Supermassive Black Hole Studies with the LSST

Niel Brandt and the
LSST AGN Science Collaboration

Talk Outline

Quick LSST review.

AGN selection with LSST and multiwavelength data.

Examples of exciting science investigations:

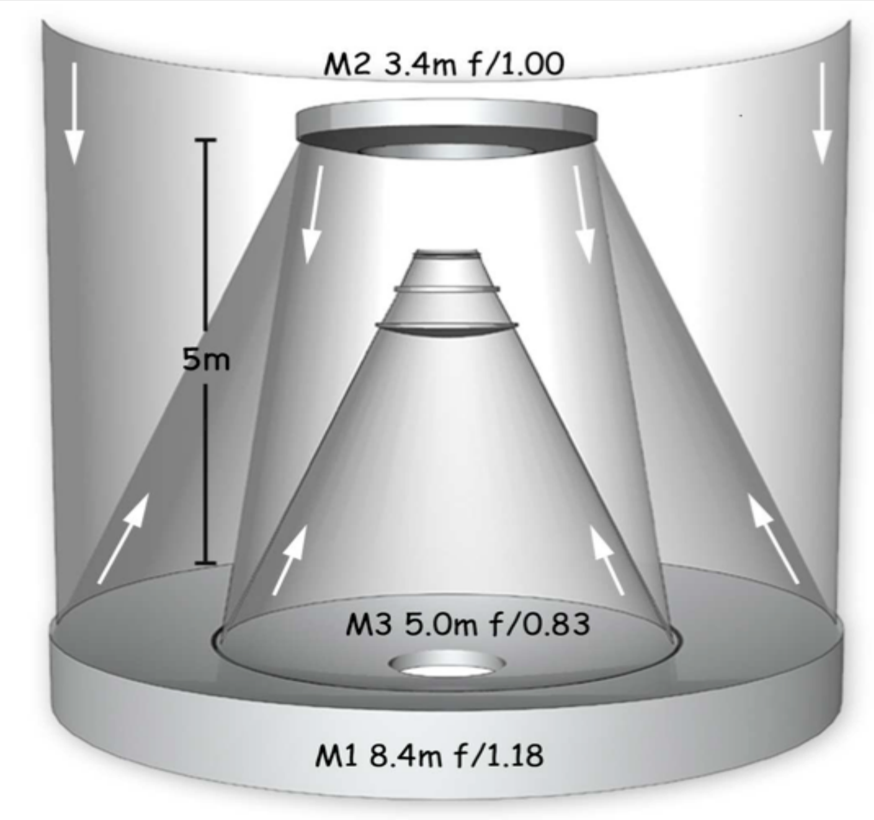
- Massive AGN variability studies
- Transient SMBH fueling events
- AGN investigations at high redshift

The LSST AGN Science Collaboration and future plans.

Quick LSST Review

Very Brief Summary

A public optical/NIR survey of ~ half the sky in the *ugrizy* bands to *r* ~ 27.5 based on ~ 820 visits over a 10-year period.



8.4 m, 6.7 m effective - 10 deg^2 - 3.2 Gpix camera

Wide
The observable southern sky. Each exposure covers 50 full Moons.

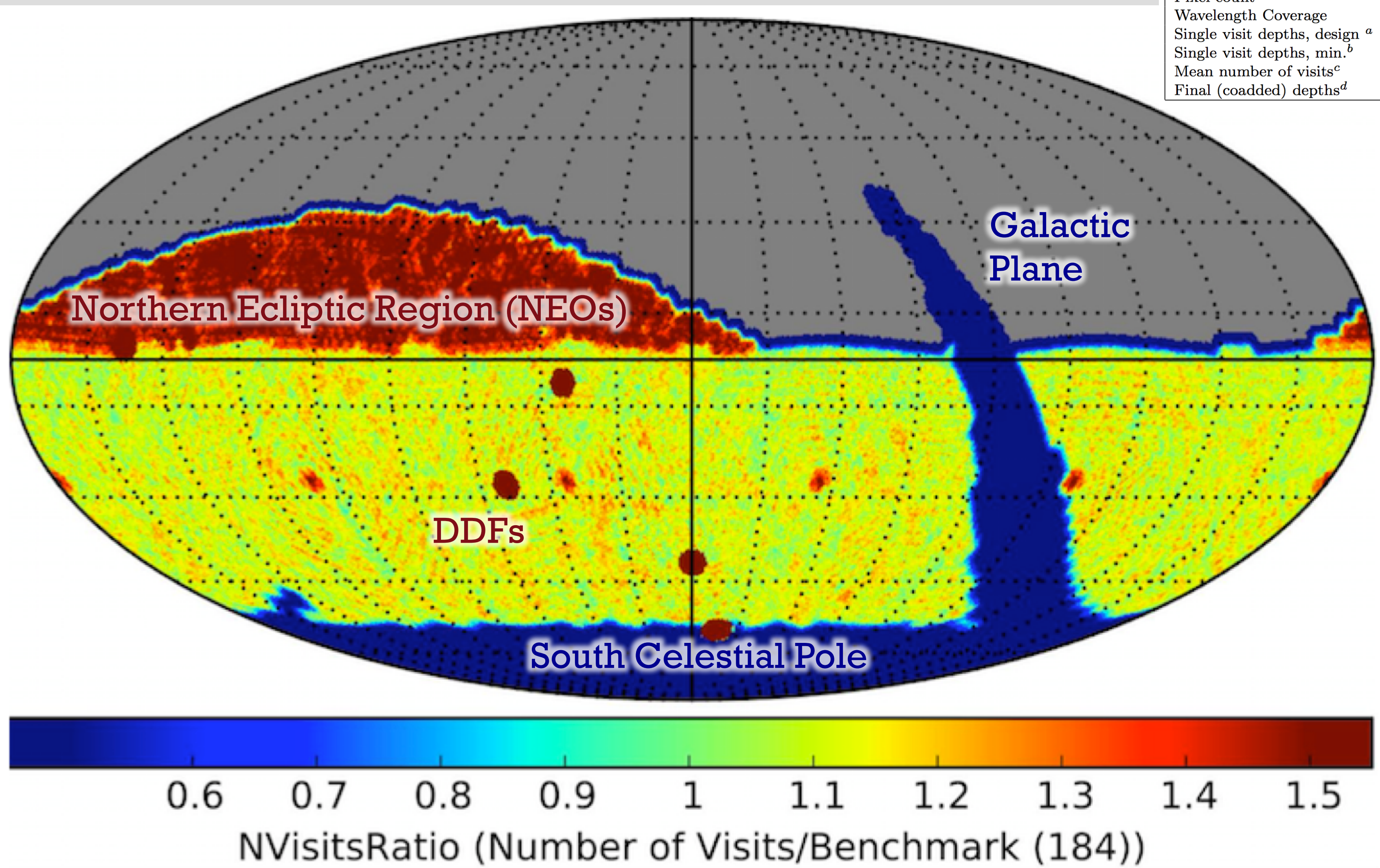
Deep
10-100 times deeper than other very wide-field surveys.

Fast
Rapidly scans the sky with 15 sec exposures, providing a color movie of objects that change or move. Whole observable sky scanned every 3-4 nights.

See arXiv:0805.2366 for more details.

Main Survey - Brief Details

Operations Simulation of *r*-Band Visits



THE LSST BASELINE DESIGN AND SURVEY PARAMETERS

Quantity	Baseline Design Specification
Optical Config.	3-mirror modified Paul-Baker
Mount Config.	Alt-azimuth
Final f-ratio, aperture	f/1.234, 8.4 m
Field of view, étendue	9.6 deg^2, 319 m^2deg^2
Plate Scale	50.9 μm/arcsec (0.2" pix)
Pixel count	3.2 Gigapix
Wavelength Coverage	320 – 1050 nm, *ugrizy*
Single visit depths, design [a]	23.9, 25.0, 24.7, 24.0, 23.3, 22.1
Single visit depths, min.[b]	23.4, 24.6, 24.3, 23.6, 22.9, 21.7
Mean number of visits[c]	56, 80, 184, 184, 160, 160
Final (coadded) depths[d]	26.1, 27.4, 27.5, 26.8, 26.1, 24.9

Main survey optimized for homogeneity of depth and number of visits.

Other Cadence Programs

About 90% of the time will be spent on the main survey.

Remaining ~ 10% will be used for other cadence programs.

Deep-Drilling Fields

- Blank fields (e.g., E-CDF-S, XMM-LSS, COSMOS, ELAIS-S1)
- Nearby clusters of galaxies (e.g., Fornax)
- Local Group and the Galaxy (e.g., LMC, SMC, open clusters)
- Solar System (e.g., TNOs, Neptune Trojans, Jupiter Trojans)

Blank fields aim for 5300-14000 visits per band reaching
$urgi = 28.5$, $z = 28.0$, $y = 27.0$.

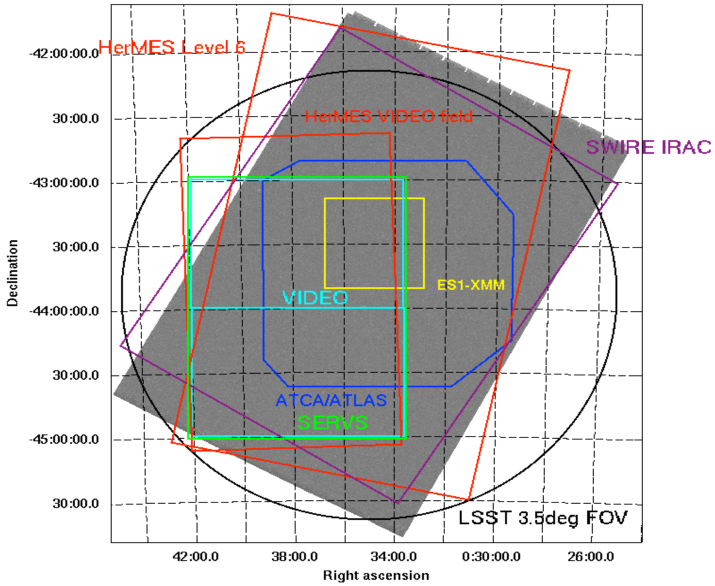
Details under discussion by the Deep-Drilling Interest Group.

