

AGN Science with the LSST

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The LSST, with its unprecedented combination of sky coverage, photometric and astrometric accuracy, sensitivity, broad wavelength coverage, and time sampling, will provide a new window into the nature of AGNs. Well-defined, large ($> 10^7$ objects) samples of AGNs at $0 < z < 6$ can be constructed via three approaches: location in color-color space, variability, and lack of proper motion. The samples will allow determination of the AGN luminosity function down to Seyfert luminosities out to $z \sim 4$. The near-infrared wavelength coverage/high sensitivity of LSST enables detection of the population of red quasars, and the proper motion criteria will be particularly effective at separating $z > 4$ AGNs from brown dwarfs. The time baseline coupled with the sample size will produce a data set that can be used to address the physics of the AGN accretion process, including insights into the lifetime of AGNs.

Quasar Surface Density

In order to determine the expected number of quasars that will be detected and selected by the LSST, we first estimate the true surface density of quasars to a limiting magnitude of $i=24$. The estimate is based on a combination of the luminosity functions of Croom et al. (2004, MNRAS, 349, 1397) for $z < 3$ and Fan et al. (2001, AJ, 121, 54) for $z > 3$. This calculation required considerable extrapolation for the faint end of the quasar luminosity function (determination of the faint end of the quasar luminosity function is, of course, one of the goals of the LSST program).

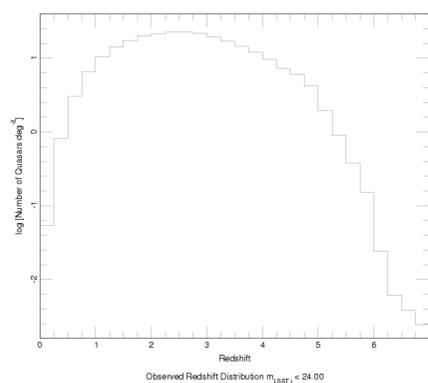


Fig. 1 – Histogram of the expected number of quasars per square degree with $i < 24$ as a function of redshift. Assuming a high completeness rate expected from the results shown in this poster, **well over 100 quasars per square degree should be able to be identified** with LSST observations.

Color Selection

The primary selection technique of most quasar surveys has been multi-color selection. The LSST will have 5 filters – g, r, i, z, Y – giving a four-dimensional color space. Without a near-UV filter, low-redshift quasars will not be as well separated from the stellar locus as they are in surveys such as the SDSS. However, most quasars will still be distinguishable from stars in color space, and high-redshift quasars will be selected with relative ease. To demonstrate this, we have taken existing photometric data on stars and quasars from the SDSS DR1 (Schneider et al. 2003), and transformed the colors to the expected LSST system. The transformations were determined by convolving a synthetic quasar spectrum, and stellar spectra from the Gunn & Stryker atlas (1983), with the filter transmission curves for both the SDSS and LSST systems.

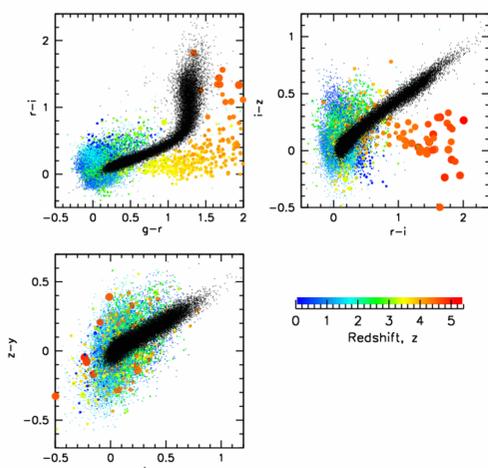


Fig. 2 – Color-color plots of known quasars (colored dots) and stars (black dots) in the LSST photometric system. The quasars are color coded by redshift according to the color key, and for clarity, the dot size is inversely proportional to the expected surface density as a function of redshift. Since there is no Y filter in the SDSS system, a random Gaussian color offset has been added to the z - Y color according to the width of the stellar locus in the i - z color. The greatest incompleteness will occur at redshifts between about 2.5 and 3.

Variability

It is well-known that AGNs vary in brightness at optical and UV wavelengths. The amplitude of variability depends upon rest frame time lag, wavelength, luminosity, and possibly redshift (Vanden Berk et al. 2004). We use the parameterized description of AGN variability from the SDSS (Ivezic et al. 2004) extrapolated to fainter apparent magnitudes, to estimate the fraction of AGNs in the LSST that may be detected as significantly variable. We assume that the 10 sigma detection limit in a single-epoch LSST image is 24 in the i band, and calculate the magnitude difference at which only 1% of the non-variable stars will be flagged as a 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 (as it determines rest wavelength and rest time lag), luminosity, observed time lag, and the number of observing epochs.

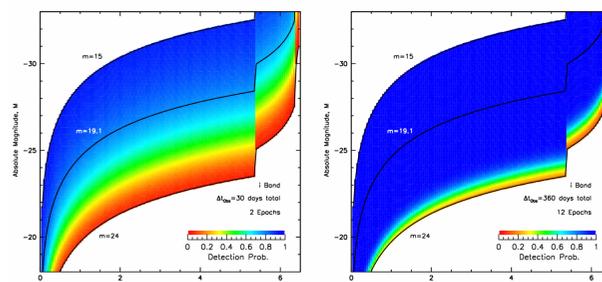


Fig. 3 – The probability of detecting an AGN as variable as a function of redshift and absolute magnitude. *Left*: 2 epochs separated by 30 days. *Right*: 12 epochs spanning a total of 360 days. Nearly all of the AGNs between the limiting apparent magnitudes would be detected as variable after 1 year.

Even with only 2 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; intervening Lyman series absorption shortward of the 1216Å emission line also affects the detection probability. 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 5 bands will improve the detection fraction even further.

