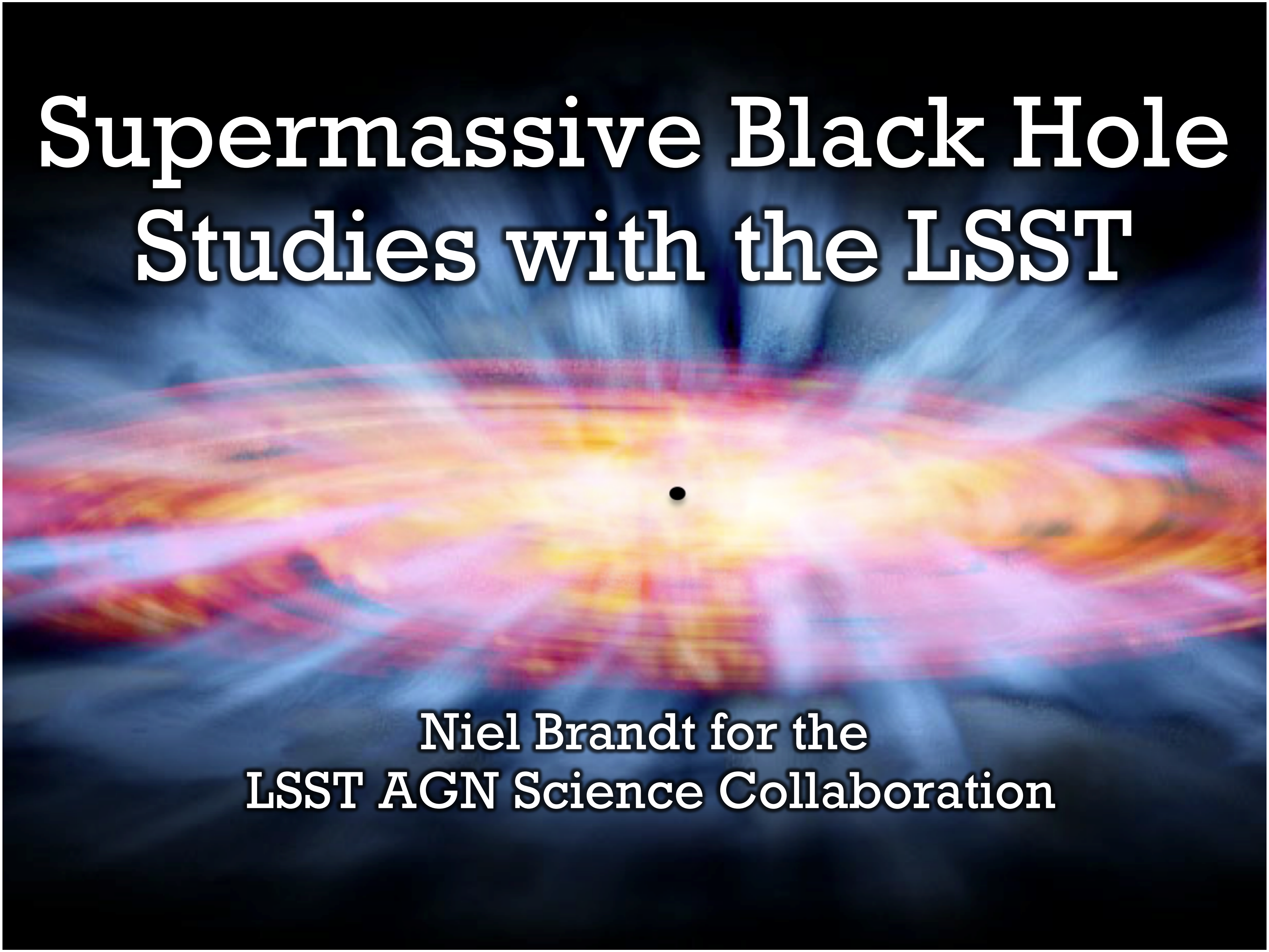

Supermassive Black Hole
Studies with the LSST
Niel Brandt for the
LSST AGN Science Collaboration

LSST Coming Along Well

Project & Community Workshop – 2017 August

LSST Summit Facility – 2018 January

M1M3 after polishing (Tucson Airport)

Aiming for “first light” in ~ 2020 and main survey start in ~ 2022.

Talk Outline

Quick review of the LSST surveys.

The LSST AGN Science Collaboration and its future plans.

AGN selection with LSST and multiwavelength data.

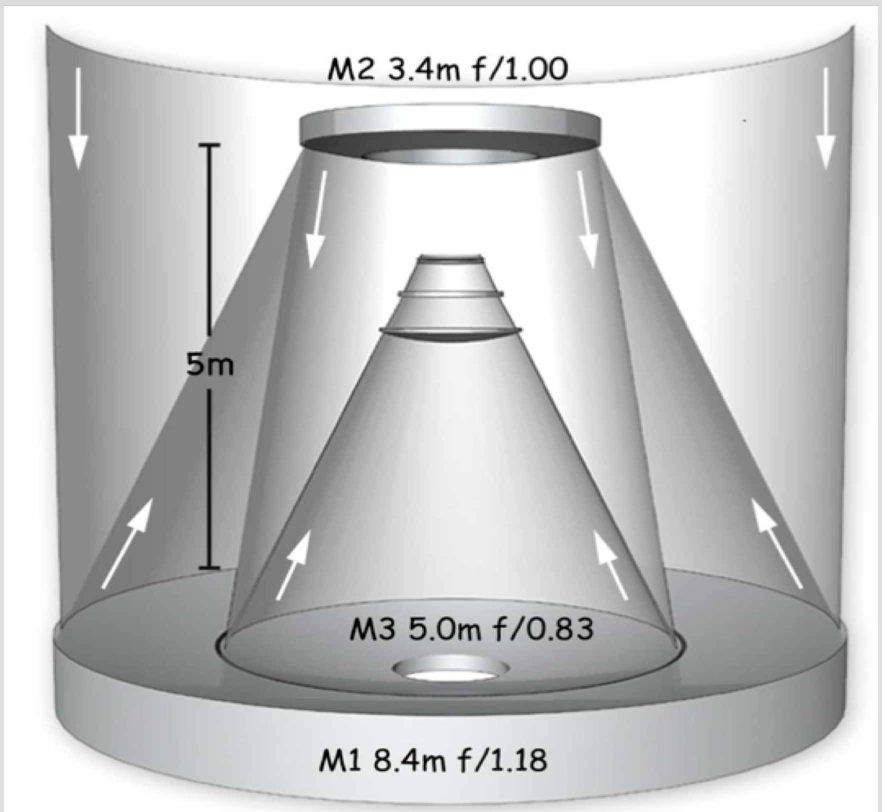
Examples of exciting science investigations:

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

Quick Review of the LSST Surveys

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.

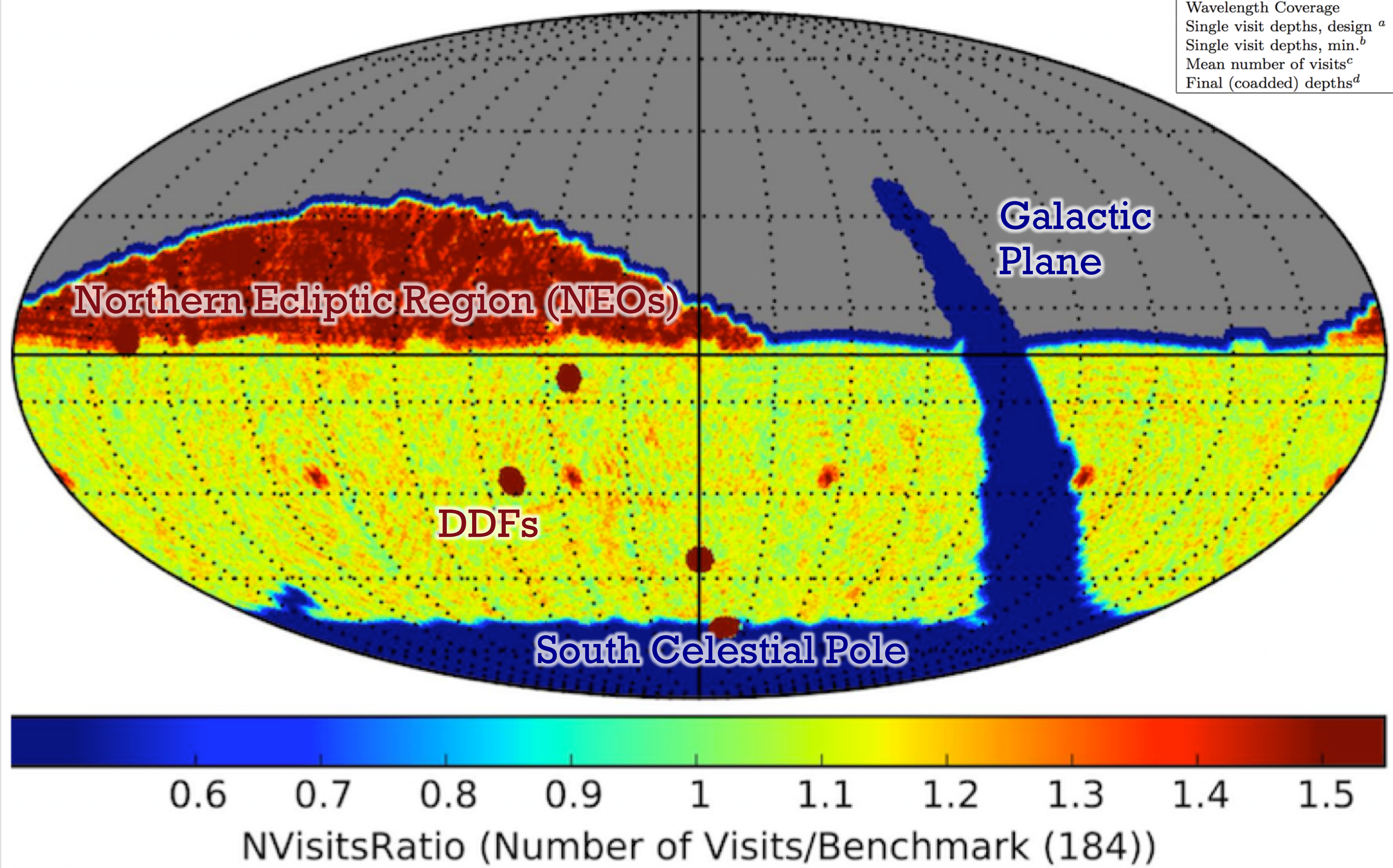
See arXiv:0805.2366 for more details.

Main Survey - Brief Details

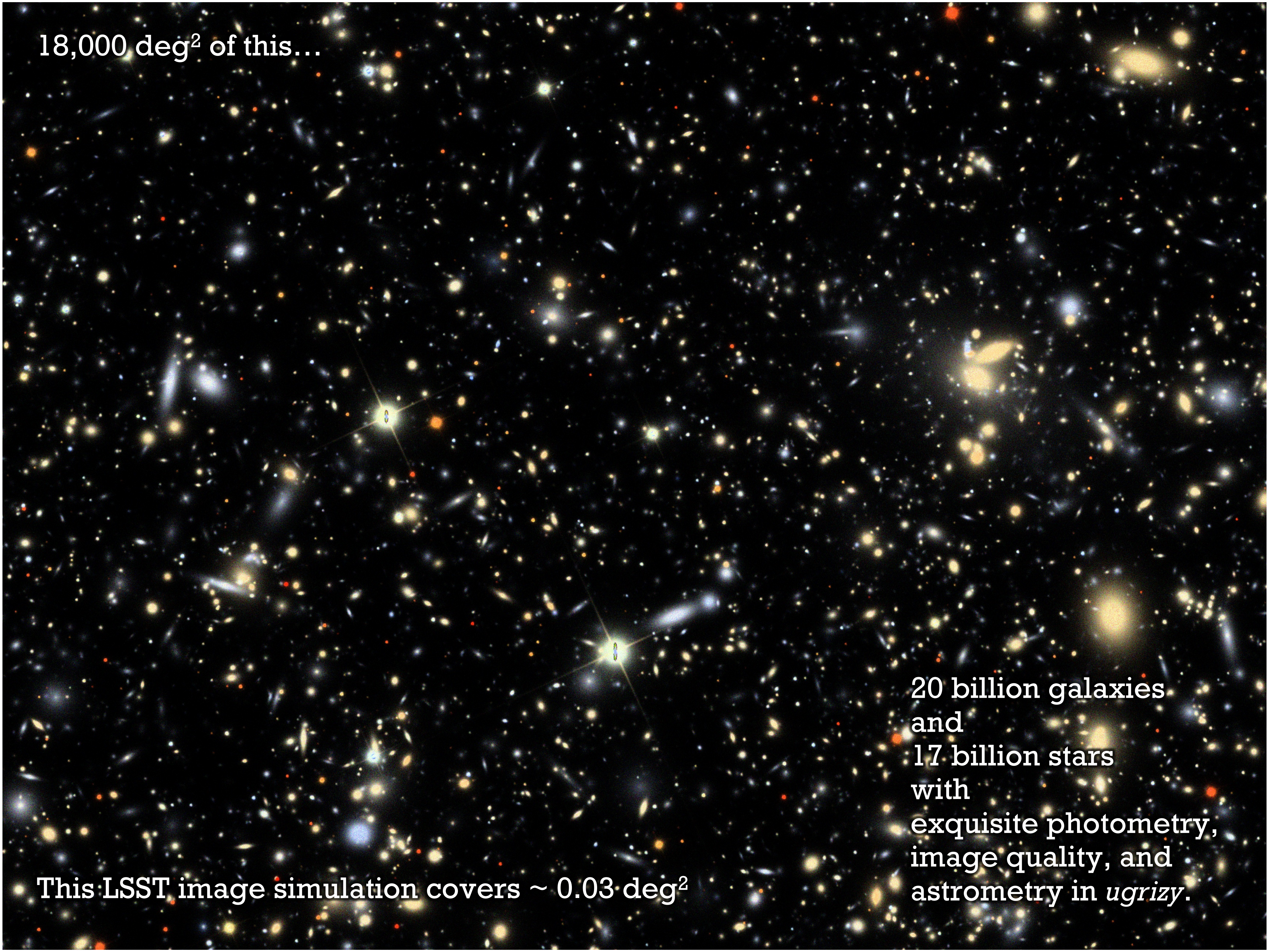
THE LSST BASELINE DESIGN AND SURVEY PARAMETERS

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 $m^2 deg^2$
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

Operations Simulation of *r*-Band Visits



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


18,000 deg² of this…
20 billion galaxies
and
17 billion stars
with
exquisite photometry,
image quality, and
astrometry in *ugrizy*.
This LSST image simulation covers ~ 0.03 deg²

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)

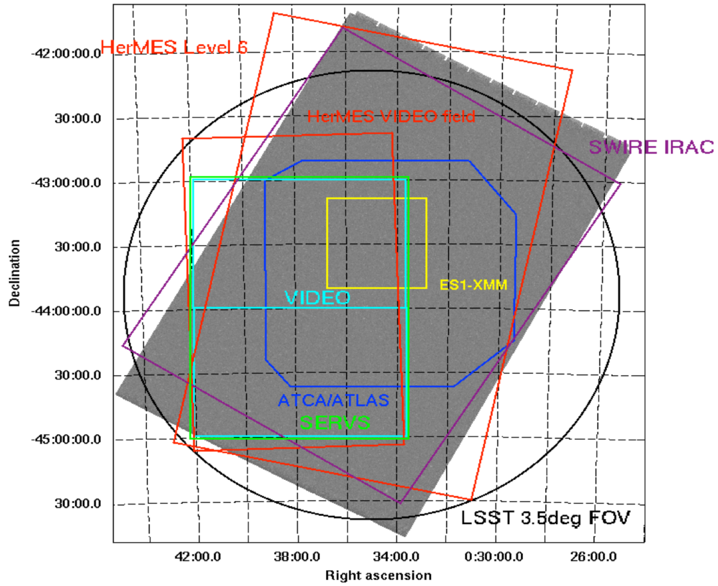
Blank fields aim for 5300-14000 visits per band reaching $urgi$ = 28.5, z = 28.0, y = 27.0. But details not settled.

