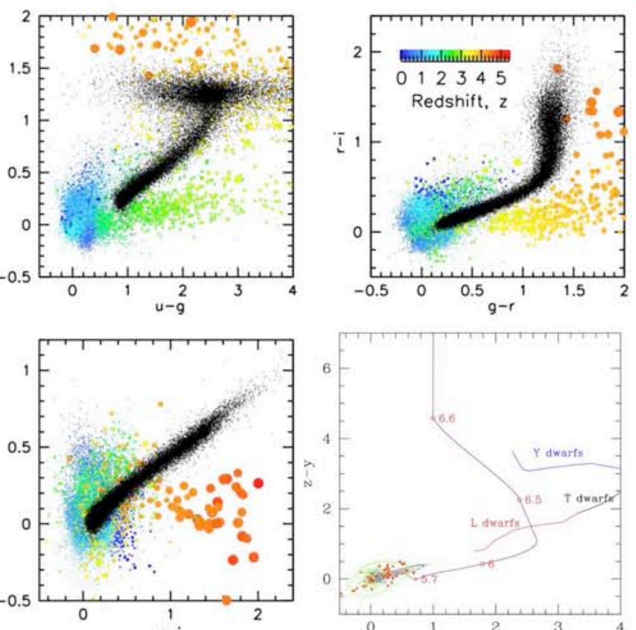
The LSST AGN survey will produce a high-purity sample of at least ten million well-defined, optically-selected AGNs. The LSST AGN sample will span a luminosity range of more than a factor of 1000 at a given redshift, and will allow the detection of AGN out to z~7. Such a sample will revolutionize our understanding of the growth of super-massive black holes (SMBHs) with cosmic time, AGN fueling mechanisms, the detailed physics of accretion disks, the contribution of AGN feedback to galaxy evolution, the cosmic dark ages, and gravitational lensing.

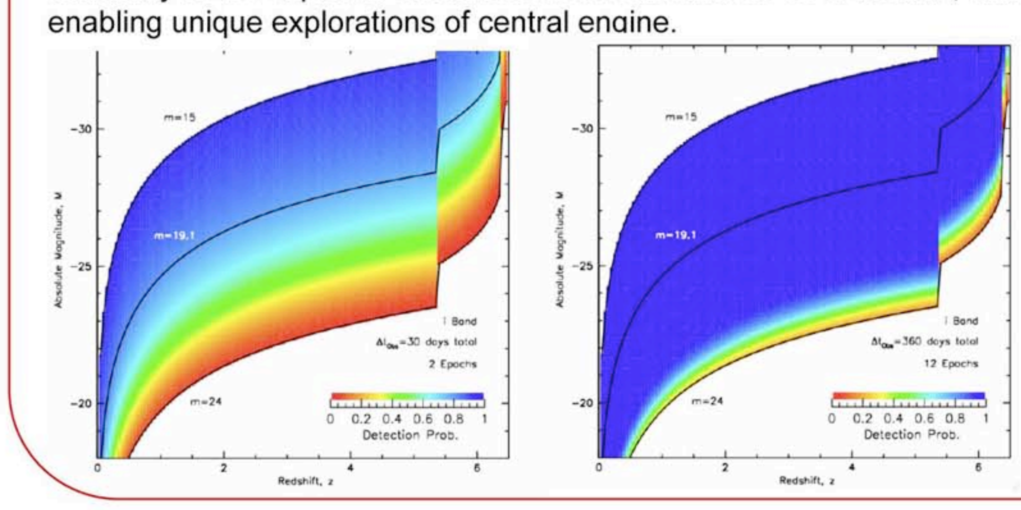
SMBHs at the centers of galaxies are intimately connected to the evolution of galaxies. Observations and simulations suggest that feedback from AGN regulates star formation, thereby directly influencing galaxy evolution. Thus, the goal of LSST AGN statistical studies is to define and measure the changing demographics and accretion history of SMBHs with cosmic time, and to relate these to the formation and evolution of galaxies. By virtue of sheer numbers, LSST will enable much more sophisticated clustering analyses. AGN clustering reflects the dark matter halos in which these objects are embedded. LSST's enormous dynamic range in luminosity and redshift will place important constraints on models for the relationship between AGN and the dark matter distribution. Because AGN are an inherently broad-band phenomenon, the overlap between the LSST AGN survey and surveys at other wavelengths will enable a large number of multi-wavelength studies. Moreover, a key benefit of this enormous LSST sample will be the discovery of unexpected, previously unknown, and/or extremely rare events such as transient fueling events or large numbers of multiply-lensed AGN.