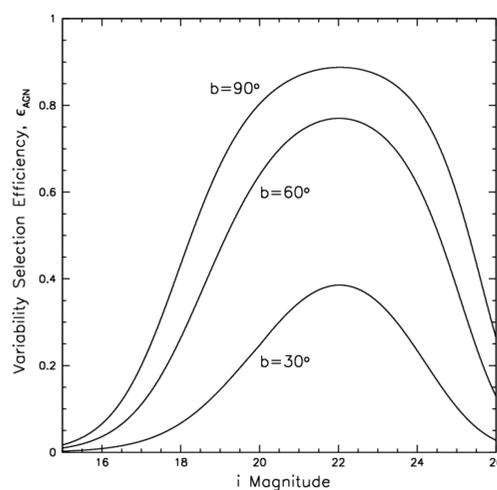


Fig. 4 – The selection efficiency for AGNs (fraction of true AGNs among AGN candidates) in the LSST as a function of apparent i band magnitude and Galactic latitude. We have assumed that 1% of the stars will be selected as variable due to measurement uncertainty, and we have assumed the stellar surface density distribution of Bahcall & Soneira (1980).

Non-AGN variable sources include a wide variety of variable stars. These can be largely separated from the AGN sample using colors and proper motions, but also by using lightcurves. Many types of variable stars have characteristic lightcurve signatures which differ significantly from the aperiodic structure functions of AGNs.

Proper Motion

Zero proper motion will further distinguish faint quasars from stars to varying degrees of success. The 3 sigma upper limit on proper motion for the full 10 years of the LSST survey is intended to be 0.006"/yr. To estimate the fraction of a given stellar population eliminated by an upper limit on proper motion, we use a Galactic model consisting of a thin disk, a thick disk with scale height of ~ 1 kpc, and a round halo with effective radius ~ 4 kpc. (e.g., Ibata et al. 2001). That halo fits an isothermal sphere with circular velocity at large radius of ~ 200 km/s. We assume that the tangential velocity dispersion is equivalent to the radial velocity dispersion as observed at the Galactic Poles. For the estimate we adopt dispersions (e.g., Beers & Sommer-Larsen 1995): Disk: 30 km/s, Thick Disk: 60 km/s, Outer Halo: 130 km/s. The table shows the fraction of stars in each Galactic component that will be eliminated by proper motion, as a function of distance above the mid-plane.

Distance above mid-plane	15 pc	150 pc	500 pc	1 kpc	5 kpc	10 kpc
3- σ limit on transverse vel. (km/s)	0.5	43	14.2	28	142	284
Percentage of thin disk stars eliminated	98%	89%	64%			
Percentage of thick disk stars eliminated	99%	94%	81%	64%	2%	
Percentage of halo stars eliminated	99.7%	97%	91%	83%	28%	3%

Halo main sequence stars from turn-off through late K will be contaminants only at intermediate brightnesses. At the full stacked image limit equivalent to $r=26$ mag, a turn-off star in the outer halo would be at a distance of 160 kpc. Even an M4 dwarf would be at ~ 10 kpc at the magnitude limit. Main sequence stars overlapping quasars with $3.6 < z < 4.0$ in color-color space will be more prevalent at $r \leq 23$ mag. That limit puts a K5 star at 14 kpc and an M0 at 9 kpc.

At the extreme limit of $g=26$, a white dwarf with $M_V = 10.5$ will be at a distance of 12.6 kpc, still within the distant halo, while a cool white dwarf with $M_V = 15.5$ will be at 1.3 kpc, possibly a thick disk member.

The very red i, z, Y colors of L and T dwarfs make them prime contaminants of the high- z quasar population, so here the proper motion limits are important discriminants. For an L5 star with $M_r = +20$ (Hawley et al. 2002), a survey limit of $r=26$ puts the object at 160 pc. For a T5 brown dwarf with $M_r = +25$, the distance is 15 pc.

The stringent upper limit on proper motions will essentially eliminate L and T dwarfs as contaminants of the very high- z quasar candidate lists. Cool white dwarfs will also be effectively screened. Hotter white dwarfs and main sequence stars earlier than K spectral type will be eliminated from the magnitude range typical of the current SDSS samples. An increasing fraction of the halo white dwarfs will remain as contaminants as the LSST survey limits are approached. The decrease in surface density of very distant halo main sequence stars will somewhat counteract the increasing fraction of the population with apparently zero PM from the relaxing of tangential velocity limits toward the faintest survey magnitudes.

Quasar Lifetimes

The long time baseline, high photometric quality, and large number of detected quasars will allow limits to be placed on the lifetimes of quasars.

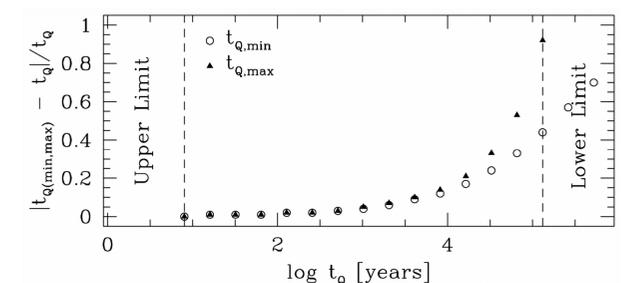


Fig. 5 – Quality of the potential measurement of the quasar lifetime by the LSST as a function of quasar lifetime. The constraint or measurement of t_q is based on reobservations of 120,000 quasars 10 yr after their epoch of spectroscopic identification, which provides a net time baseline of approximately 500,000 yr for the redshift distribution of the SDSS EDR. The magnitude of the lower (open circles) and upper (filled triangles) bounds on t_q has been computed with Poisson statistics (Martini & Schneider, 2003).