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

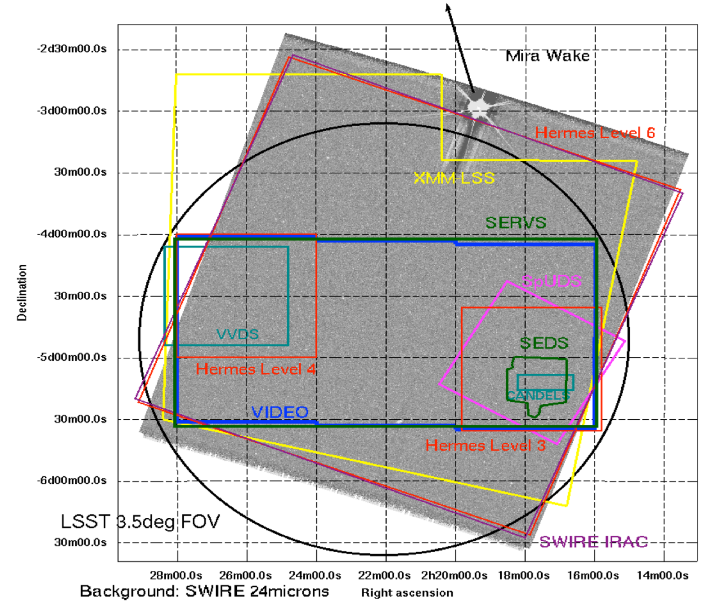
Call for mini-surveys White Papers in June 2018 - likely deadline in Oct-Nov 2018. These will be assessed by the Science Advisory Committee.

The Four Selected DDFs: Multiwavelength Coverage

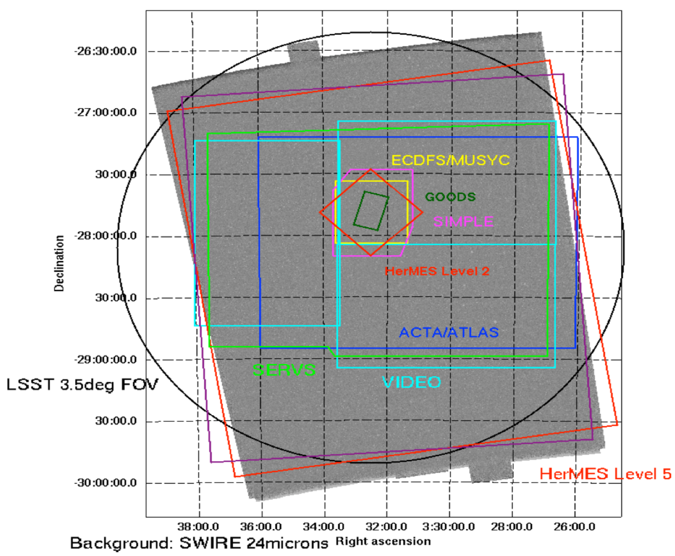
ELAIS-S1



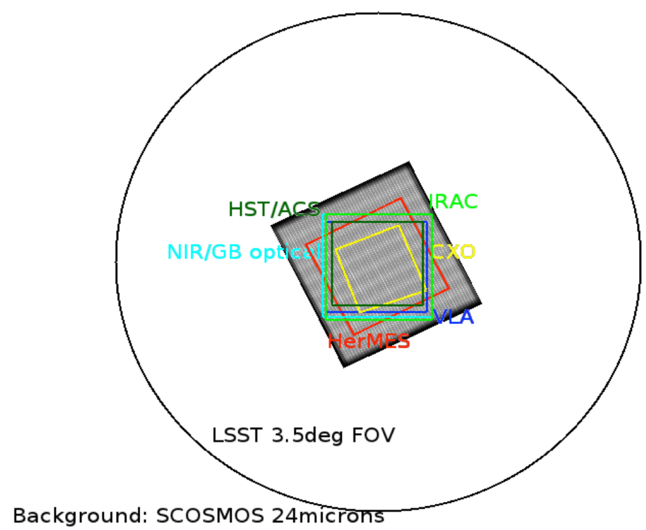
XMM-LSS



Extended CDF-S



COSMOS



Example Multiwavelength Coverage

Table 1: Some of the Current/Scheduled 1–10 deg^2 Multiwavelength Coverage of XMM-SERVS

Band	Survey Name	Coverage (W-CDF-S, ELAIS-S1, XMM-LSS); Notes
Radio	Australia Telescope Large Area Survey (**ATLAS**)[a]	3.7, 2.7, – deg^2; 15 μJy rms depth at 1.4 GHz
	MIGHTEE Survey (Starting Soon)[b]	4.5, 3, 4.5 deg^2; 1 μJy rms depth at 1.4 GHz
FIR	*Herschel* Multi-tiered Extragal. Surv. (**HerMES**)[c]	0.6–18 deg^2; 5–60 mJy depth at 100–500 μm
MIR	*Spitzer* Wide-area IR Extragal. Survey (**SWIRE**)[d]	8.2, 7.0, 9.4 deg^2; 0.04–30 mJy depth at 3.6–160 μm
NIR	*Spitzer* Extragal. Rep. Vol. Survey (**SERVS**)[e]	4.5, 3, 4.5 deg^2; 2 μJy depth at 3.6 and 4.5 μm
	VISTA Deep Extragal. Obs. Survey (**VIDEO**)[f]	4.5, 3, 4.5 deg^2; $ZYJHK_s$ to $m_{\rm AB} \approx 23.8$–25.7
	VISTA Extragal. Infr. Legacy Survey (**VEILS**)[g]	3, 3, 3 deg^2; JK_s to $m_{\rm AB} \approx 24.5$–25.5
	Euclid Deep Field[h]	10, –, – deg^2; YJH to $m_{\rm AB} \approx 26$, VIS to $m_{\rm AB} \approx 26.5$
Optical Photometry	Dark Energy Survey (**DES**)[i]	9, 6, 9 deg^2; Multi-epoch $griz$, $m_{\rm AB} \approx 27$ co-added
	Hyper Suprime-Cam (**HSC**) Deep Survey[j]	–, –, 5.3 deg^2; $grizy$ to $m_{\rm AB} \approx 25.3$–27.5
	Pan-STARRS1 Medium-Deep Survey (**PS1MD**)[k]	8, –, 8 deg^2; Multi-epoch $grizy$, $m_{\rm AB} \approx 26$ co-added
	VST Opt. Imaging of CDF-S and ES1 (**VOICE**)[l]	4.5, 3, – deg^2; Multi-epoch $ugri$, $m_{\rm AB} \approx 26$ co-added
	SWIRE optical imaging[d]	7, 6, 8 deg^2; $u'g'r'i'z'$ to $m_{\rm AB} \approx 24$–26
	LSST deep-drilling field (Planned)[m]	10, 10, 10 deg^2; $ugrizy$, $\gtrsim 10\,000$ visits per field
Optical/NIR Spectroscopy	Carnegie-*Spitzer*-IMACS Survey (**CSI**)[n]	4.8, 3.6, 6.9 deg^2; 140 000 redshifts, 3.6 μm selected
	PRIsm MUlti-object Survey (**PRIMUS**)[o]	2.0, 0.9, 2.9 deg^2; 77 000 redshifts to $i_{\rm AB} \approx 23.5$
	AAT Deep Extragal. Legacy Survey (**DEVILS**)[p]	1.5, –, 3.0 deg^2; 43 500 redshifts to $Y = 21.2$
	VLT **MOONS** Survey (Scheduled)[q]	4.5, 3, 4.5 deg^2; 210 000 redshifts to $H_{\rm AB} \approx 23.5$
UV	*GALEX* Deep Imaging Survey[r]	7, 7, 8 deg^2; Depth $m_{\rm AB} \approx 25$

References: [a] Franzen et al. (2015); [b] Jarvis et al. (2017); [c] Oliver et al. (2012); [d] Lonsdale et al. (2003); [e] Mauduit et al. (2012); [f] Jarvis et al. (2013); [g] `http://www.ast.cam.ac.uk/~mbanerji/VEILS/veils_index.html`; [h] Scaramella et al. (2017); [i] Diehl et al. (2014); [j] `http://www.naoj.org/Projects/HSC/surveyplan.html`; [k] Tonry et al. (2012); [l] Vaccari et al. (2017); [m] `http://www.lsst.org/News/enews/deep-drilling-201202.html`; [n] Kelson et al. (2014); Patel et al. (2015); [o] Coil et al. (2011); [p] `https://devilsurvey.org/wp/`; [q] `http://www.roe.ac.uk/~ciras/MOONS/VLT-MOONS.html`; [r] `http://www.galex.caltech.edu/researcher/techdoc-ch2.html`.

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

The LSST AGN Science Collaboration and Its Future Plans

The LSST AGN Science Collaboration

The LSST AGN Science Collaboration currently has ~ 47 members. New members welcome!

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

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

Also gathering key multiwavelength data.

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

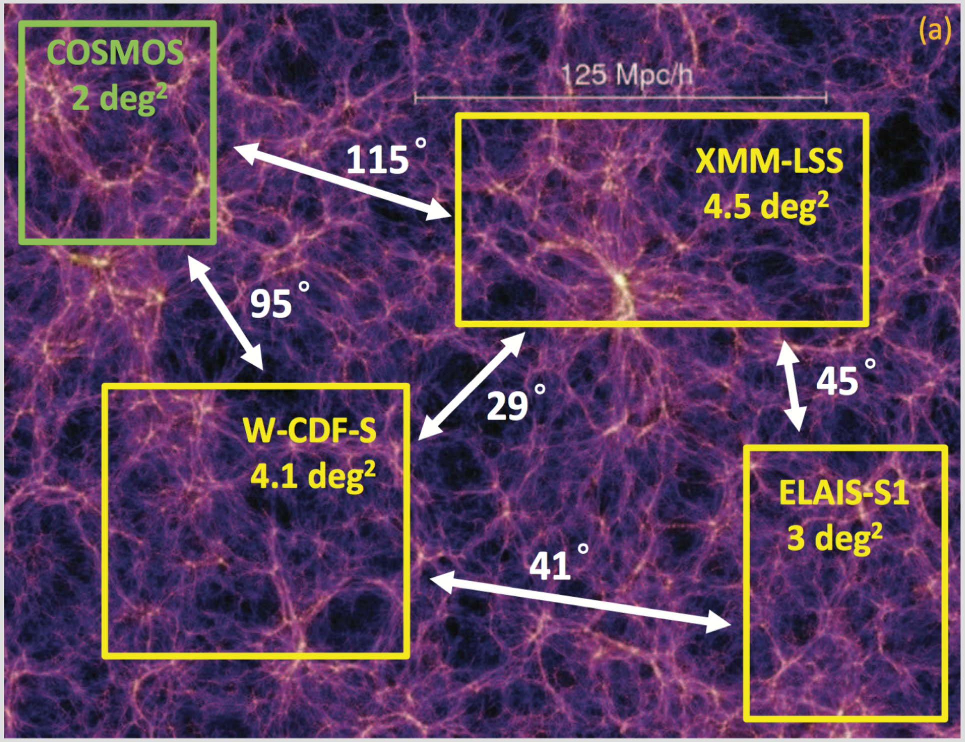
Feedback welcome at lsst-agn@lsstcorp.org

LSST AGN SC Members

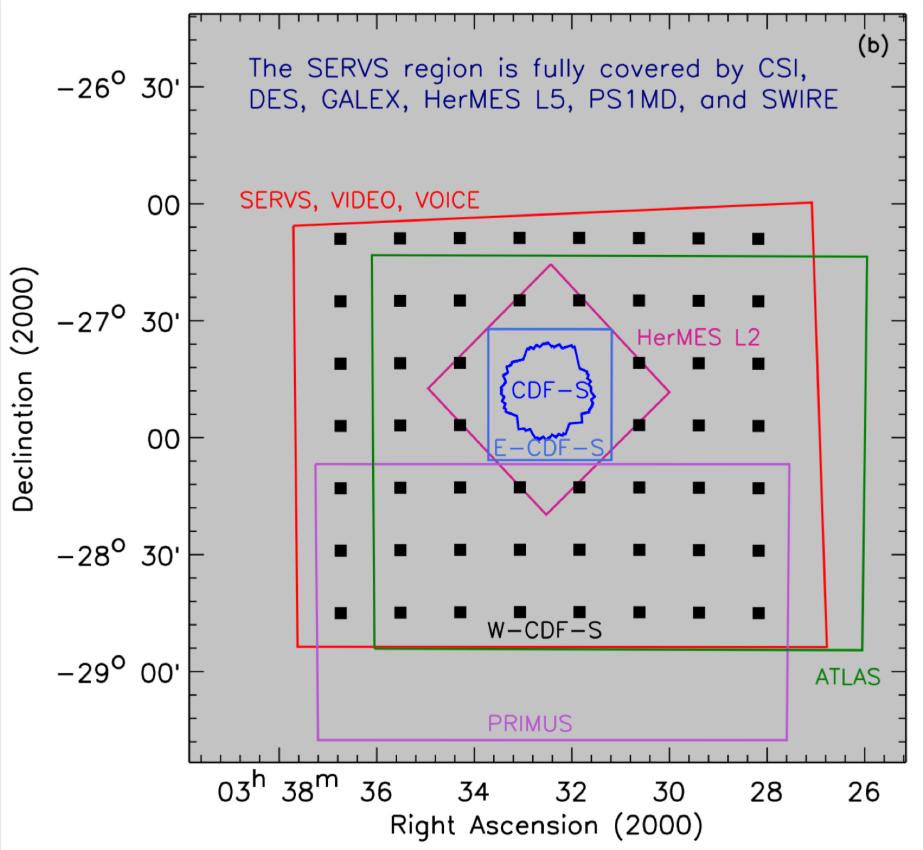
Scott Anderson (Univ Washington)
Roberto Assef (Univ Diego Portales)
David Ballantyne (GA Tech)
Aaron Barth (UC-Irvine)
Franz Bauer (Pont Univ Catolica)
Niel Brandt (Penn State)
Mike Brotherton (Univ Wyoming)
Robert Brunner (Univ Illinois)
George Chartas (College of Charleston)
Claudia Cicone (INAF - Osservatorio Astronomico di Brera)
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)
Matt Jarvis (Oxford)
Yan-Fei Jiang (UCSB)
Amy Kimball (NRAO, Socorro)
Mark Lacy (NRAO, Charlottesville)
Marco Landoni (INAF - Istituto Nazionale di Astrofisica)
Andy Lawrence (ROE)
Paulina Lira (Univ de Chile)
Chelsea MacLeod (CfA)
Greg Madejski (SLAC)
Ian McGreer (Univ Arizona)
Richard McMahon (Cambridge IoA)
Carole Mundell (Univ Bath)
Jeffrey Newman (Univ Pitt)
Tina Peters (Univ Toronto)
Luka Popovic (Ast Obs Belgrade)
Gordon Richards (Drexel Univ)
Jessie Runnoe (Univ. Michigan)
Don Schneider (Penn State)
Anil Seth (Univ Utah)
Ohad Shemmer (Univ North Texas)
Howard Smith (Harvard/Smithsonian CfA)
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)