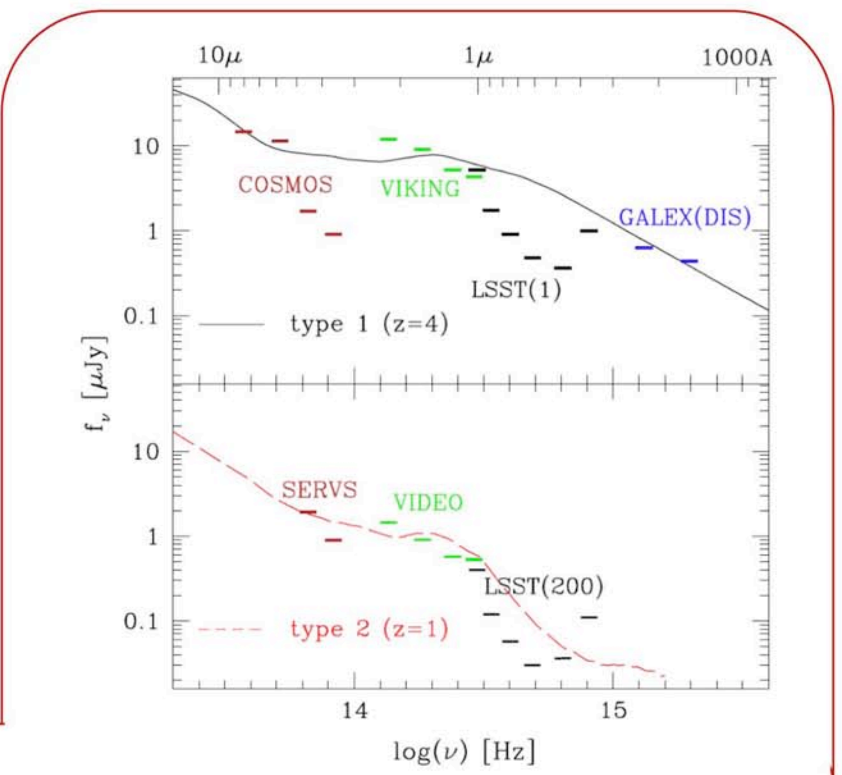
Here we summarize the selection of AGN from LSST data and how those AGN will be used for investigations of clustering, transients, the luminosity function, and multi-wavelength phenomena.

AGN Selection

Two ways in which AGN will be identified by LSST are from their colors in the LSST six-band filter system, and from their variability (Vanden Berk et al. 2004; Sesar et al. 2007). On the right, we show the distribution of known quasars in LSST *ugrizy* color space. The *u*-band data are crucial for low-z quasars, while the *y*-filter should allow quasars with redshifts of 7.5 to be selected. The figure below shows the fraction of quasars that can be selected by variability as a function of magnitude and redshift. Even with only two epochs separated by 30 days, a large fraction of AGN will be detected as variable objects. After 12 epochs with a total temporal baseline of 360 days, nearly all of the AGN to a limiting apparent magnitude of 24 will be detected as variable Eventually, each region of LSST sky will eventually receive roughly 1000 visits over the decade-long survey (with as many as 200 in each band), allowing variability to be explored on timescales from minutes to a decade, and enabling unique explorations of central engine.