Other possible cadence programs include North Ecliptic Spur, South Celestial Pole, improved Galactic plane, TOOs, etc.

The Four Selected DDFs: Multiwavelength Coverage

ELAIS-S1

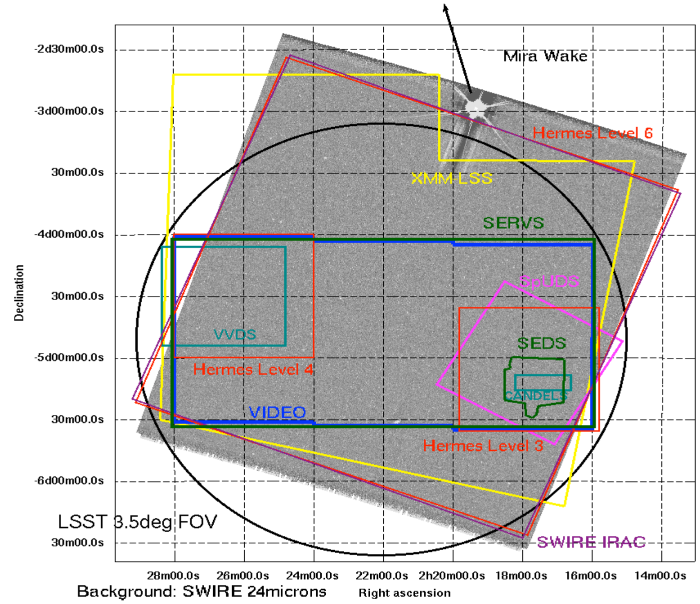
New Spitzer



XMM-LSS

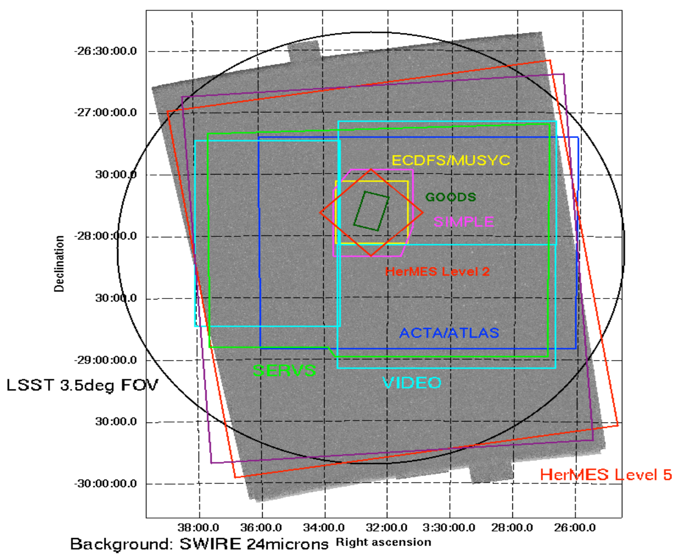
New Spitzer

New XMM-Newton ongoing

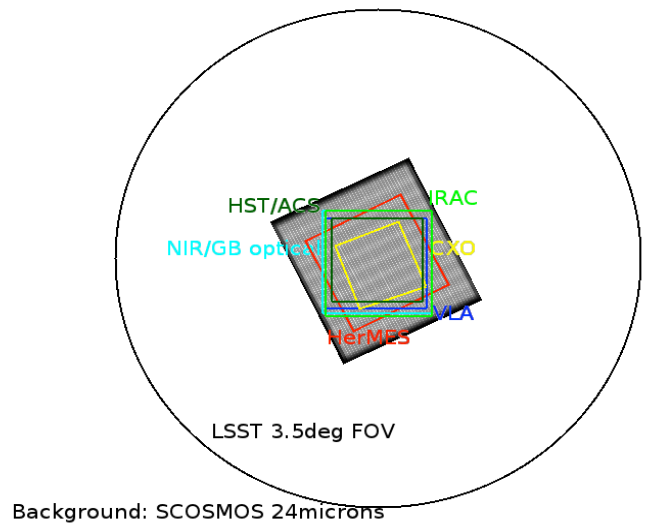


Extended CDF-S

New Spitzer



COSMOS



LSST Deep-Drilling Field White Papers

Distant Extragalactic

LSST Deep Drilling for Galaxies

Authors: H. C. Ferguson,

Contact Information for Lead Author/Authors: Henry C. Ferguson, Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218 ferguson@stsci.edu (410) 338-5098

Ultra-deep *ugrizy* Imaging to Reduce Main Survey Photo-z Systematics and to Probe Faint Galaxy Clustering, AGN, and Strong Lenses

Authors: Eric Gawiser, Jeff Newman, Hu Zhan, David Ballantyne, Niel Brandt, Andy Connolly, Jack Hughes, Philip Marshall, Sam Schmidt, Ohad Shemmer, and Tony Tyson

Using LSST Deep Drilling Fields to Improve Weak Lensing Measurements

Authors: Zhaoming Ma (BNL), Jeffrey Newman (Pittsburgh), Ian Dell'Antonio (Brown), Mike Jarvis (UPenn), Gary Bernstein (UPenn), David Wittman (UC Davis), Tony Tyson (UC Davis), Ryan Scranton (UC Davis), Erin Sheldon (BNL), Rachel Mandelbaum (Princeton), Bhuvnesh Jain (UPenn), Morgan May (BNL/Columbia)

Supernova Light Curves (March 20, 2011)

Authors: Richard Kessler (U.Chicago), Pierre Astier (U.Paris VI& VII), David Cinabro (Wayne State), Joshua Frieman (U.Chicago,FNAL), Saurabh Jha (U.Rutgers), Maryam Modjaz (Columbia U), Dovi Poznanski (U.C. Berkeley), Masao Sako (U.Penn), Michael Wood-Vasey (U.Pitt)

Standard Candle Relations and Photo-diversity of Type Ia Supernovae
Arlin Crotts

Galactic and Local Group

Mapping the Milky Way's Ultracool Dwarfs, Subdwarfs, and White Dwarfs

S. Dhital (Vanderbilt), P. Thorman (UC–Davis), J. J. Bochanski (Penn State), P. Boeshaar (UC–Davis), A. J. Burgasser (UC–San Diego), P. A. Cargile (Vanderbilt), K. R. Covey (Cornell), J. R. A. Davenport (Washington), L. Hebb (Vanderbilt), T. J. Henry (Georgia State), E. J. Hilton (Washington), Z. Ivezić (Washington), J. S. Kalirai (STSci), S. Lépine (AMNH), J. Pepper (Vanderbilt), S. J. Schmidt (Washington), K. G. Stassun (Vanderbilt), L. M. Walkowicz (UC–Berkeley), A. A. West (Boston Univ)

High Cadence Observations of the Magellanic Clouds and Select Galactic Cluster Fields

Authors: P. Szkody (U Washington), K. S. Long (STScI), R. DiStefano (CfA), A. Henden (AAVSO), J. Kalirai (STScI), V. Kashyap (CfA), M. Kasliwal (Cal Tech), J. A. Smith (APSU), K. Stassun (Vanderbilt)

Solar System

Opportunities for Solar System Science

Authors: A.C. Becker (U. Washington), C.A. Trujillo (Gemini Observatory), R.L. Jones (U. Washington), N.A. Kaib (CITA), D. Ragozzine (SAO), S.T. Ridgway (NOAO), *and* the LSST Solar System Science Working Group

AGN Selection

LSST AGN Selection

Multicolor selection in *ugrizy* from z = 0-7.5

- Ultraviolet excess below $z \sim 2.5$
- Lyman-α forest at high redshifts
- Works best when $L_{\mathrm{AGN}} > L_{\mathrm{Host}}$

Variability

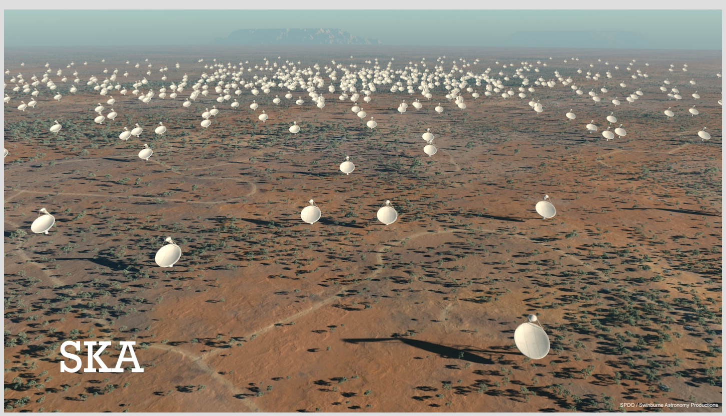
- 55-185 samplings per band over 10 yr
- Highly effective complement to color selection
- Still need effectiveness assessments when $L_{\mathrm{AGN}} \sim L_{\mathrm{host}}$