X-SERVS: X-ray Coverage of the Deep-Drilling Fields

X-SERVS Fields



Wide CDF-S Multiwavelength Data

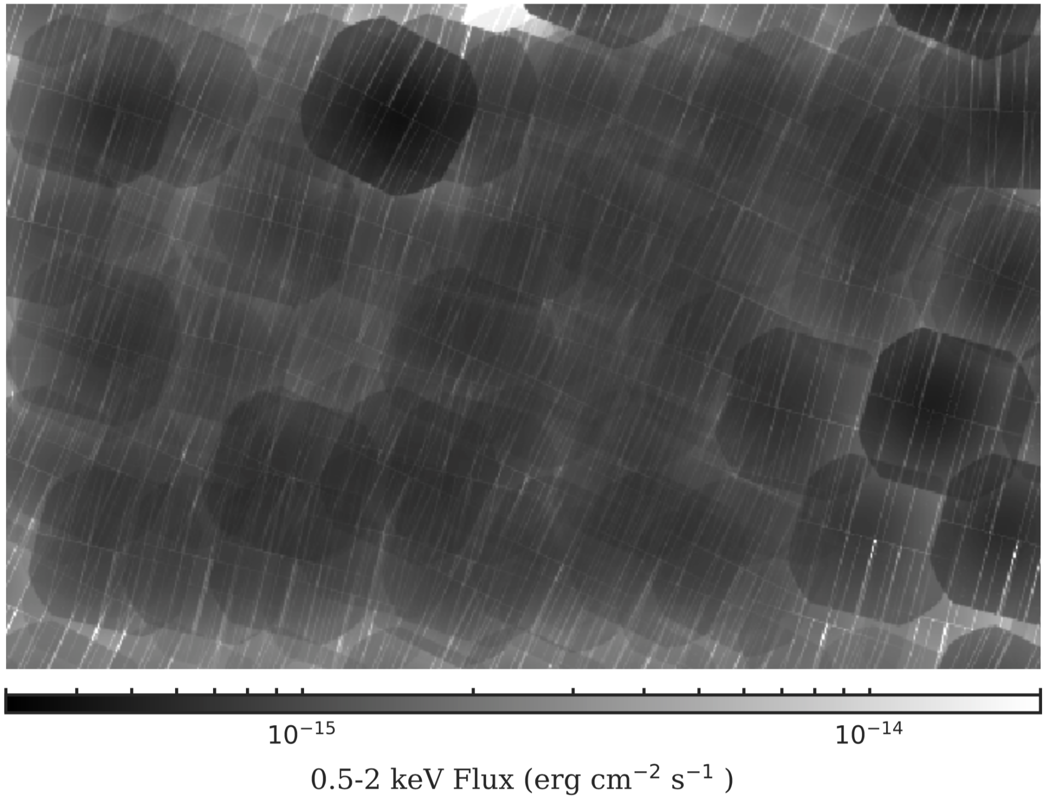


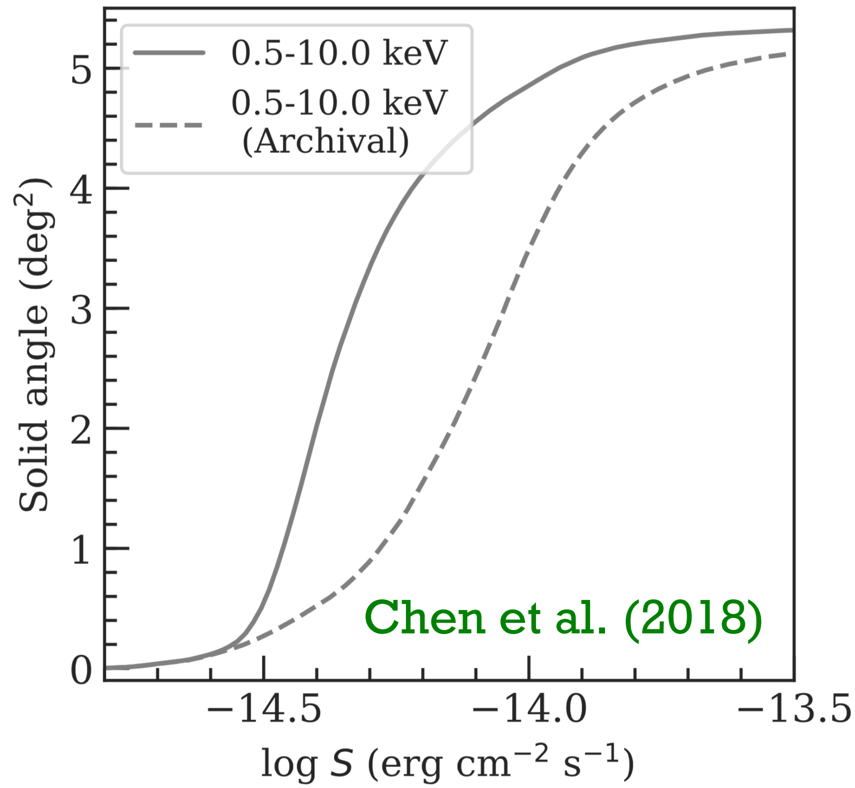
At 50 ks XMM-Newton depth, expect 12,000 AGNs and 760 X-ray groups/clusters.

Study SMBH growth across the full range of cosmic environments – voids to massive clusters.

Will have incredible legacy value when combined with LSST, DES, HSC, MOONS, PFS, VEILS, Euclid, MIGHTEE, etc.

Current Status of the X-SERVS XMM-LSS Field



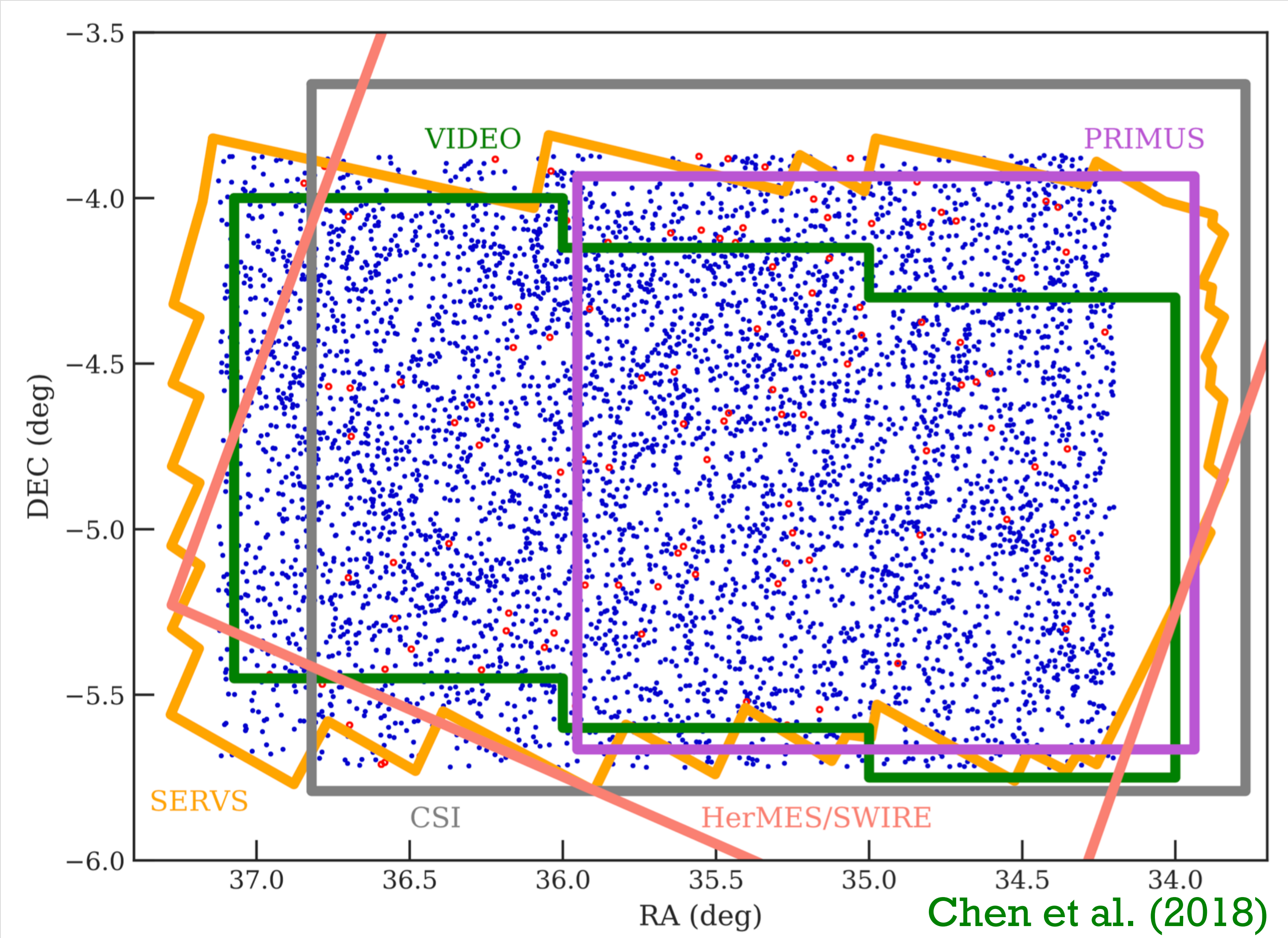


1.1 Ms additional good XMM-Newton exposure

5.3 deg^2 at ~ 46 ks depth

5242 total X-ray sources – 2381 new

Current Status of the X-SERVS XMM-LSS Field



5242 total X-ray sources - 90% good identification rate (assessed with Chandra)

Mostly AGNs - will be extremely useful for AGN science in this LSST DDF

Spitzer DEEPDRILL Survey

Spitzer Space Telescope General Observer Proposal #11086.

A warm Spitzer survey of the LSST/DES "Deep drilling" fields

Principal Investigator: Mark Lacy

Institution: National Radio Astronomy Observatory (NRAO)

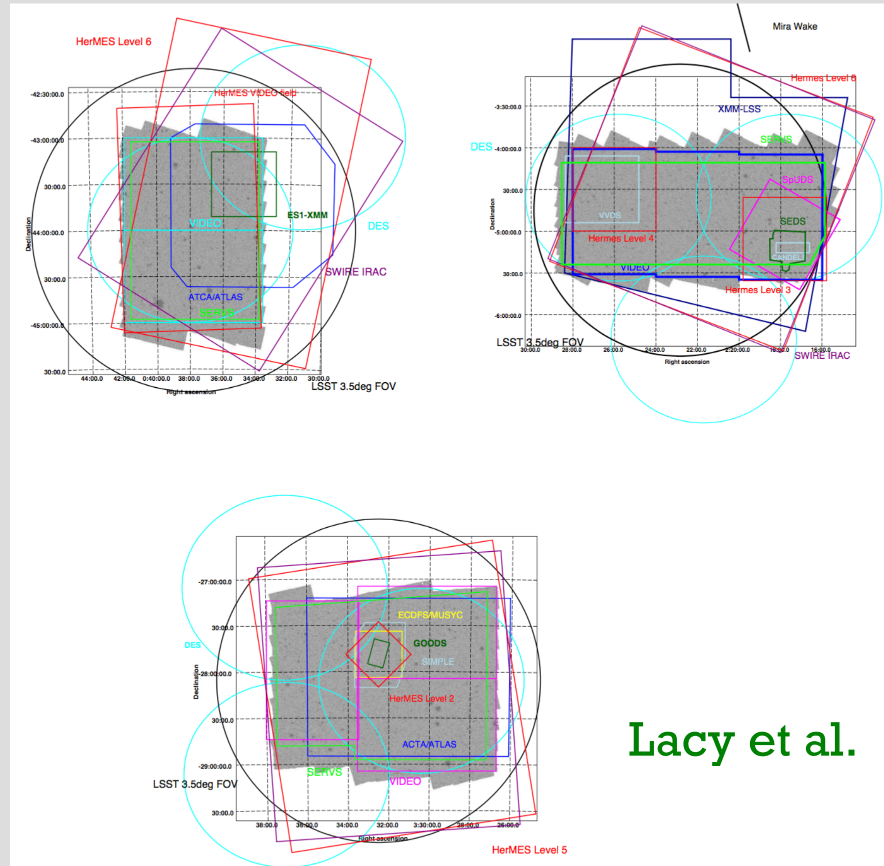
Electronic mail: mlacy@nrao.edu

Technical Contact: Mark Lacy, National Radio Astronomy Observatory (NRAO)