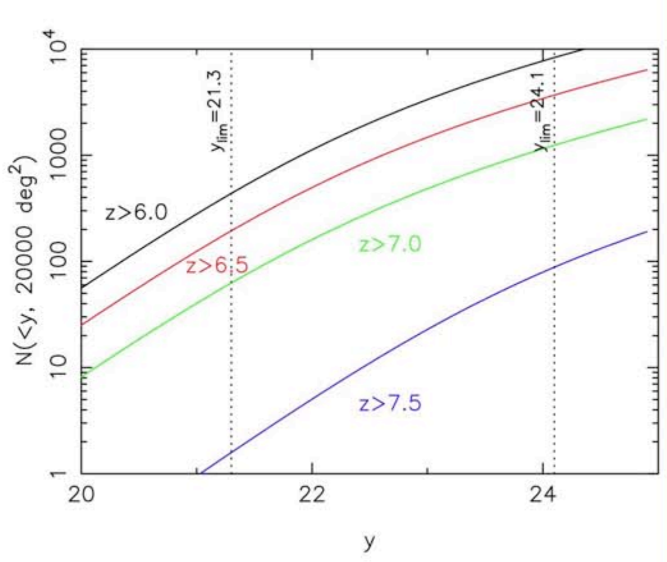


Multiwavelength

AGN are an inherently broad-band phenomenon with emission from the highest-energy gamma-rays to long-wavelength radio probing different aspects of the physics of the central engine (e.g., Elvis et al. 1994). The rich diversity of radiation that adds complexity to their SEDs also enable a more detailed understanding of their complicated, multi-region structure from the accretion disk, to corona, to jets, to outflowing winds. LSST will overlap surveys carried out in a broad range of wavelengths, allowing studies of a large number of multi-wavelength phenomena. LSST's multi-wavelength power comes from the ability to compare with both wide-area and "pencil-beam" surveys at other wavelengths. The former are important for investigations of "rare" objects, while the latter probe intrinsically more numerous, but undersampled population. The figure above compares the LSST single epoch depth to other large area fields (*top*) in addition to showing examples of where the co-added depth of LSST complements deep observations at other wavelengths (*bottom*). Multi-wavelength data for the LSST AGN census will produce the largest inventory of AGN SEDs over a very wide wavelength range, allowing better constraints on typical accretion and reprocessing mechanisms.

By the Numbers

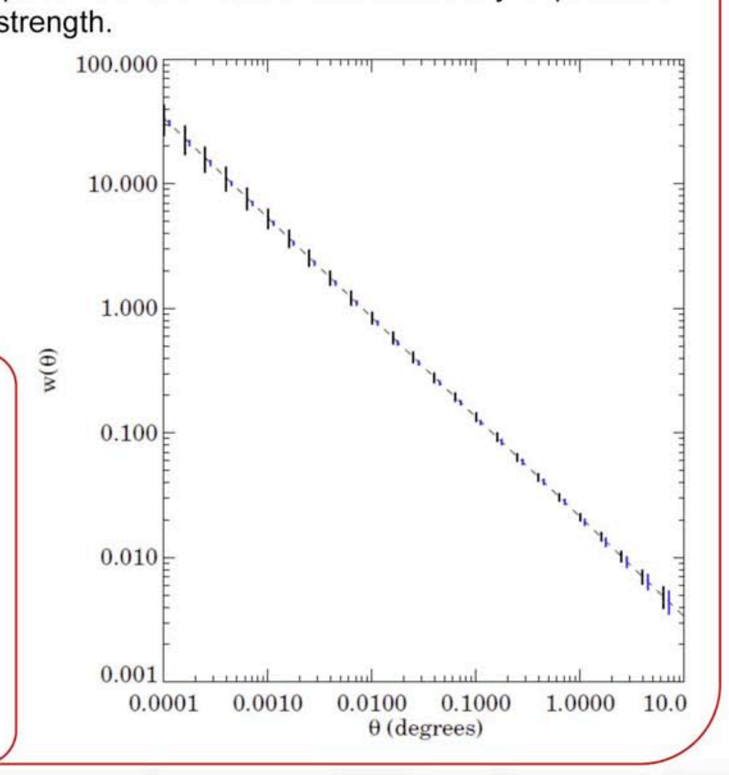
Utilizing large sky coverage, depth, six filters extending to 1μm, and valuable temporal information, the LSST AGN survey will dwarf the largest current AGN samples by more than an order of magnitude. The table below indicates that, in 20,000 deg^2, as many as 16 million AGN will be detected to i<26.5 according to the Hopkins et al. (2007) luminosity function. At high redshift, a better estimate is provided by Jiang et al. (2009). The figure on the right graphically illustrates the vast numbers of AGN that will be found at z>6; The current number is only ~40.