Astrometry - Lack of proper motion and differential chromatic refraction

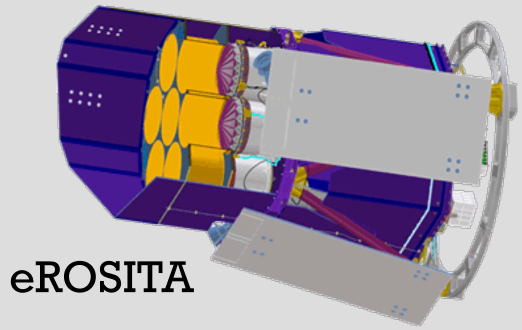
- Will reach ~ 1 mas yr^{-1} at $r \sim 24$
- Minimizes confusion with stars

Multiwavelength AGN Selection

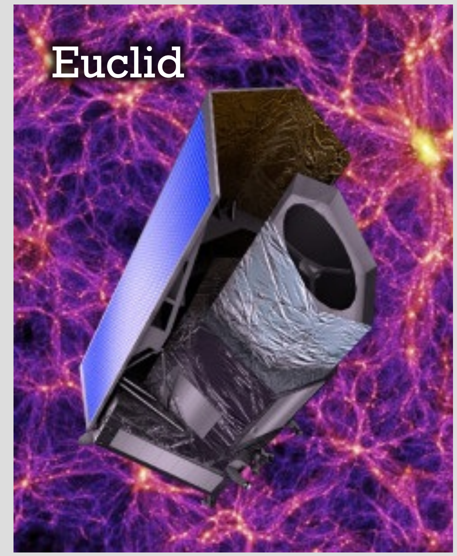
L_R, T_b, morphology



L_X and Γ_X

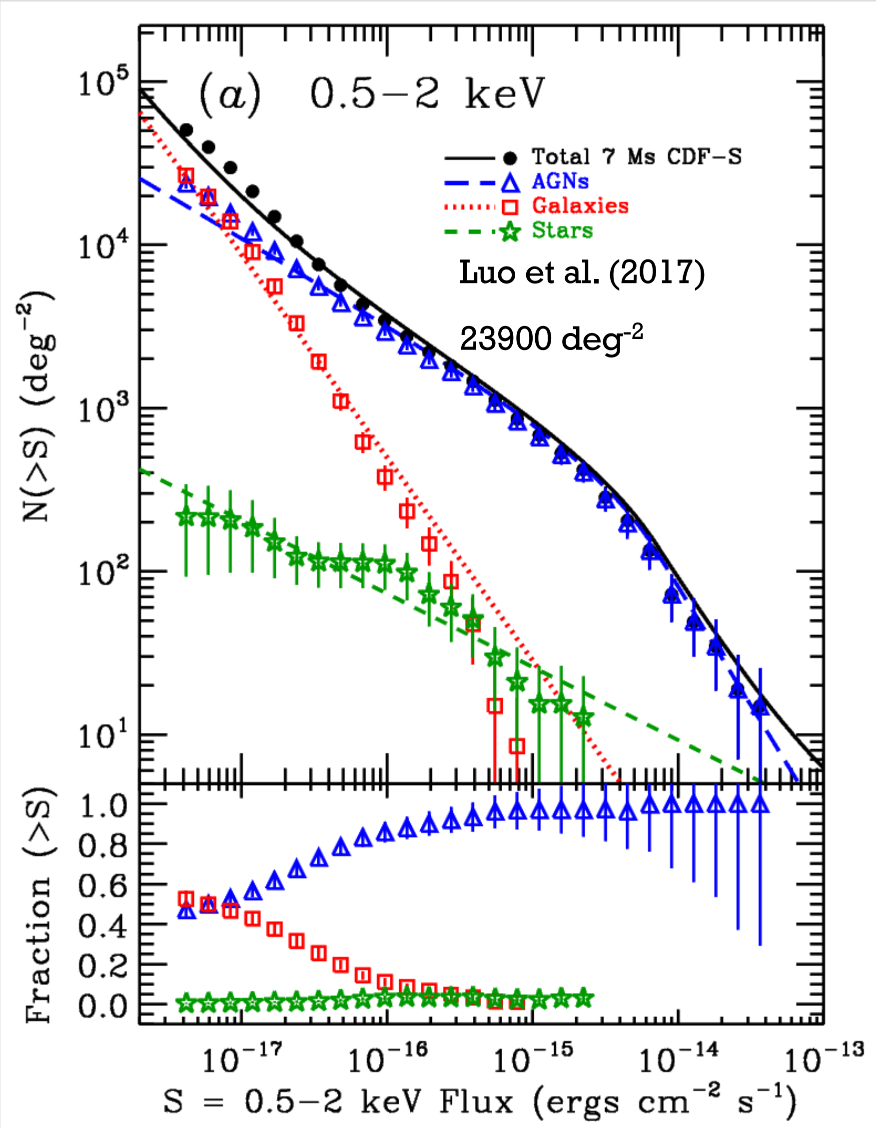


Infrared-optical colors



Plausible AGN Yields

Chandra Deep Field-South Number Counts



Will *detect* ~ 300+ million AGNs in 18000 deg^2 primary LSST survey area.

Obscuration and host-galaxy dilution will hinder AGN *selection*.

Confidently can select 20 million.

Hope to select 50+ million, especially using multiwavelength data.

Overwhelming statistics to investigate AGN evolution as a function of environment - voids to superclusters.

Plausible AGN Yields

Variability Selected Quasar Predictions from Palanque-Delabrouille et al. (2013)

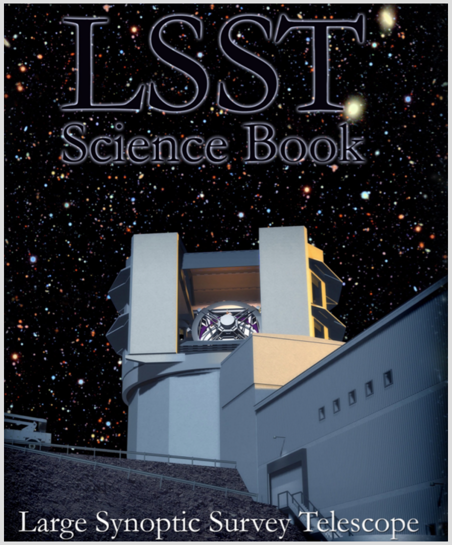
Table 8. Predicted number of quasars over $15.5 < g < 25$ and $0 < z < 6$ for a survey covering 10 000 deg^2, based on our best-fit luminosity function.

g/z	0.5	1.5	2.5	3.5	4.5	5.5	Total
15.75	76	15	0	0	0	0	92
16.25	174	55	11	0	0	0	239
16.75	402	172	61	0	0	0	635
17.25	939	535	180	6	0	0	1661
17.75	2163	1630	508	21	1	0	4323
18.25	4740	4720	1409	57	2	0	10 928
18.75	9456	12 380	3784	156	5	0	25 781
19.25	16 612	27 796	9409	422	14	0	54 255
19.75	25 537	51 561	20 579	1128	39	1	98 846
20.25	35 185	80 209	38 096	2923	107	4	156 523
20.75	45 008	110 341	59 939	7085	289	10	222 671
21.25	54 980	141 918	82 650	15 386	779	27	295 740
21.75	64 988	176 959	103 733	28 916	2036	74	376 706
22.25	74 189	217 815	122 861	46 636	5064	201	466 766
22.75	80 370	266 716	141 310	65 652	11 408	545	566 001
23.25	79 024	325 945	160 621	82 972	22 419	1436	672 417
23.75	61 347	398 006	182 048	97 320	37 756	3632	780 110
24.25	15 976	480 676	206 510	109 295	55 090	8401	875 949
24.75	0	492 283	234 874	120 118	71 481	17 111	935 866
Total	571 169	2 789 734	1 368 583	578 092	206 489	31 444	5 545 510

Notes. Bins are centered on the indicated magnitude and redshift values. The ranges in each bin are $\Delta g = 0.5$ and $\Delta z = 1$.

where we call "quasar" an object with a luminosity $M_i[z = 2] < -20.5$ and either displaying at least one emission line with FWHM greater than 500 km s^{-1} or, if not, having interesting/complex absorption features.

Example AGN Science Investigations



See Chapter 10 of the LSST Science Book for more details and other examples.

Nightly LSST SMBH Science

Monitoring of ~ 3 million AGNs (~ 10+ million total).

Discovery of ~ 50 large AGN flares
(e.g., blazars and accretion-disk instabilities).

Discovery of ~ 3 stellar tidal disruption events.

Discovery of ~ 0.1 strong quasar microlensing events.

Binary SMBH inspirals and mergers?

Also ~ 2500 supernovae and ~ 5 “orphan” GRB afterglows.

Massive AGN Variability Studies

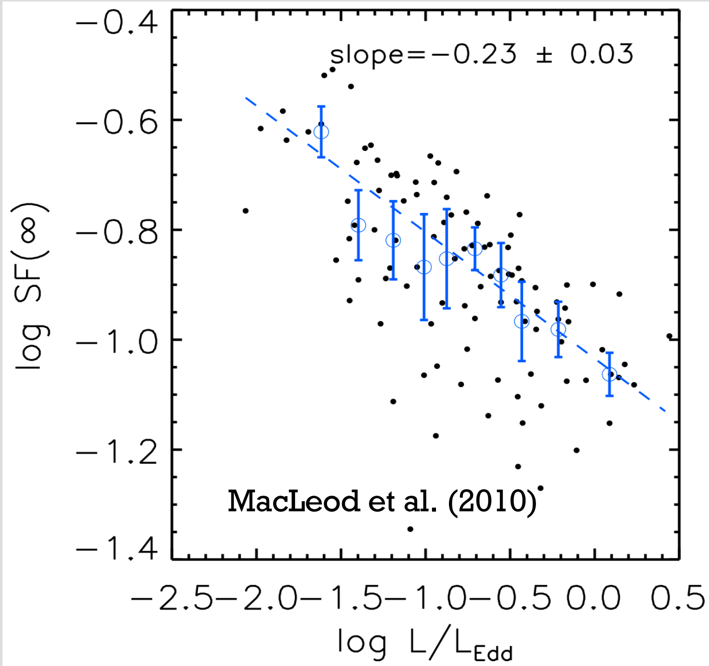
Massive AGN Variability Studies

Millions of well-sampled, accurate, multicolor AGN light curves, spanning minutes-to-years (billions of photometric measurements).