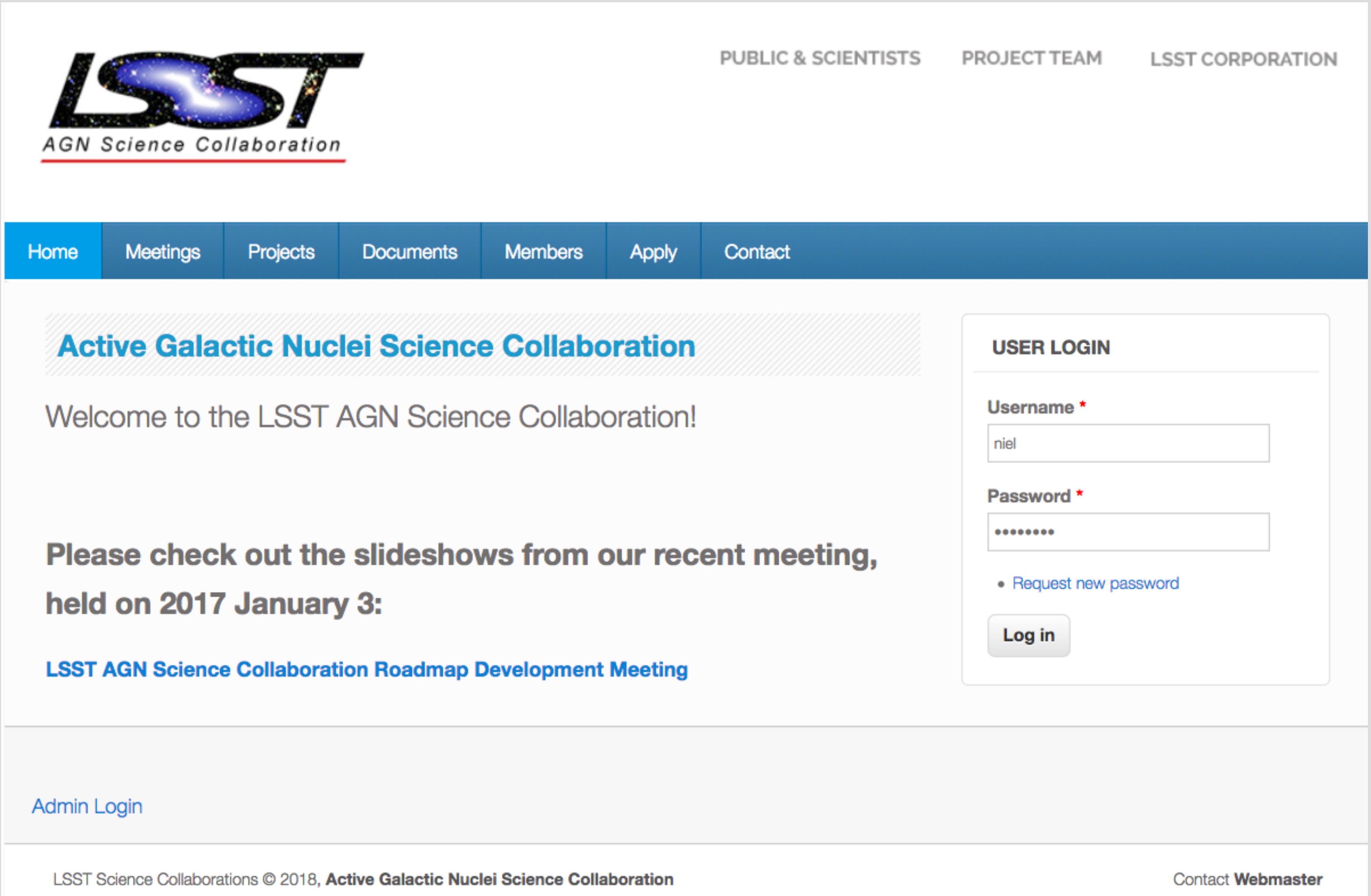
Co–Investigators: Duncan Farrah, Virginia Tech
Niel Brandt, Penn State
Masao Sako, U Penn
Gordon Richards, Drexel
Ray Norris, CSIRO/Macquarie University
Susan Ridgway, NOAO
Jose Afonso, Lisbon
Robert Brunner, Illinois
Dave Clements, Imperial College

et al.

Abstract:
We propose a warm Spitzer survey to microJy depth of the four predefined Deep Drilling Fields (DDFs) for the Large Synoptic Survey Telescope (LSST) (three of which are also deep drilling fields for the Dark Energy Survey (DES)). Imaging these fields with warm Spitzer is a key component of the overall success of these projects, that address the "Physics of the Universe" theme of the Astro2010 decadal survey. With deep, accurate, near–infrared photometry from Spitzer in the DDFs, we will generate photometric redshift distributions to apply to the surveys as a whole. The DDFs are also the areas where the supernova searches of DES and LSST are concentrated, and deep Spitzer data is essential to obtain photometric redshifts, stellar masses and constraints on ages and metallicities for the >10000 supernova host galaxies these surveys will find. This "DEEPDRILL" survey will also address the "Cosmic Dawn" goal of Astro2010 through being deep enough to find all the >10^11 solar mass galaxies within the survey area out to z~6. DEEPDRILL will complete the final 24.4 square degrees of imaging in the DDFs, which, when added to the 14 square degrees already imaged to this depth, will map a volume of 1–Gpc^3 at z>2. It will find ~100 > 10^11 solar mass galaxies at z~5 and ~40 protoclusters at z>2, providing targets for JWST that can be found in no other way. The Spitzer data, in conjunction with the multiwavelength surveys in these fields, ranging from X–ray through far–infrared and cm–radio, will comprise a unique legacy dataset for studies of galaxy evolution.



The LSST AGN SC Web Site



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:

Ohad Shemmer (University of North Texas); ohad@unt.edu
Niel Brandt (The Pennsylvania State University); wnbrandt@gmail.com
Gordon Richards (Drexel University); gtr@physics.drexel.edu
Organizing committee members may be contacted with any questions.

Description of AGN Science Collaboration Activities and Goals
Niel Brandt, The Pennsylvania State University

Challenges for Quasar Science with LSST
Gordon Richards, Drexel University

Supermassive Black Holes Studies in the Time Domain with LSST
Carole Mundell, University of Bath

A Review of AGN Variability Studies using Survey Data: Prospects for LSST
Chelsea MacLeod, Harvard-Smithsonian Center for Astrophysics

Coffee Break: 10:30 - 11:00 Group Photo

Session 2: 11:00 - 12:30

Chair: Niel Brandt, The Pennsylvania State University

The AGN Population in the LSST Era
Roberto Assef, Universidad Diego Portales

Quasar Astrometric Redshifts with LSST
Christina Peters, University of Toronto

Extracting Information From AGN Variability: an LSST AGN Collaboration Proposal
Vishal Kasliwal, University of Pennsylvania and Princeton University

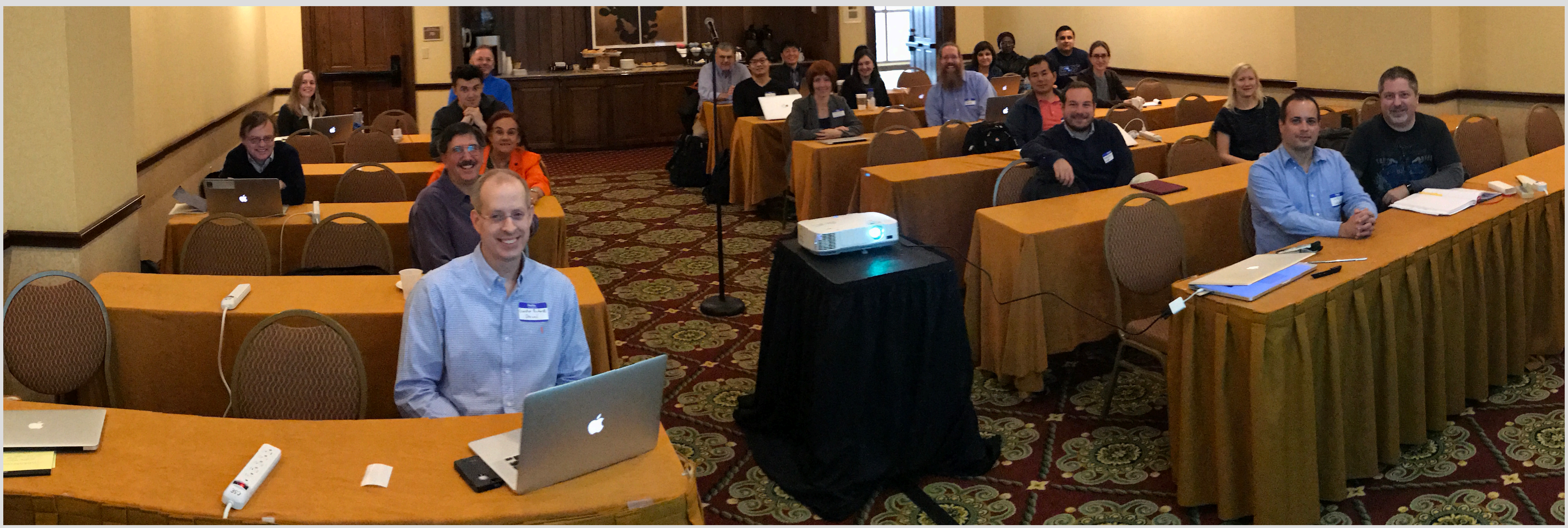
Characterization of AGN Variability in the Optical and Near Infrared Regimes
Paula Sanchez, Universidad de Chile

Constraining Black Hole Accretion Disks by Detecting Time Lags Between Quasar Continuum Emission Bands
Yan-Fei Jiang, University of California, Santa Barbara

Talk slides available on AGN SC Web page.

Audio recordings for all talks available from Niel Brandt or Ohad Shemmer.


Meeting Event



Not endorsed by the
American Heart Association!

UK AGNs and Galaxies Folks

Some Chilean AGN Folks

LSST AGN SC Roadmap

LSST
AGN Science Collaboration
Roadmap

Prepared by the LSST AGN Science Collaboration,
with support from the LSST Corporation

Version 1.0
January 24, 2018

Contents

AGN Inputs into LSST Cadence

Science-Driven Optimization of the LSST Observing Strategy

Prepared by the LSST Science Collaborations,
with support from the LSST Project.

Version 1.0

Most recent commit: fe3d2ad

(Mon, 14 Aug 2017 02:08:33 -0700)

8 Active Galactic Nuclei

Chapter editors: *Ohad Shemmer*, *Timo Anguita*.

Contributing authors: *Vishal Kasliwal*, *Christina Peters*, *Niel Brandt*, *Gordon Richards*, *Scott Anderson*, *Matt O'Dowd*, *Robert Wagoner*

Summary

To zeroth order, AGN science with LSST will benefit from the longest temporal baseline (to aid both selection and variability studies), the most uniform cadence in terms of even sampling for each band, and uniform sky coverage while maximizing the area, but excluding the Galactic plane. It is also expected that any reasonable perturbation to the nominal LSST observing strategy will not have a major effect on AGN science. While denser sampling at shorter wavelengths will aid investigations of the size and structure of the AGN central engine via intrinsic continuum variability and microlensing, care must be taken not to compromise the coadded Y-band depth which is crucial for detecting the distant-most quasars. Assuming two visits per night, two different bands are preferred. Science cases related to intrinsic continuum and broad-emission line variability will benefit from the denser sampling offered in the DDFs. These fields will provide powerful "truth tables" that are crucial for AGN selection algorithms, enable construction of high-quality power spectral density functions, and enable measurements of continuum-continuum and line-continuum time lags. The benefits and tradeoffs with respect to the main survey involve high-quality light curves but for only a small fraction ($\sim 1\%$) of all sources, preferentially those at lower luminosities. Certain science cases will benefit greatly from even denser sampling, i.e., $\sim 1-1000$ d^{-1}, of a smaller area, perhaps during the commissioning phase, as long as the temporal baseline will extend over the ten years of the project. Another justification to this strategy is the fact that very few AGNs, or transient AGNs, have been monitored at these frequencies on such a long baseline, leaving room for discovery.

8.1 Introduction

The purpose of this chapter is to identify AGN science cases that may be affected by the LSST observing strategy and to specify the metrics that can be used to quantify any potential effects. Since the total number of metrics that can be quantified is quite large, and the potential effects are not likely to be significant in most cases, the goal of this chapter is to identify potential "show stoppers" that may undermine key AGN research areas. For example, certain perturbations may reduce significantly the number of "interesting" AGNs, such as $z > 6$ quasars, lensed quasars, or transient AGNs. Another example is photometric reverberation mapping which is one of LSST's

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 $L_{\mathrm{AGN}} > L_{\mathrm{Host}}$