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

Clustering

AGN clustering is a reflection of the dark matter halos in which these objects are embedded. The relationship between AGN clustering and that of "ordinary" galaxies can give important clues about how the two are physically related. The galaxy correlation function at low redshift has been measured precisely, using samples of hundreds of thousands of galaxies (e.g., Zehavi et al. 2005), allowing quite accurate determination of the bias as a function of scale for various subsets of galaxies. However, AGN are rarer, and the measurements are not as accurate (for example, the mean separation between z~3 quasars in the SDSS is of order 150 co-moving Mpc). The enormous AGN samples selectable from LSST data will cover a very large range of luminosity at each redshift, allowing the clustering, and thus bias and host galaxy halo mass, to be determined over a large range of cosmic epoch and black hole accretion rate. The figure below shows both the angular quasar auto-correlation, and the quasar-galaxy cross-correlation, that we might expect for a sample of 250,000 quasars with 2.75<*z*<3.25 with *g*<22.5 (i.e., easily visible in a single visit). In fact, our photometric redshifts will be good enough to explore clustering in substantially finer redshift bins, strengthening the clustering signal. Even with broad redshift bins, correlation function errors are small enough that we can divide the sample into many bins in luminosity, color, or other properties, allowing us to explore both the redshift and luminosity dependence of the clustering strength.



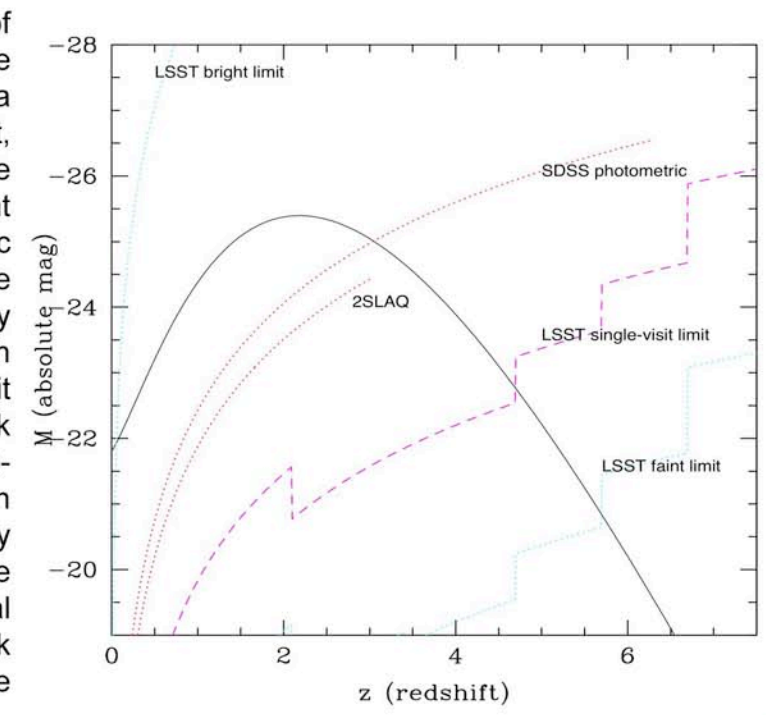
Transient SMBH Phenomena

Strong transient outbursts from galactic nuclei can occur when a star, planet, or gas cloud is tidally disrupted and partially accreted by a central SMBH. An optical flare lasting several months is expected when a star disintegrates outside the event horizon. LSST will be a premier facility for discovering and monitoring such transient SMBH phenomena, enabling and aiding studies across the electromagnetic spectrum as well as detections with gravitational waves. Gezari et al. (2009) predict that LSST should detect at least 130 tidal disruptions per year.