Even better sampling and depth for ~ 10^5 AGNs in the DDFs.

Can combine with DES, HSC, Pan-STARRS, SDSS for longer baselines.

Eddington-Ratio Dependence of Long-Timescale RMS Variability

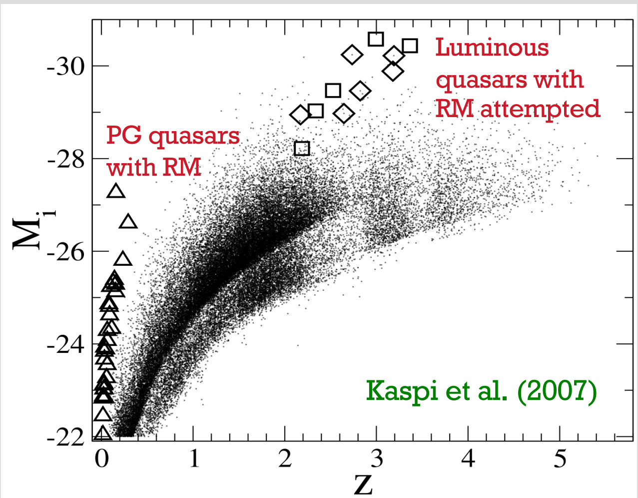


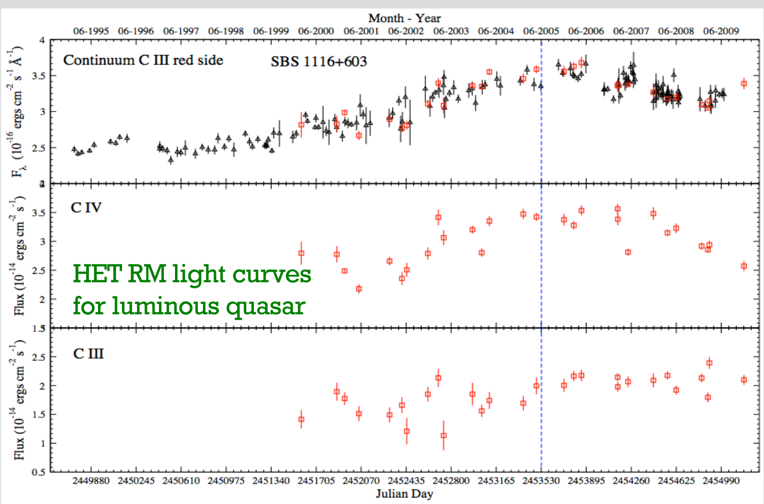
Can powerfully study general luminosity and spectral variability as a function of L, z, λ, Δt, color, radio properties, line properties, M_{BH}, L/L_{Edd} (some require one-epoch spectra).

Rare but important events - large disk instabilities, strong jet flares, swan-song events, QPOs.

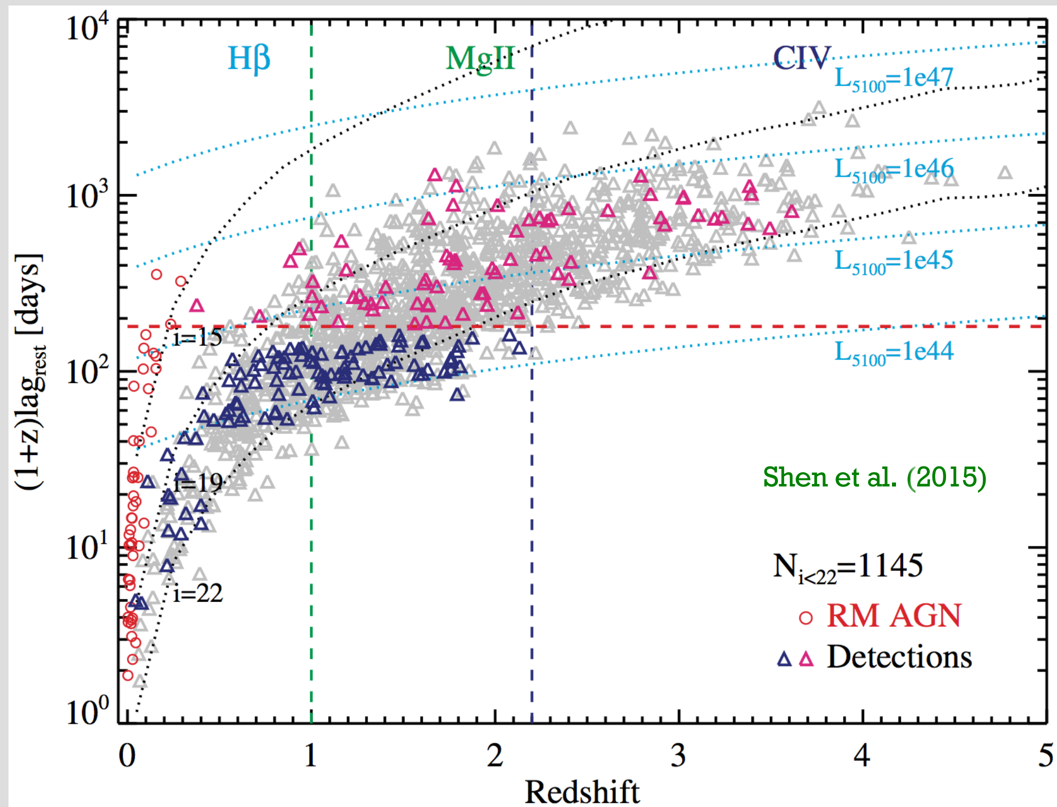
Triggered Spectroscopic Follow-Up: RM

Strong Quasar Continuum Variations Can Trigger Reverberation Mapping Follow-Up





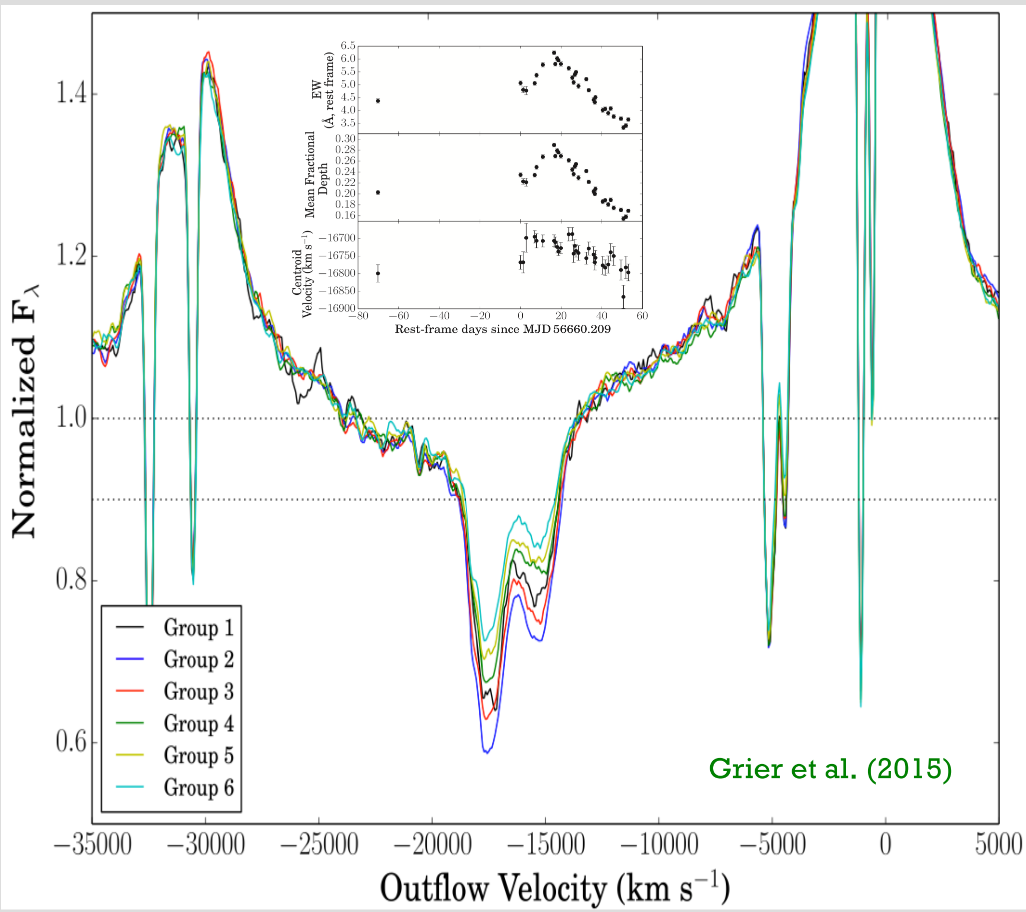
Multi-Object AGN Reverberation Mapping with SDSS