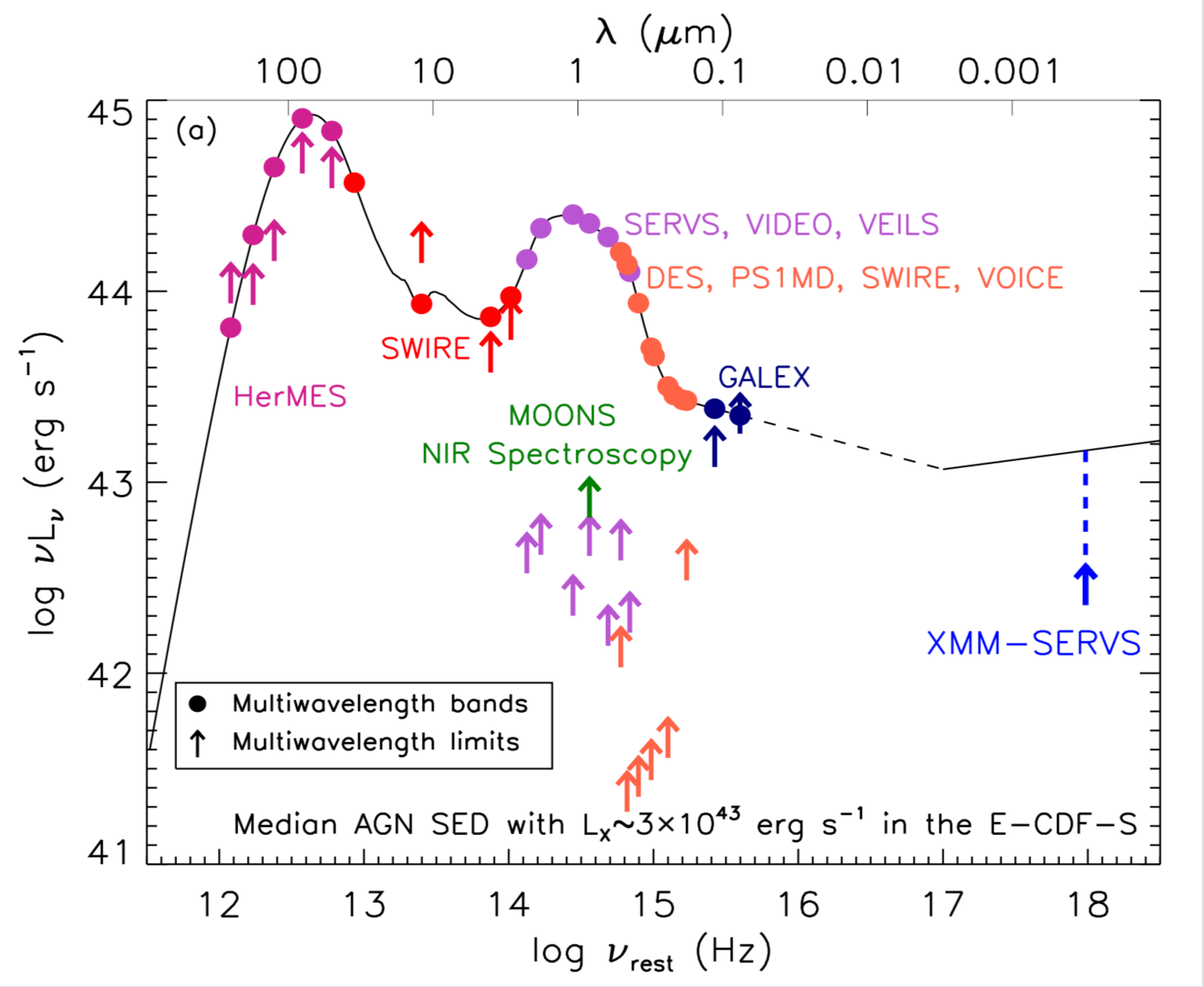
Variability

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

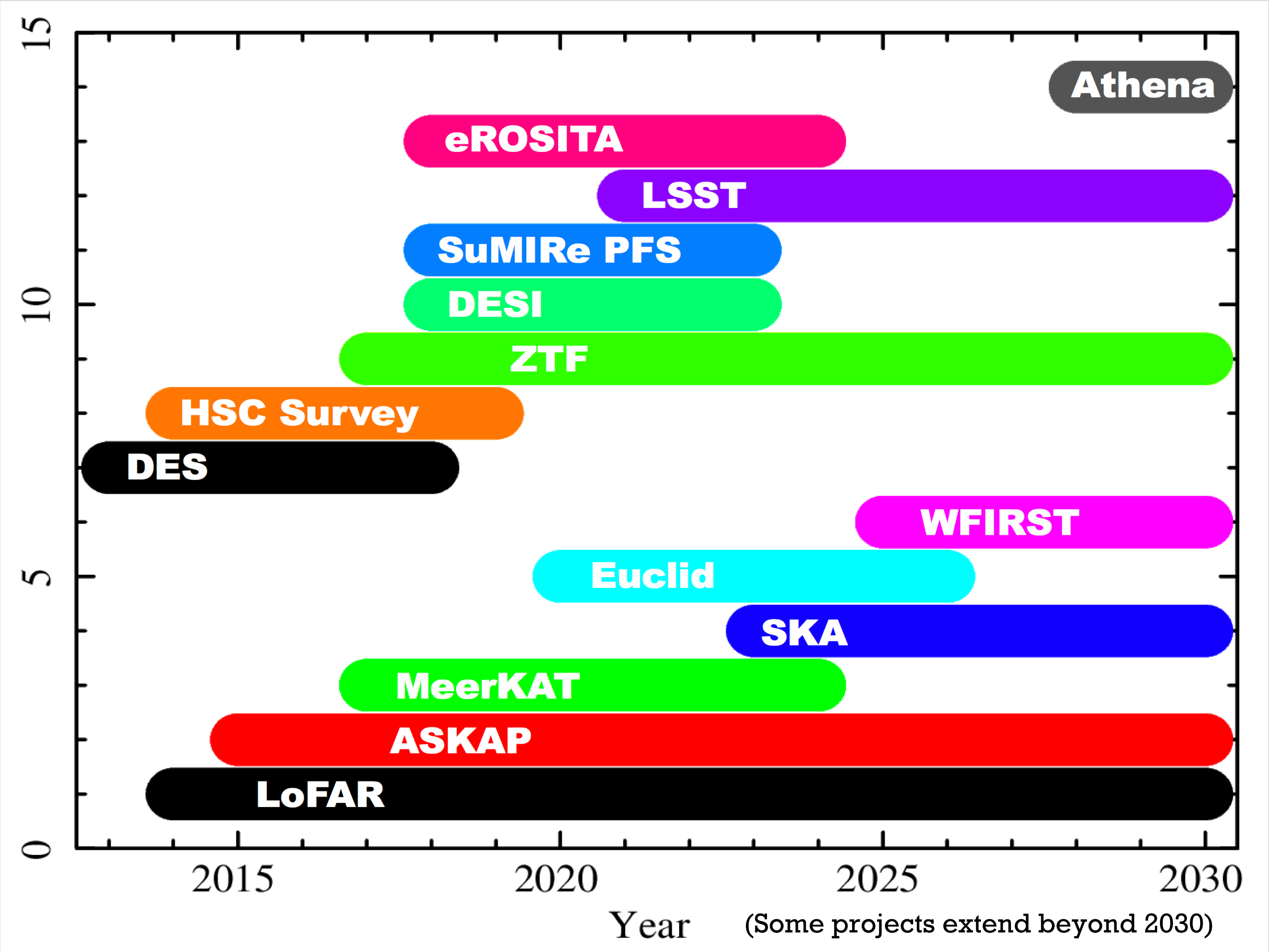
Astrometry - Lack of proper motion and differential chromatic refraction

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

Example AGN Spectral Energy Distribution

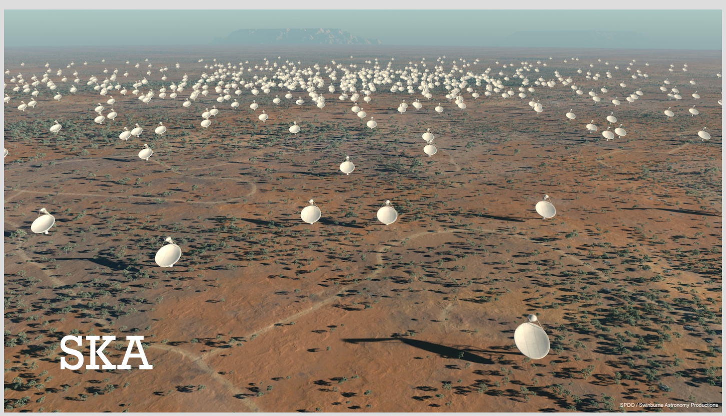


Some Future Large Survey Projects

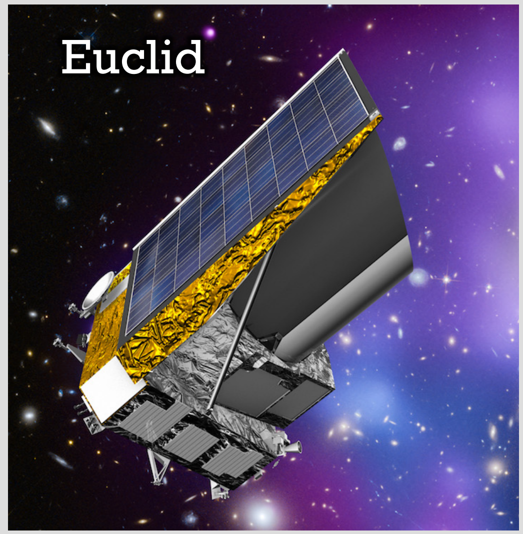


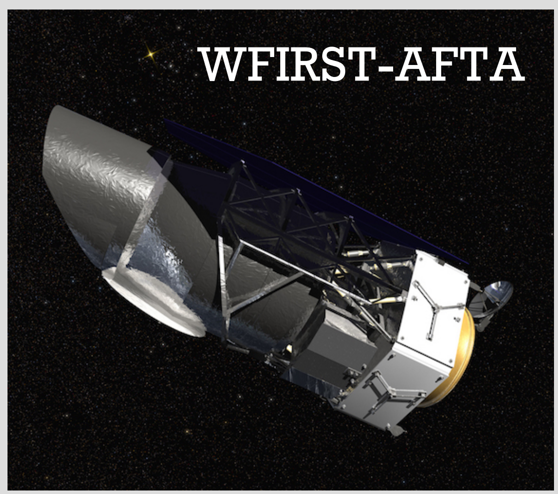
Multiwavelength AGN Selection

L_{R}, T_{b}, morphology

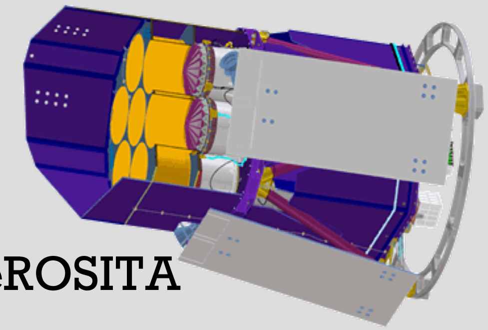


Infrared-optical colors





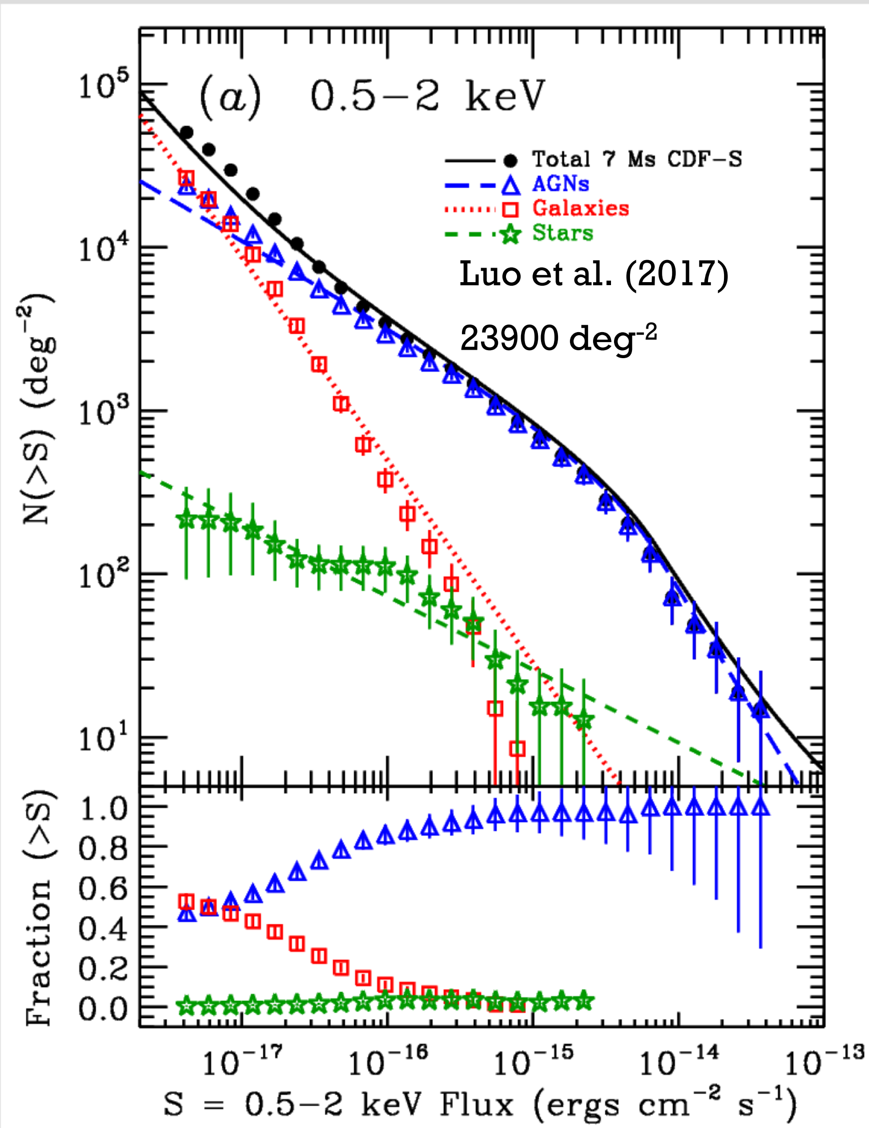
L_{X} and Γ_{X}



eROSITA

Plausible AGN Yields

Chandra Deep Field-South Number Counts



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

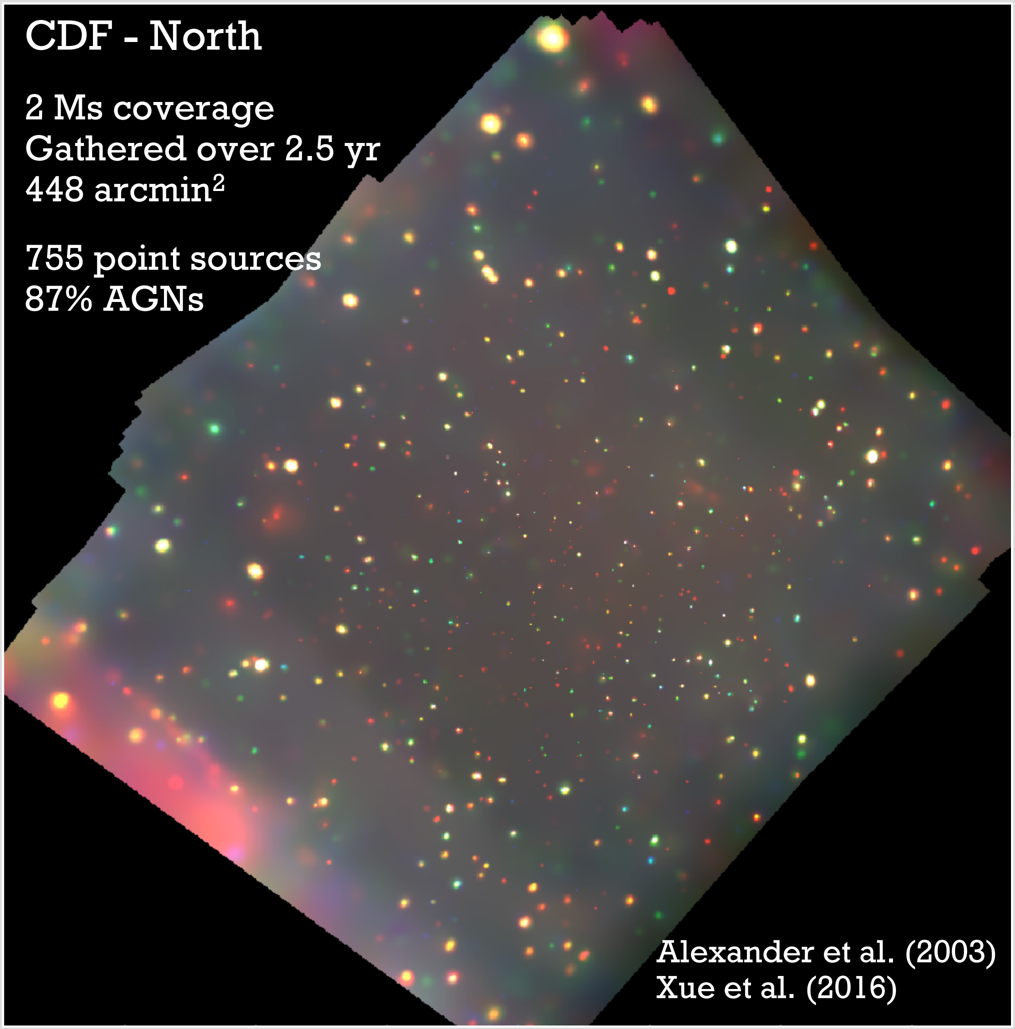
Obscuration and host-galaxy dilution will hinder AGN *selection*.