Luminosity Function

The LSST AGN sample will produce a measurement of the AGN luminosity function and its evolution that will break the luminosity-redshift degeneracy inherent to most flux-limited samples. Only ultrafaint (m>22.5) surveys can probe the populous, faint end of the AGN LF, especially at moderate to high redshifts. For example, an AGN with absolute magnitude M=-23, i.e., a high space density object from the faint end of the luminosity function, will have apparent magnitude m>22.5 at z>2.1. In the currently popular merger plus feedback model of Hopkins et al. (2006) , the faint-end slope of the luminosity function is a measure of how much time quasars spend accreting at sub-Eddington rates (either before or after a maximally accreting state). The bright-end slope, on the other hand, tells us about the intrinsic properties of quasar hosts (such as merger rates). Understanding the evolution of the bright- and faint-end quasar LF slopes is central to understanding cosmic downsizing.

The figure on the right shows a realization of one of these downsizing models: it adopts the usual double power-law shape, but allows for a break luminosity L* that evolves with redshift, as shown by the solid line. Superposed are dotted red curves representative of the faint limits of the 2SLAQ and the SDSS photometric surveys (Richards et al. 2005, 2009). These surveys, however, don't probe significantly beyond the break luminosity for redshifts much larger than 2. The faint limit in a single visit (dashed magenta line) probes to the break luminosity to z = 4.5, and to z = 5.5 in the co-added images (lower dotted cyan line), even in this model in which the break luminosity decreases rapidly at high redshift. Thus the LSST-determined quasar LF will provide crucial insights to our understanding of AGN feedback in the early Universe and how it influences the evolution of massive galaxies.



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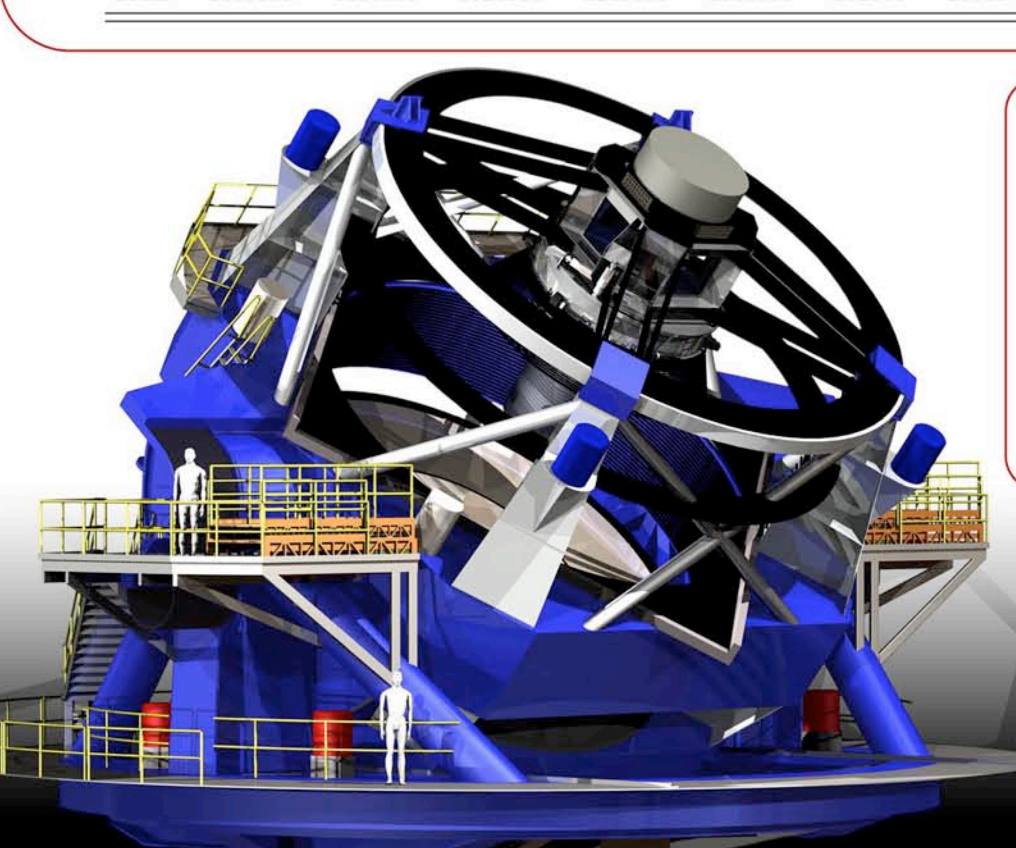

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