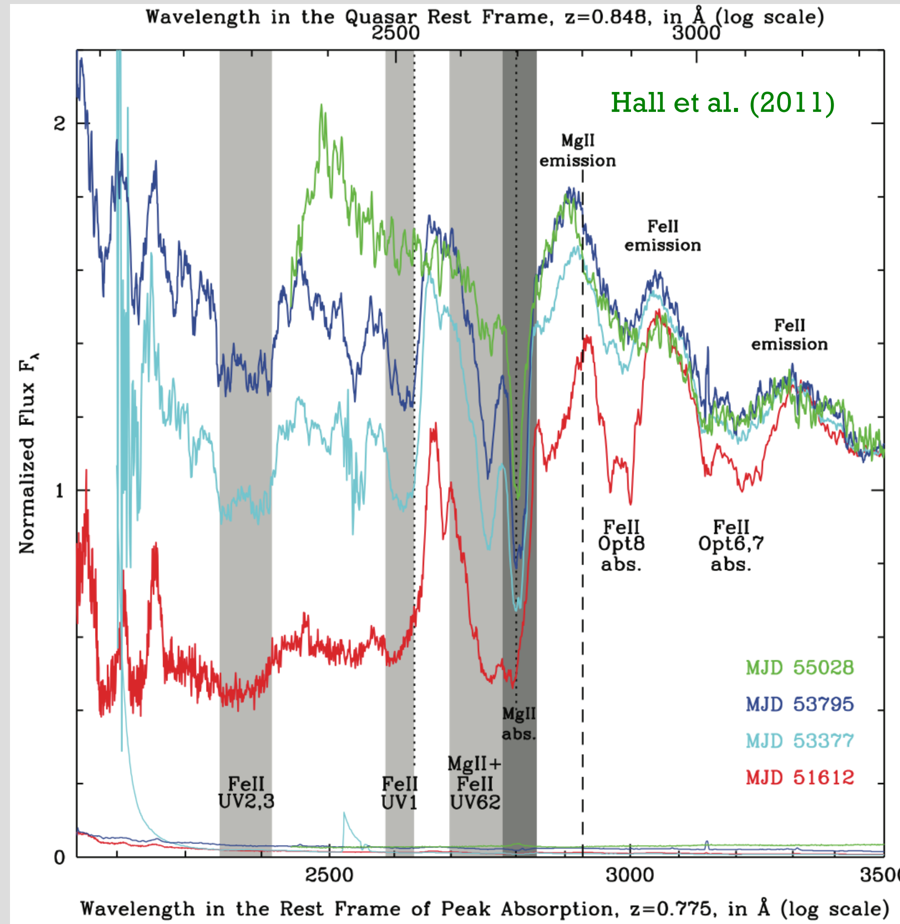


Also photometric RM (e.g., Chelouche et al. 2012, 2014).

Triggered Spectroscopic Follow-Up: BALs

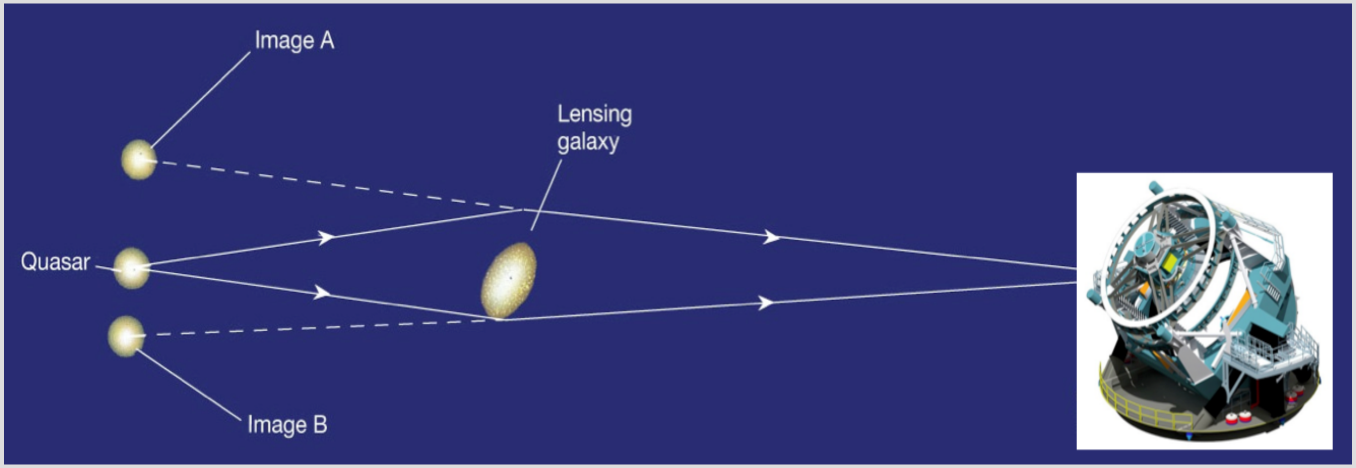
Color Changes Will Trigger Spectroscopic Follow-Up of Strong BAL Variations

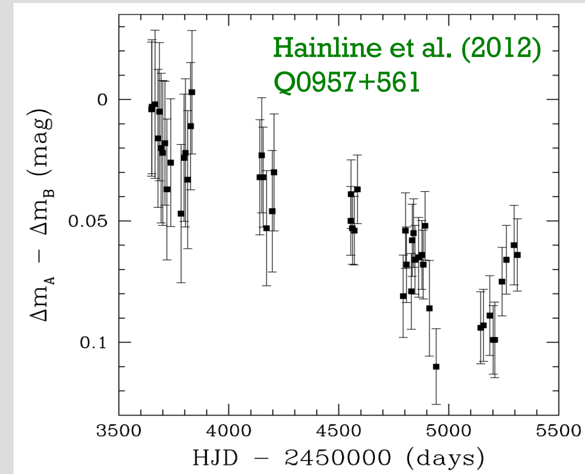




Also other absorption changes; e.g., variable dust reddening.

Microlensing of Accretion Disks





LSST will find and monitor ~ 4000 AGNs lensed into multiple images.

LSST cadence well-suited to rapid identification of microlensing events by stars in lensing galaxy - these give effective μas resolution.

Can trigger dense targeted multicolor and UV/X-ray monitoring, aiming to constrain the accretion-disk temperature profile.

With a large sample, can examine L, $L/L_{\rm Edd}$, $M_{\rm BH}$, z effects.

Small-Separation Binary SMBH

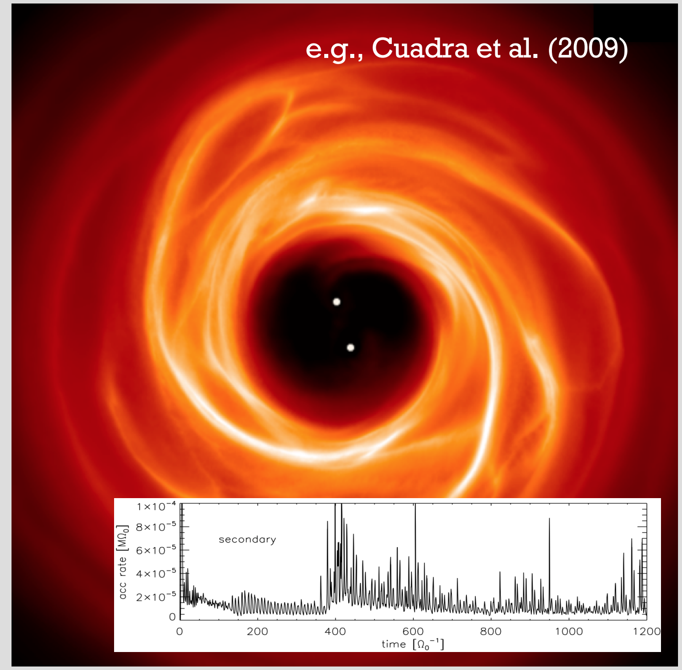
For SMBHs to move from pc to 10^{-3} pc separations, likely need gas accretion to remove binary angular momentum.

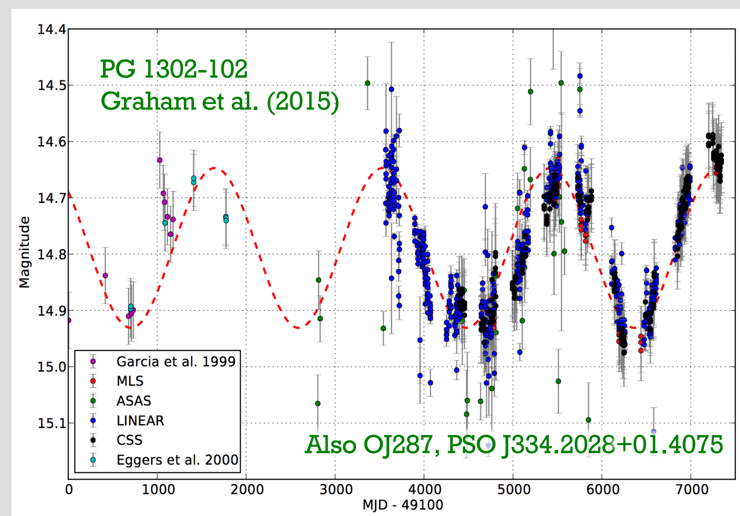
Accretion rate onto both SMBHs may vary on timescales of the binary period.

Month-to-year timescales at ~ 10^{-2} pc, well-suited to LSST monitoring and hard to find in other ways.

Massive LSST variability survey can find or usefully constrain the uncertain frequency of 10^{-2} pc binary SMBHs.