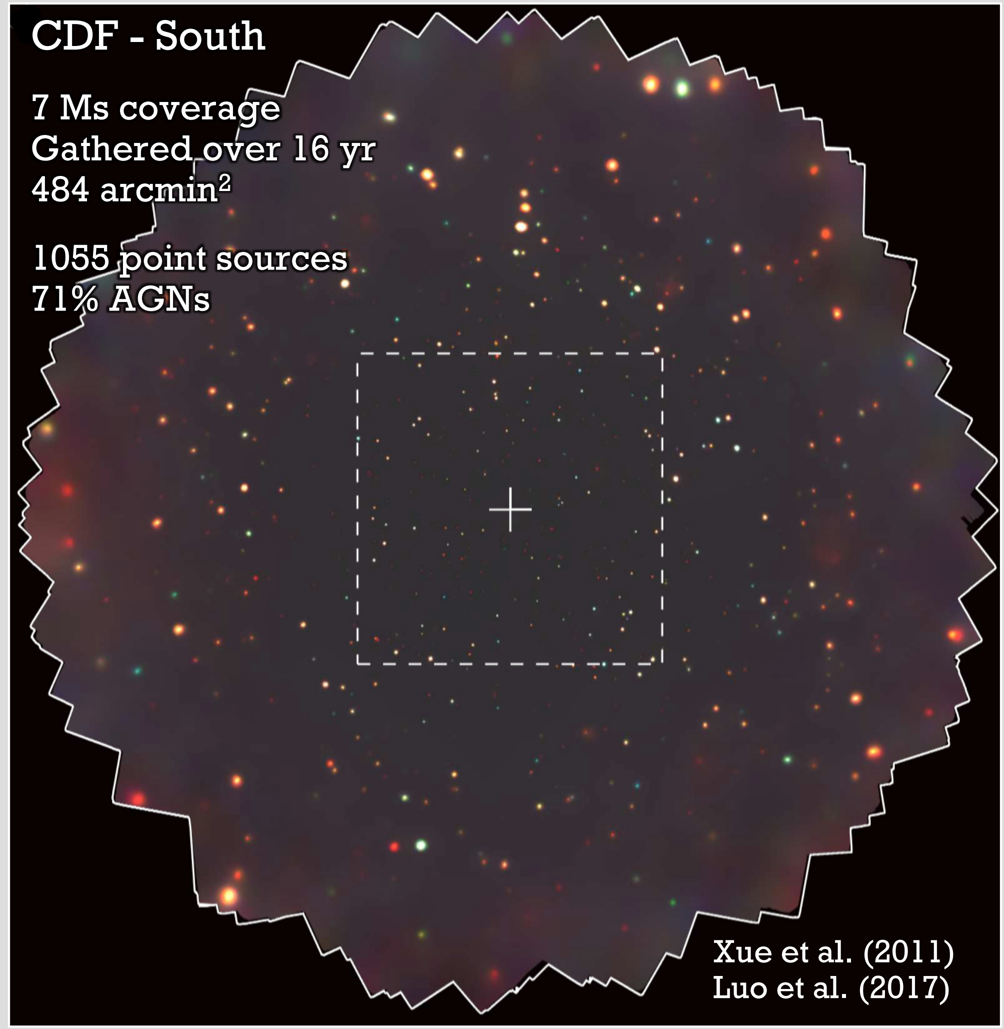
Confidently can select 20 million.

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

Overwhelming statistics to investigate, e.g., AGN evolution as a function of environment.

The Chandra Deep Fields





Faintest sources have 1 count per 10.0 days!

Plausible AGN Yields

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

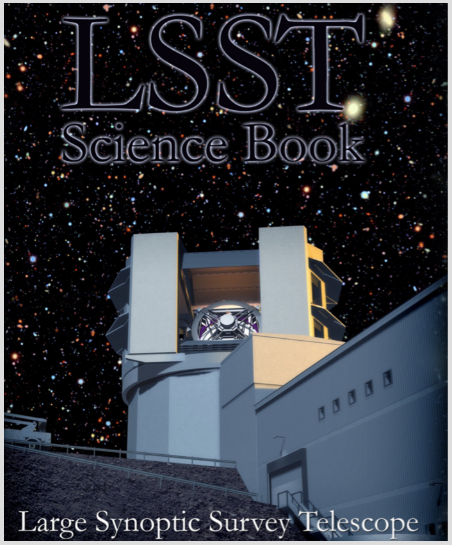
Table 8. Predicted number of quasars over $15.5 < g < 25$ and $0 < z < 6$ for a survey covering 10 000 deg^2, based on our best-fit luminosity function.

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 SNe and ~ 5 "orphan" GRB afterglows.

Massive AGN Variability Studies

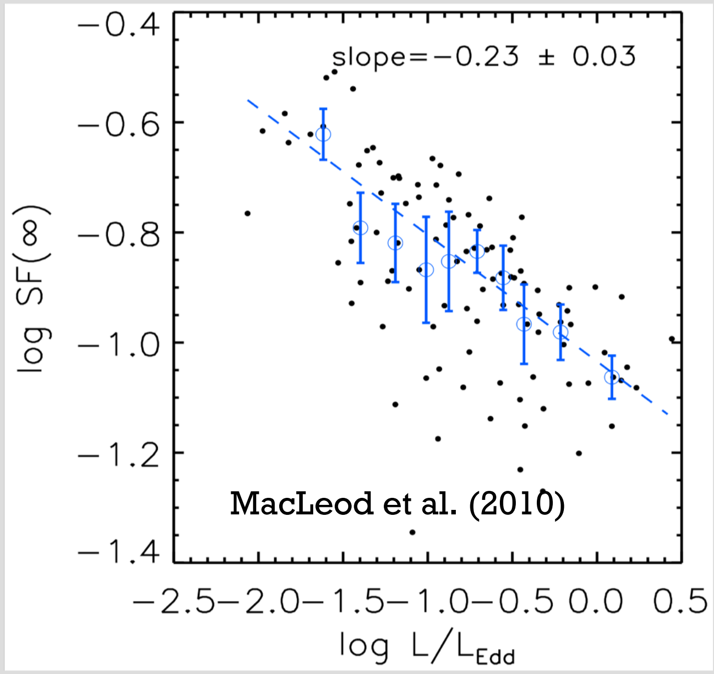
Massive AGN Variability Studies

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

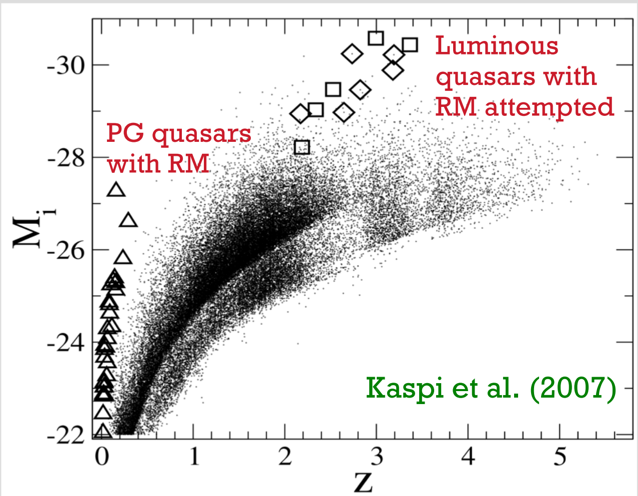


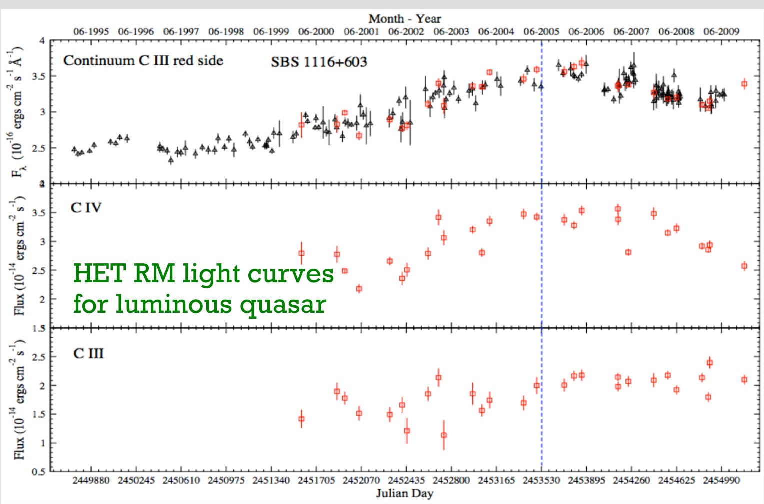
Can powerfully study general luminosity and spectral variability as a function of L, z, λ, Δt, color, radio properties, line properties, $M_{\rm BH}$, $L/L_{\rm Edd}$ (some require one-epoch spectra).

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

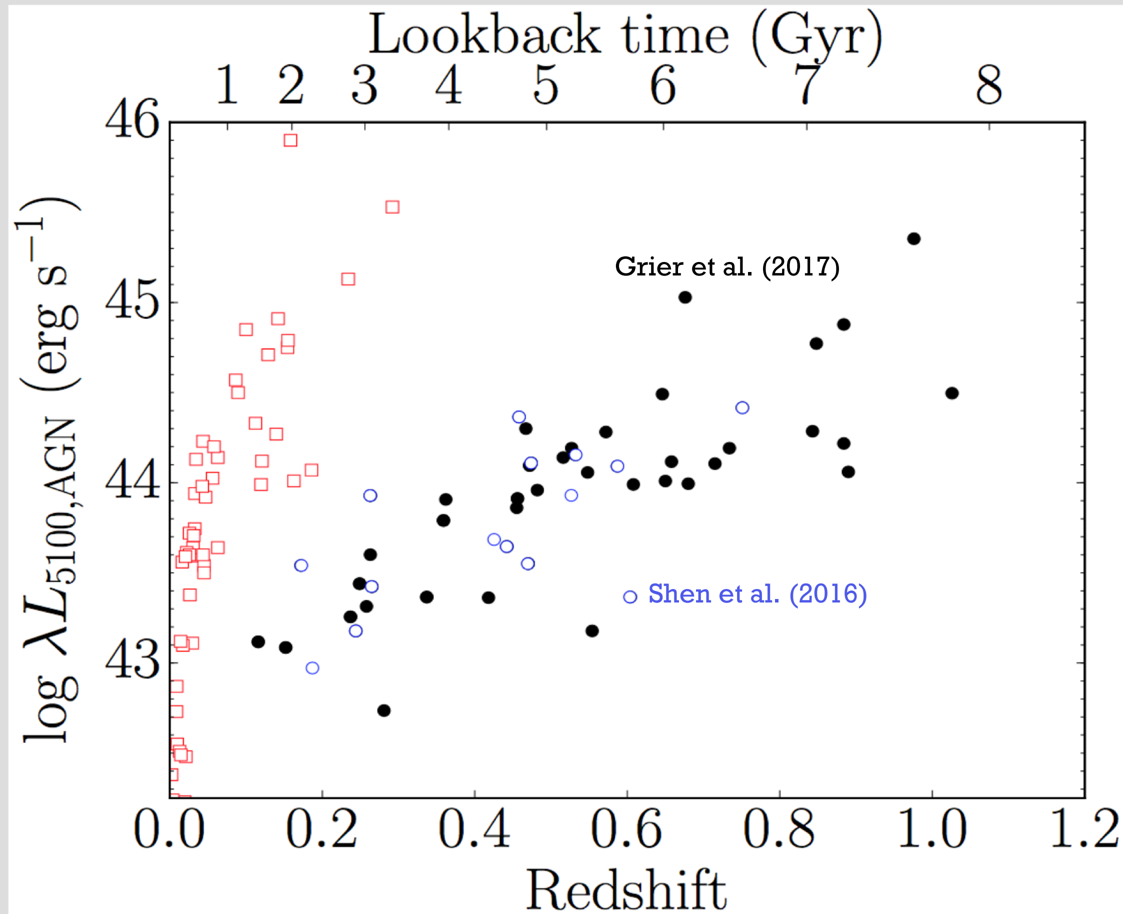
Triggered Spectroscopic Follow-Up: RM

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).

SDSS-V Connections

AS4[1] Executive Summary

Juna Kollmeier (AS4 Director) and the AS4 Science Management Team

AS4 is the ***first all-sky, time-domain spectroscopic survey***, with observational capabilities that will remain unmatched for the foreseeable future. This unique survey facility is poised to transform broad areas of astrophysics, in particular: understanding the formation of our Milky Way and other galaxies, along with the astrophysics of stars and of supermassive black holes.

In one flagship program, AS4 will provide spectroscopic data for stars across the Milky Way. This survey is unrivaled in its combination of sky coverage, time sampling, and systematic target selection throughout our Galaxy, enabled by dual-hemisphere, wide-field infrared spectroscopy. From this, we will:

- Understand the **genesis of our Galaxy** by acquiring
  - a first **global** picture of Milky Way structure and dynamics, placing our Galaxy precisely in the overall realm of galaxies,
  - comprehensive constraints on the evolutionary processes that shaped our Milky Way and other galaxies, and
  - a map of when and where the broad range of chemical elements were created in our Galaxy.
- Take the understanding of fundamental **stellar physics**, the pillar upon which much of astrophysics rests, to a new level. In combination with the *Gaia*, *Kepler* and TESS space missions, AS4 will transform our understanding of
  - the origin of supernovae,
  - the difference between planet-hosting and non-hosting stars,
  - binary stars across the Hertzsprung-Russell diagram -- as witnesses to star-formation physics, as drivers of stellar evolution and as laboratories to test stellar evolution, and
  - young, massive stars, through a vast sample of (near-IR) spectra.

At the same time, AS4 will open new frontiers in extragalactic astrophysics: it will enable us to understand **quasars as dynamical phenomena** -- through both reverberation mapping and direct black hole mass estimates from multi-epoch spectroscopy that samples time-scales from days to more than a decade. In addition, AS4 will be the only dual-hemisphere spectroscopic complement to the eROSITA mission, unveiling the nature of **X-ray sources** that shine brightly across the sky.

See arXiv:1711.03234

All-sky, time-domain spectroscopic survey (about 2020-2025).

A key component is quasars as dynamical phenomena:

- Reverberation mapping in the DDFs etc.
- General multi-epoch spectroscopy

Good LSST complementarity.

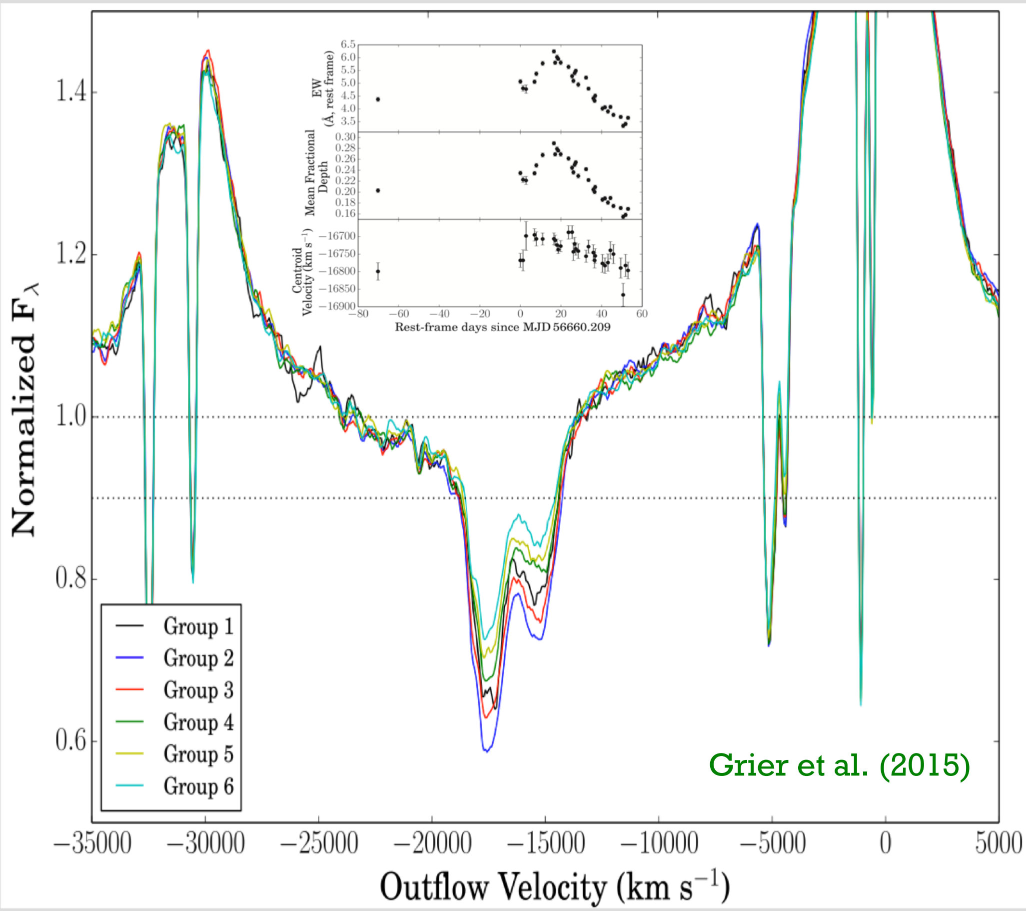
$16 million Sloan funding.

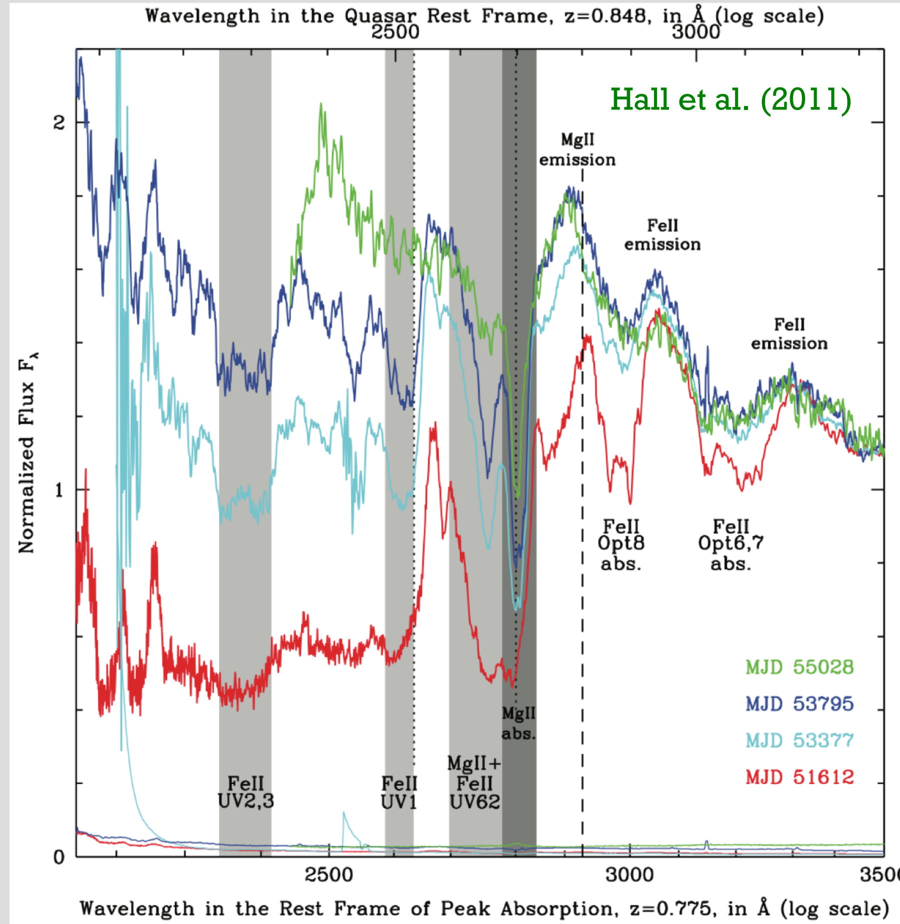
Still opportunities to buy in.

Also 4MOST, PFS, etc.

Triggered Spectroscopic Follow-Up: BALs

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

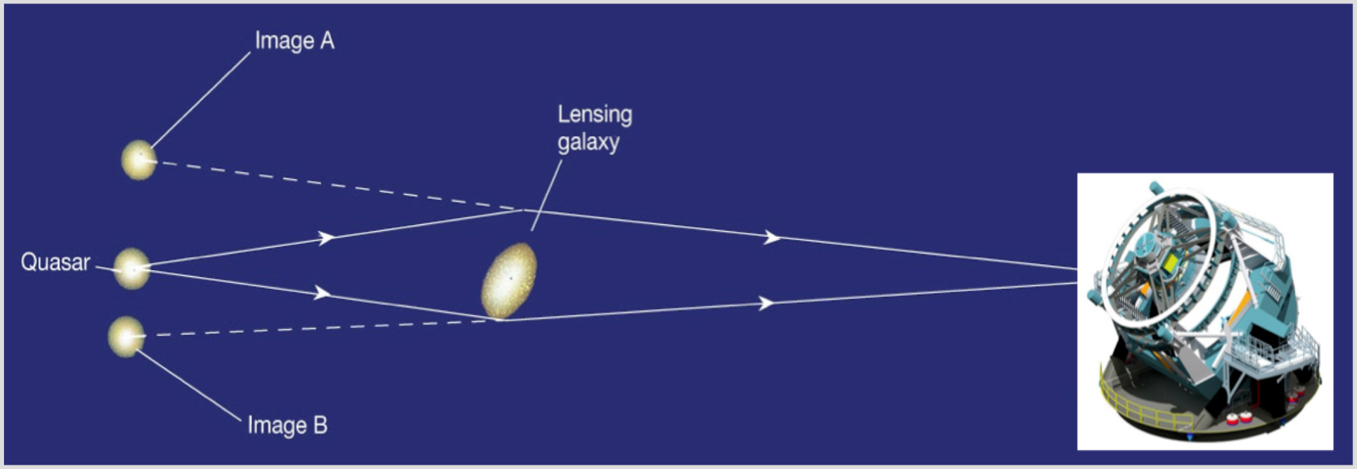


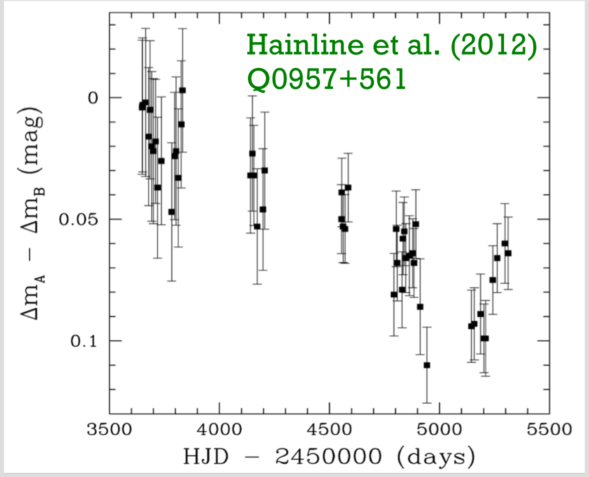


Also other absorption changes; e.g., variable dust reddening.

Also “changing look” quasars.

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_{Edd}, M_{BH}, z effects.

Small-Separation Binary SMBH

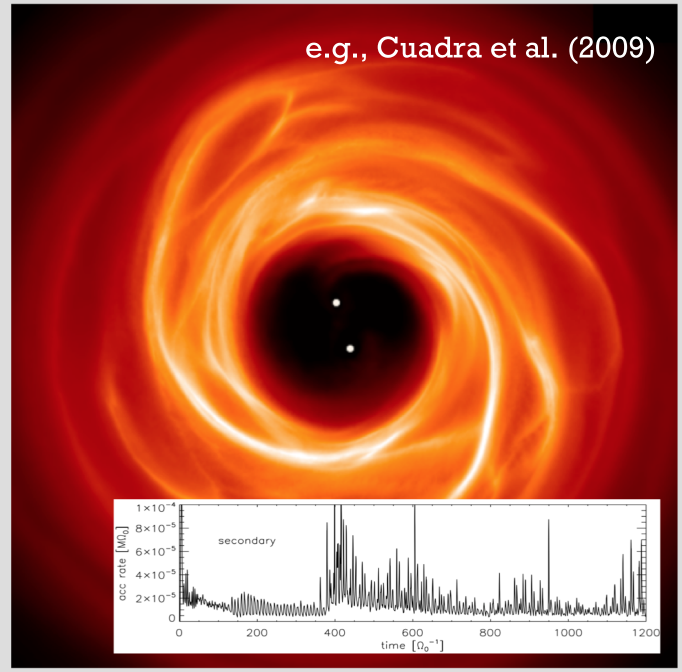
For SMBHs to move from pc to 10^{-3} pc separations, likely need gas accretion to remove binary angular momentum.

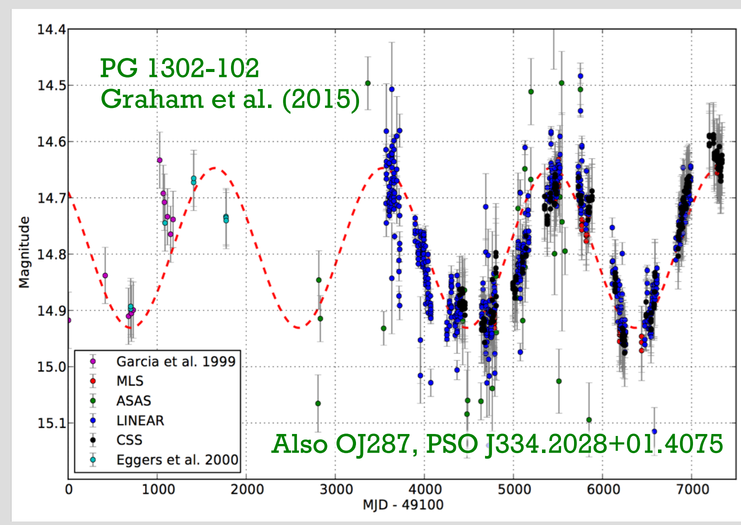
Accretion rate onto both SMBHs may vary on timescales of the binary period.

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.

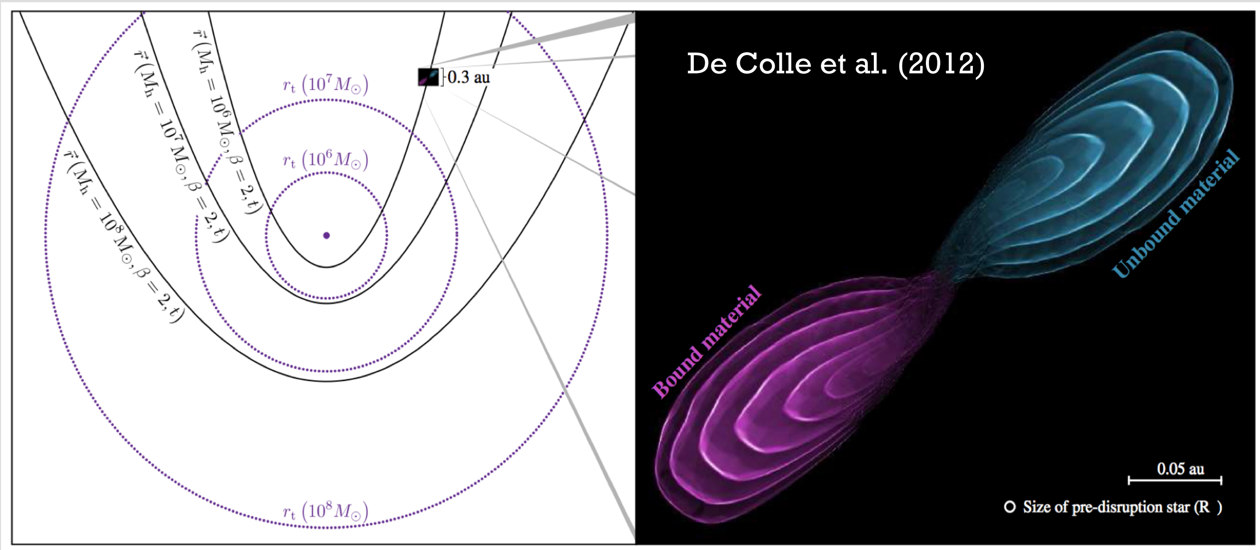
Already some candidates being found, but detailed interpretation still unclear.



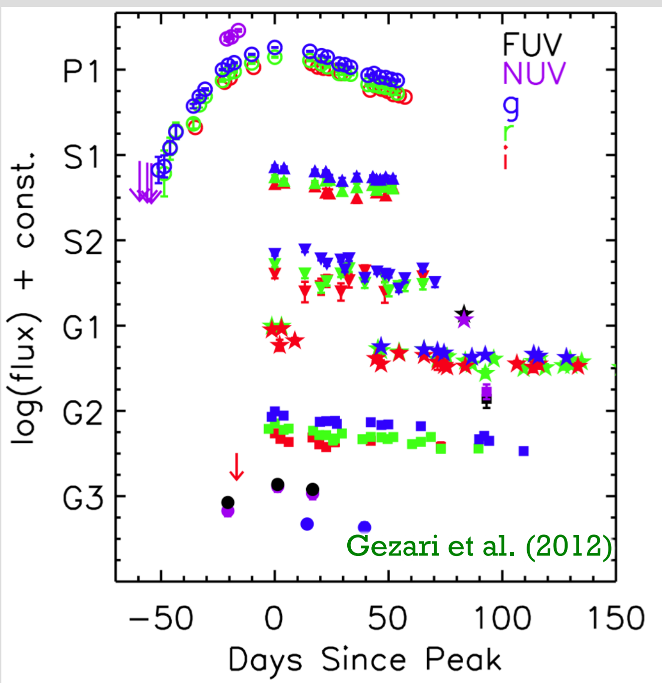


Transient SMBH Fueling Events

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).