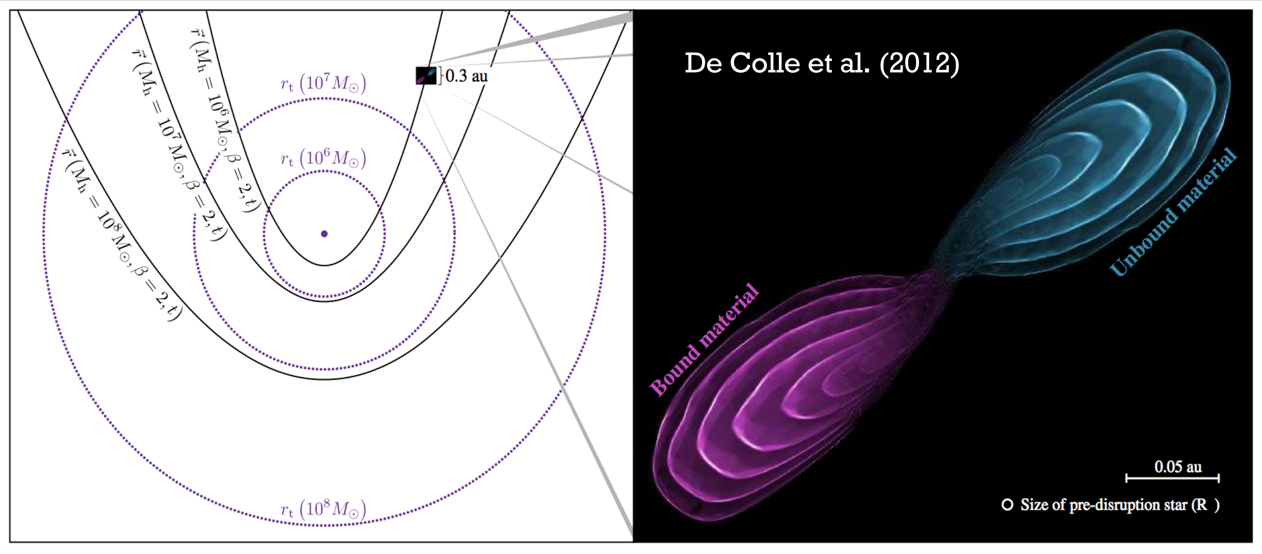
Already some candidates being found, but detailed interpretation still unclear.



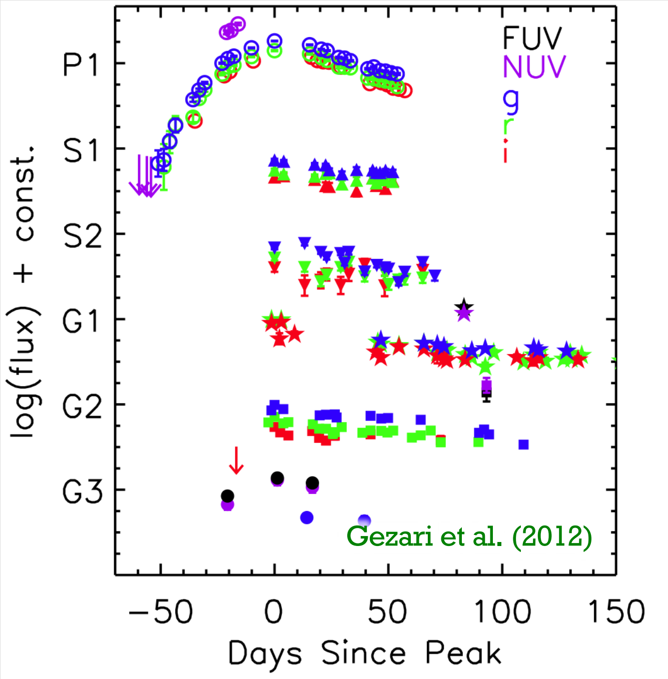


Transient SMBH Fueling Events

Transient Fueling of Dormant SMBH



A dormant SMBH can flare to AGN luminosities for months-years via tidal disruption and partial accretion of stars, planets, or gas clouds.



Originally found in the X-ray band with ROSAT with sparsely sampled light curves.

Now possible to identify in wide-field optical/UV (GALEX, SDSS, PTF, Pan-STARRS) and X-ray (Swift) monitoring surveys.

Expect to *detect* several thousand events per year with LSST, but will likely need to enforce selection cuts for unambiguous detections (confusion with SNe, AGNs).

LSST and Transient SMBH Fueling

Measure outburst rates as a function of galaxy type, redshift, and level of nuclear activity.

Assess the contribution of tidal disruptions to the AGN luminosity function (e.g., Milosavljevic et al. 2006).

Determine fraction with jets via radio follow-up and comparison with radio transient surveys (e.g., VAST, ThunderKAT, LOFAR transients).

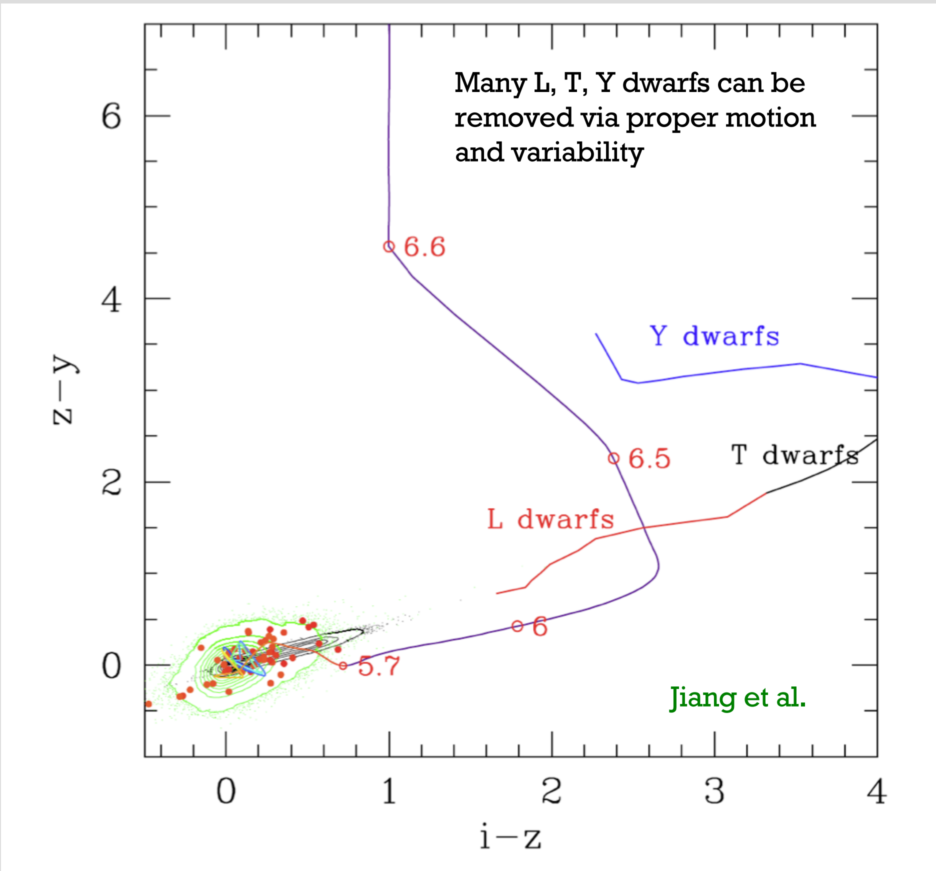
Understand diversity of these events (L_{Bol}, kT, jet power)

Find remarkable events - e.g., white dwarf disruptions by IMBH, giant planet disruptions, gas cloud captures.

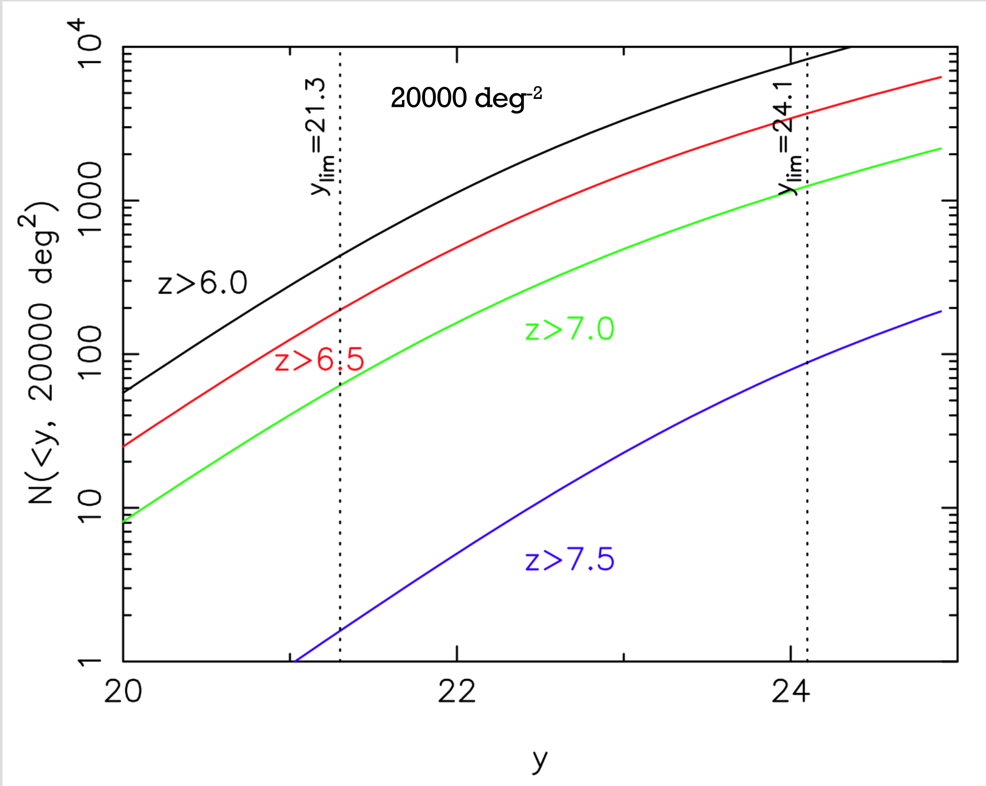
AGN Investigations at High Redshifts

High-Redshift AGN Selection

Colors of High-Redshift Quasars



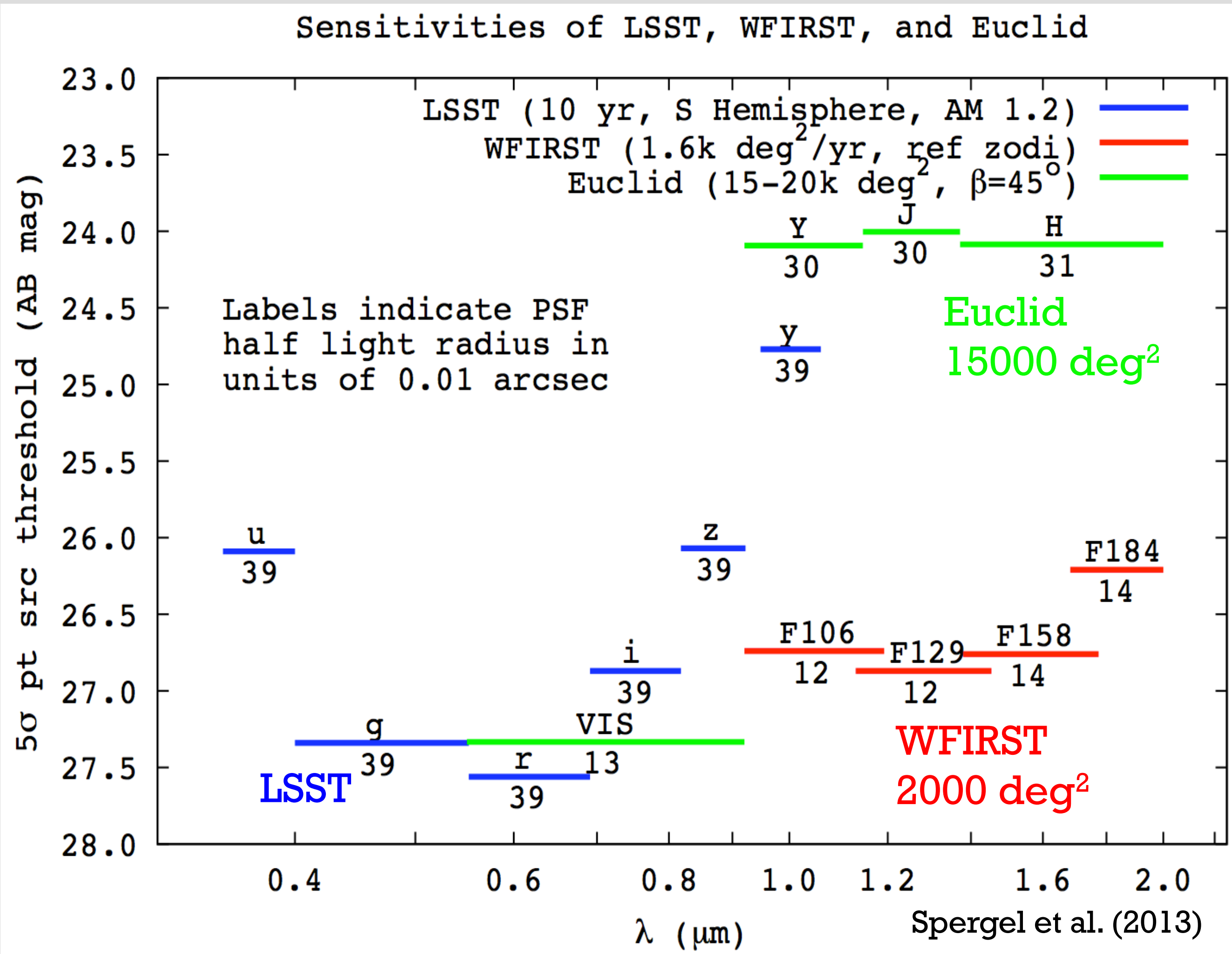
Expected Numbers of $z > 6$ Quasars



LSST alone will provide significant numbers of AGNs to $z \sim 7.5$ down to moderate luminosities ($L_{\rm Opt} \sim 10^{44}$ erg s^{-1}).

Also enables effective follow-up of blank-field X-ray and radio AGN candidates.

High-Redshift Quasars from Euclid, WFIRST, and LSST



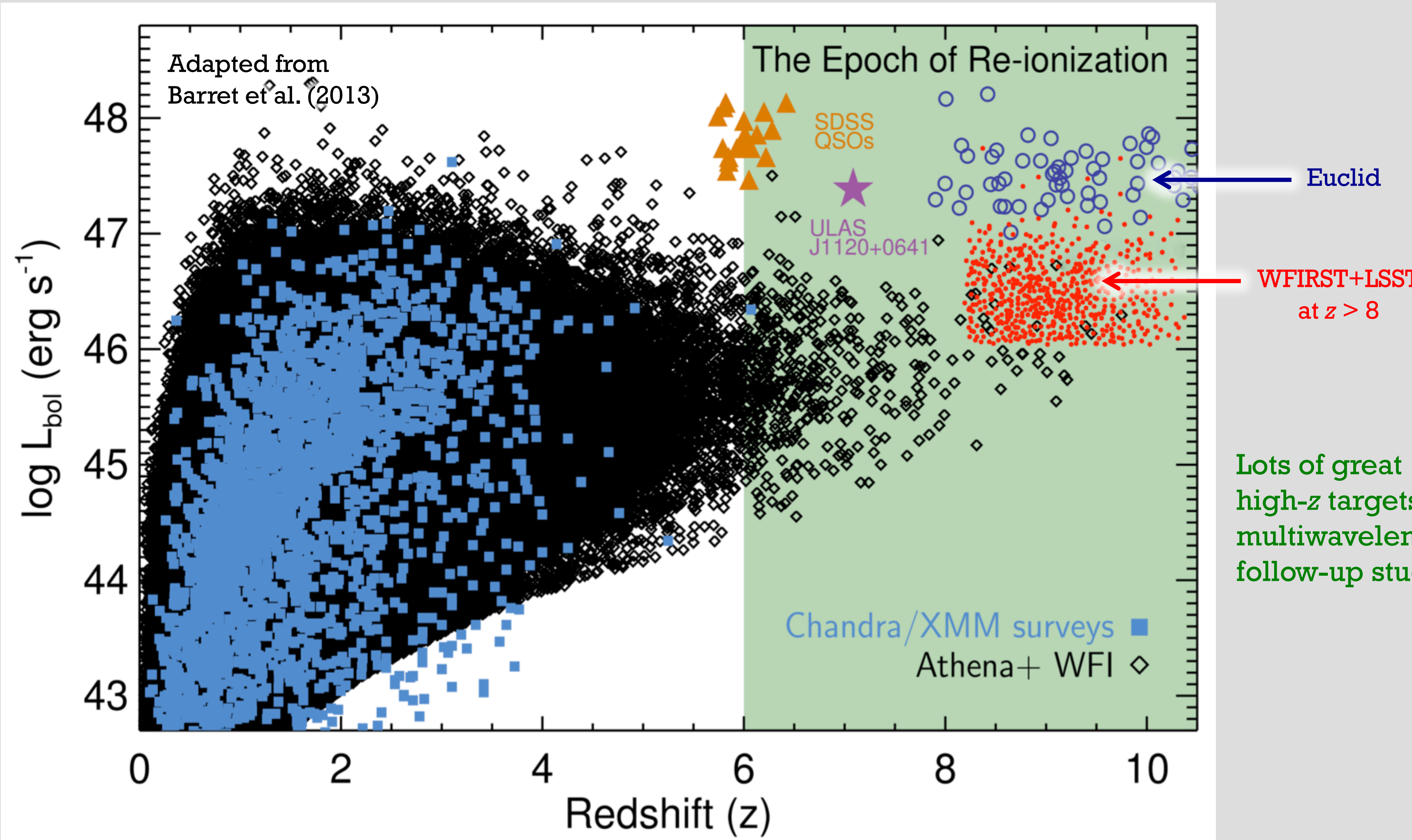
Combination of Euclid, WFIRST, and LSST will be very powerful for finding the first quasars.

Euclid should deliver ~ 1360 luminous quasars at $z > 7$, and 24 at $z > 10$.

WFIRST+LSST will push considerably deeper than Euclid over ~ 15% of the area.

Expect ~ 29 quasars at $z > 10$ (~ 1490 at $z > 7$).

Luminosity vs. Redshift for Future High-Redshift AGN Samples

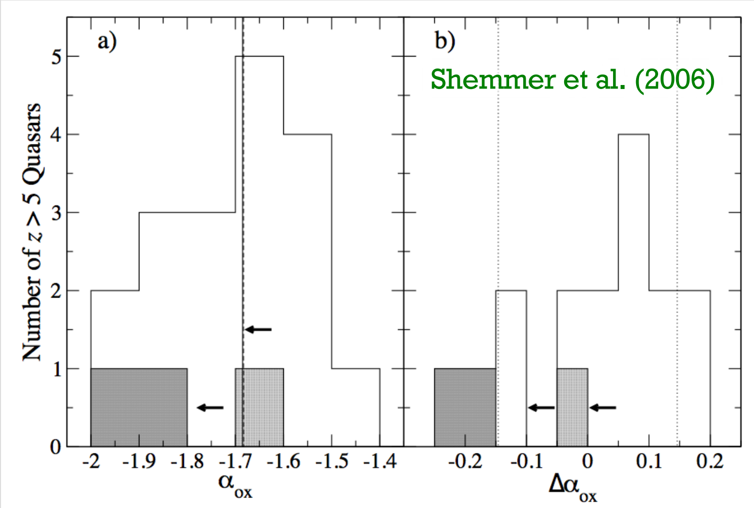


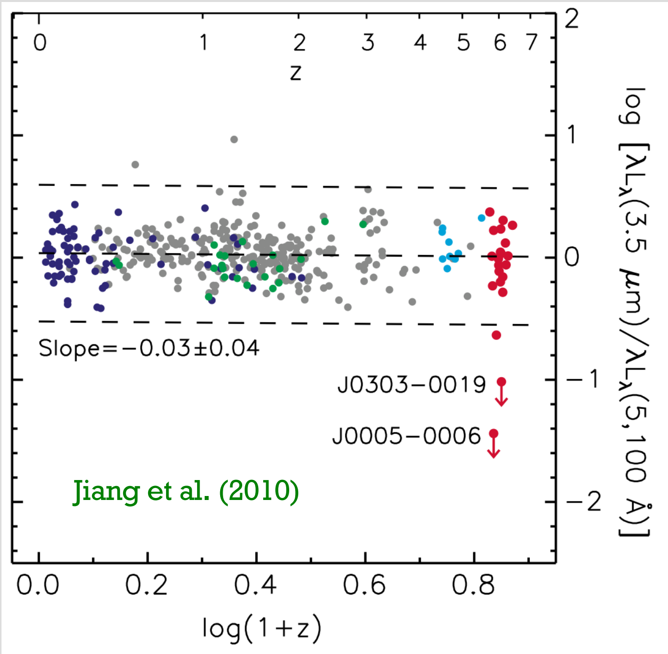
Lots of great high-*z* targets for multiwavelength follow-up studies.

Spectral Evolution at High Redshift

Generally, multiwavelength follow-up studies of the highest redshift quasars have shown little spectral evolution.

But there are notable exceptions, such as apparently dust-free quasars.





The LSST AGN Science Collaboration and Future Plans

The LSST AGN Science Collaboration

The LSST AGN Science Collaboration currently has 38 members.

Presently working as a loose confederation, but hope to become a hard-core collaboration in the future as LSST construction proceeds.

Basic plan is to bootstrap our way along: e.g., Deep Fields and Stripe 82 - DES - Pan-STARRS - SUMIRE – LSST.

A huge amount of work is needed including on basic AGN selection, analysis of LSST simulations, detailed science planning, and pooling of observational resources.

Feedback welcome at lsst-agn@lsstcorp.org

LSST AGN SC Members

Scott Anderson (Univ Washington)
Roberto Assef (Univ Diego Portales)
David Ballantyne (GA Tech)
Aaron Barth (UC-Irvine)
Niel Brandt (Penn State)
Robert Brunner (Univ Illinois)
George Chartas (College of Charleston)
Paolo Coppi (Yale Univ)
Jorge Cuadra (Pont Catholic Univ)
Wim de Vries (LLNL)
Mike Eracleous (Penn State)
Andres Escala (Univ de Chile)
Xiaohui Fan (Univ Arizona)
Rob Gibson (SimpliVity Corporation)
Alex Gray (GA Tech)
Richard Green (LBTO)
Sebastian Hoenig (Southampton)
Amy Kimball (NRAO, Socorro)
Mark Lacy (NRAO, Charlottesville)
Paulina Lira (Univ de Chile)
Greg Madejski (SLAC)
Ian McGreer (Univ Arizona)
Carole Mundell (Univ Bath)
Jeffrey Newman (Univ Pitt)
Tina Peters (Univ Toronto)
Luka Popovic (Ast Obs Belgrade)
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Don Schneider (Penn State)
Anil Seth (Univ Utah)
Ohad Shemmer (Univ North Texas)
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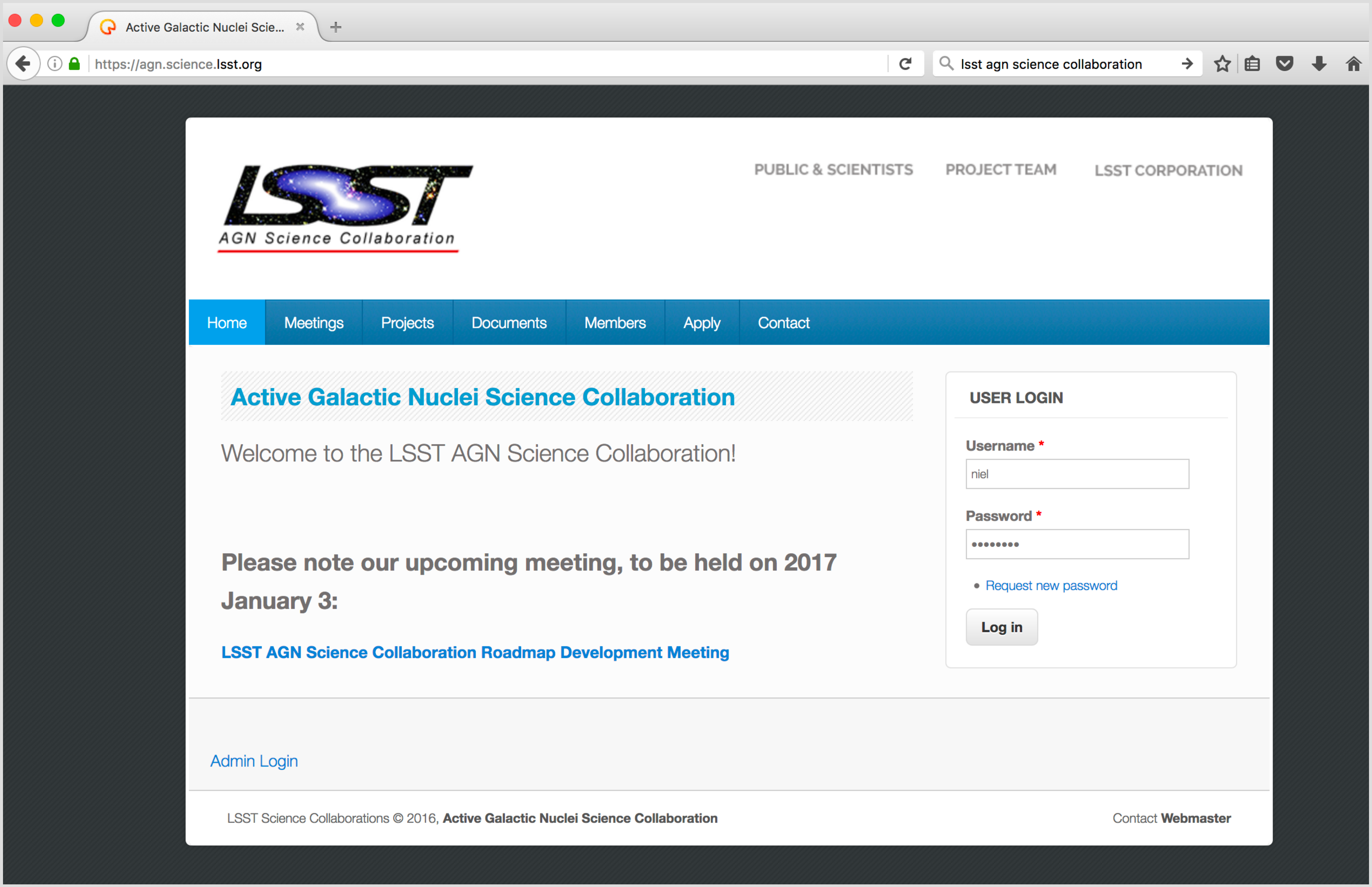
Katrien Steenbrugge (Univ Catolica del Norte)
Michael Strauss (Princeton Univ)
Ezequiel Treister (Univ Concepcion)
Laura Trouille (Adler/Northwestern)
Meg Urry (Yale Univ)
Dan Vanden Berk (St Vincent College)
Zhenia Zheng (Pont Catholic Univ)

The LSST AGN Science Collaboration



Meetings

LSST AGN Science Collaboration Roadmap Development Meeting

An Open Splinter Meeting as part of the

229th AAS Meeting, Grapevine, TX

Tuesday, January 3, 2017, 9:00 AM - 6:00 PM; Appaloosa 2 (Gaylord Texan Resort & Convention Center)

The goals of the meeting are to: 1) start the development of a comprehensive Roadmap for the Active Galactic Nuclei (AGN) Science Collaboration of the Large Synoptic Survey Telescope (LSST), presenting a coherent vision for AGN research pre- and post-LSST commissioning, 2) form dedicated Working Groups within the Science Collaboration who will work on specific projects described by the Roadmap, 3) explore funding opportunities to support the highest-ranked projects described by the Roadmap, and 4) encourage eligible active extragalactic researchers to join the AGN Science Collaboration.

Organizing Committee:

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Gordon Richards (Drexel University); gtr@physics.drexel.edu
Organizing committee members may be contacted with any questions.


The End