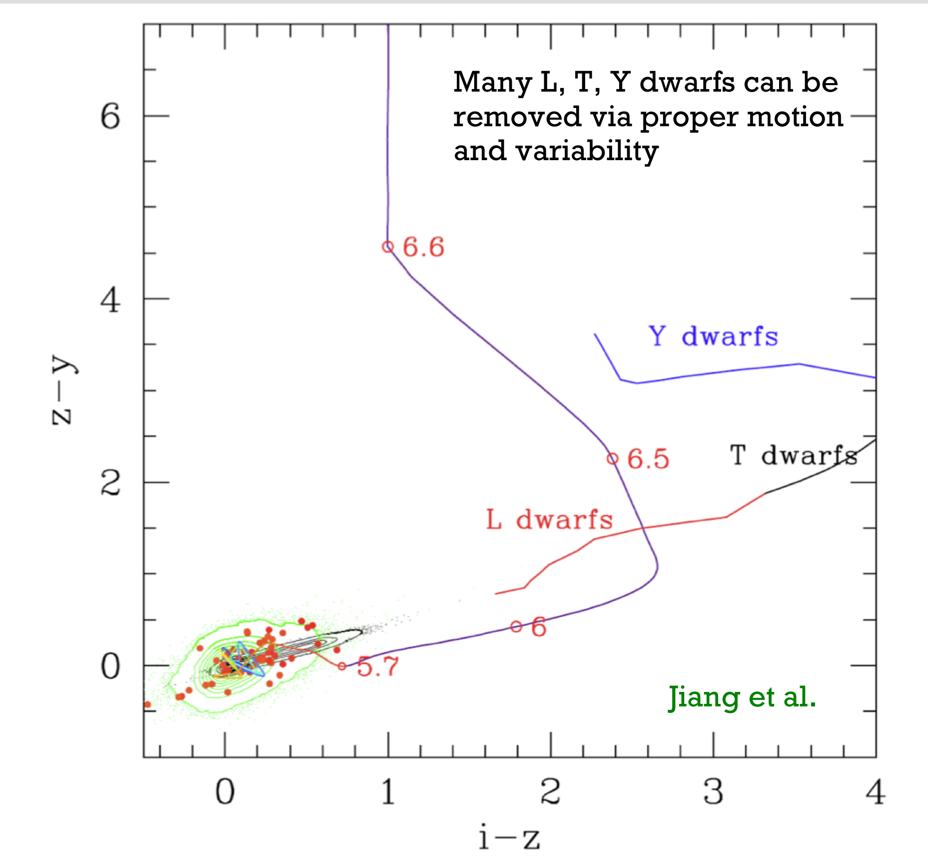
Understand diversity of these events ($L_{\rm Bol}$, kT, jet power)

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

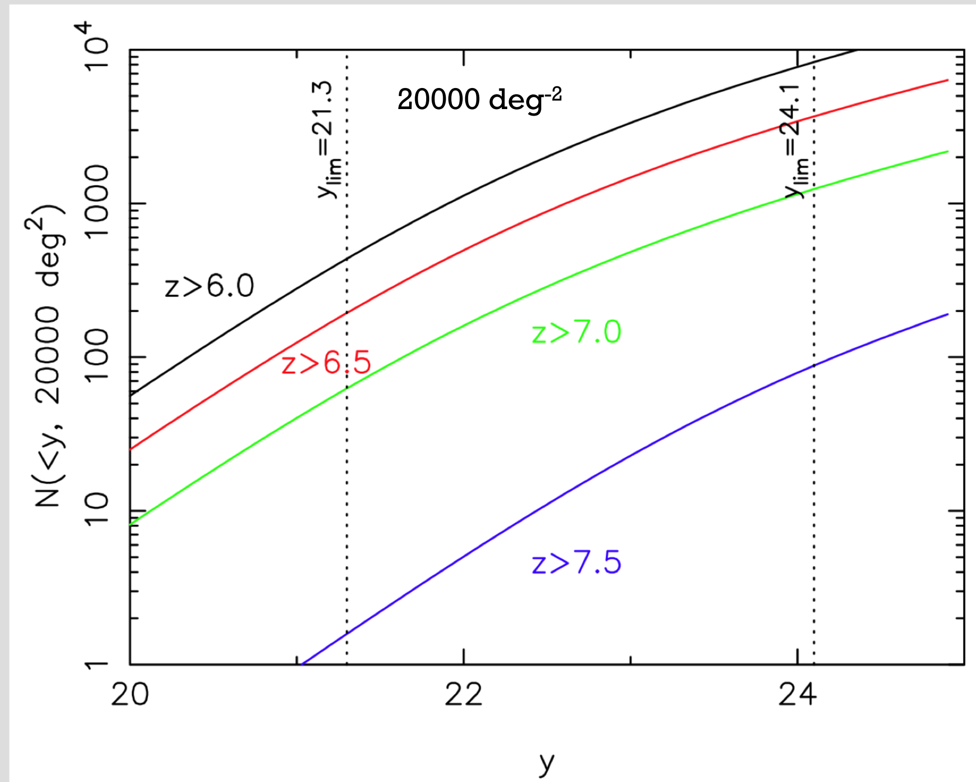
AGN Investigations at High Redshifts

High-Redshift AGN Selection

Colors of High-Redshift Quasars



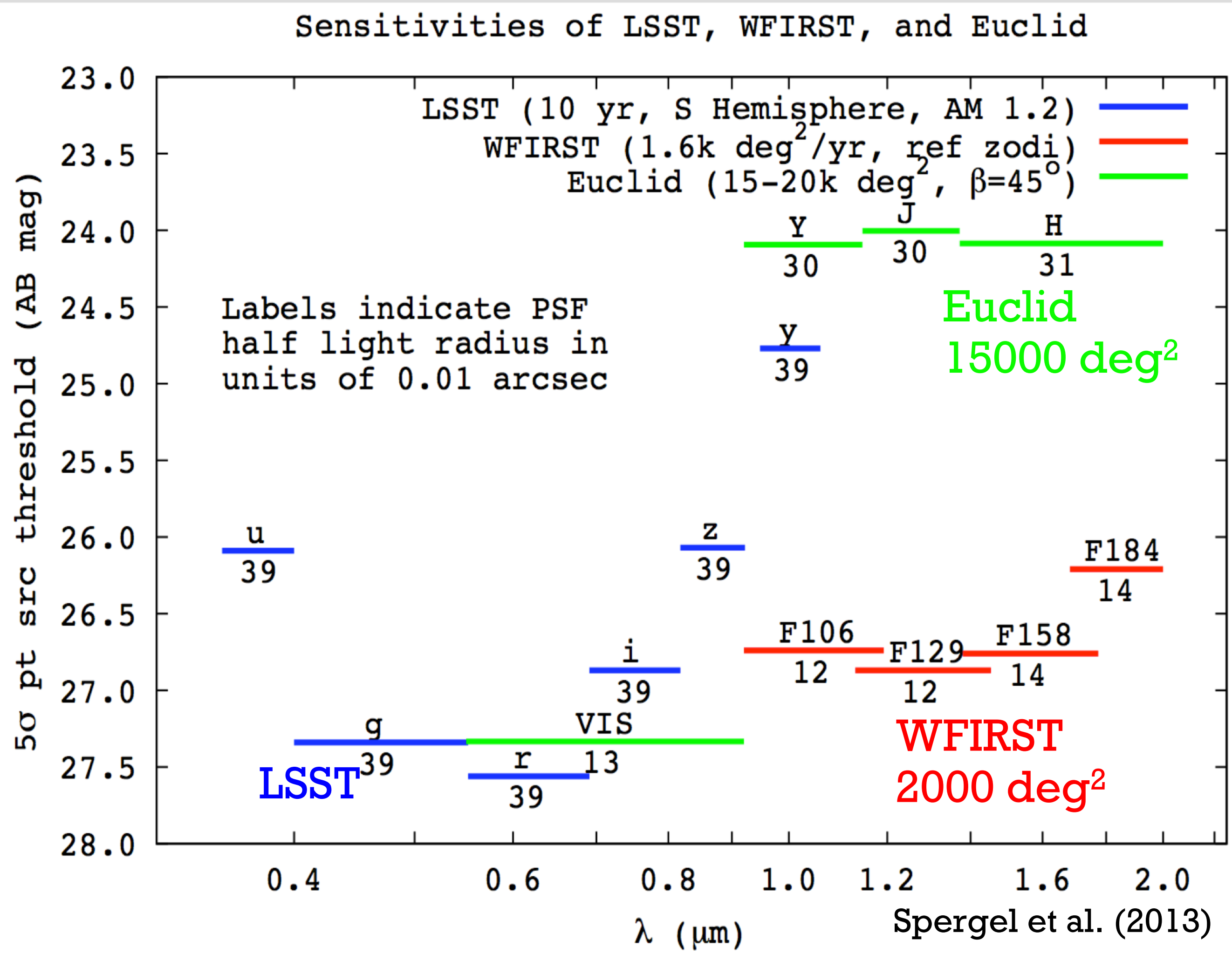
Expected Numbers of $z > 6$ Quasars



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 X-ray and radio high-redshift 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.

According to Dan Stern:

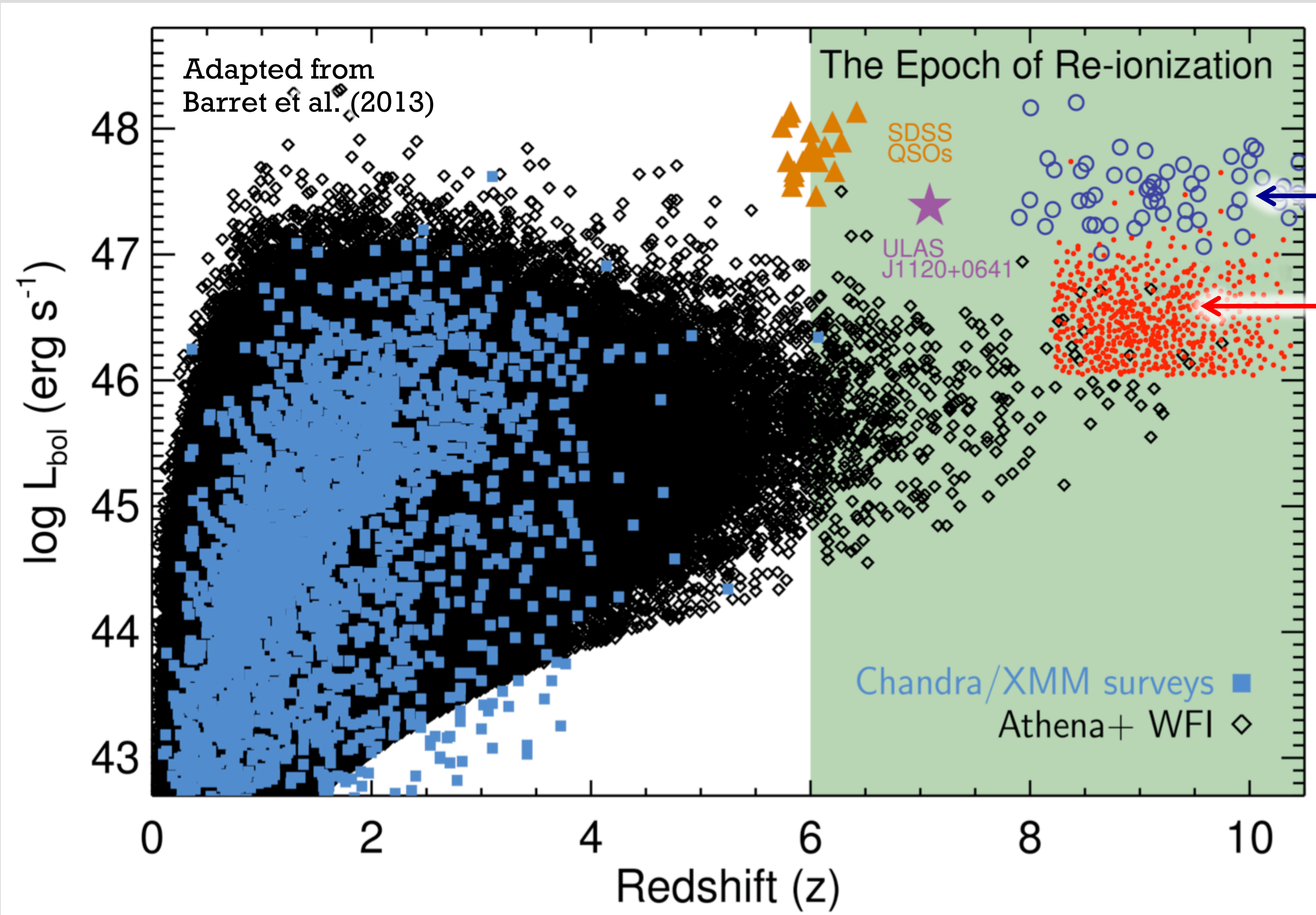
Euclid should deliver ~ 1360 luminous quasars at z > 7, and 24 at z > 10.

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

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

According to Rhys Barnett, the yields may be a factor of ~ 3 lower.

Luminosity vs. Redshift for Future High-Redshift AGN Samples



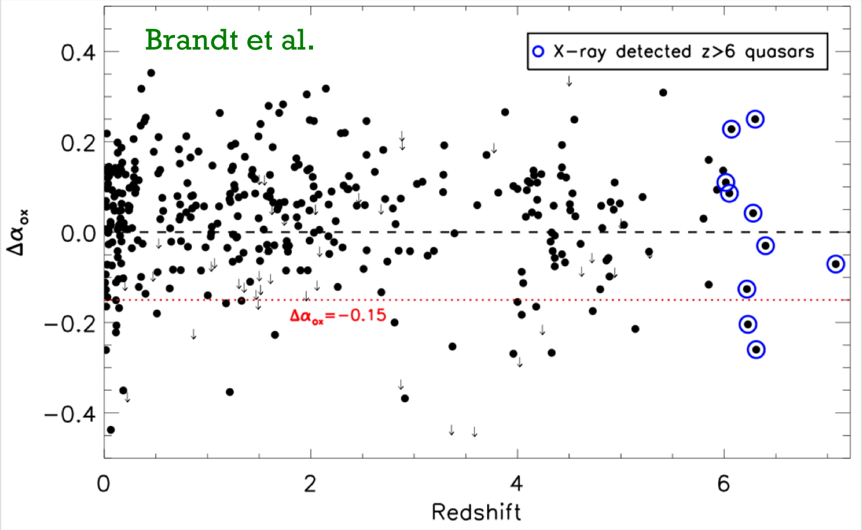
Euclid

WFIRST+LSST at $z > 8$

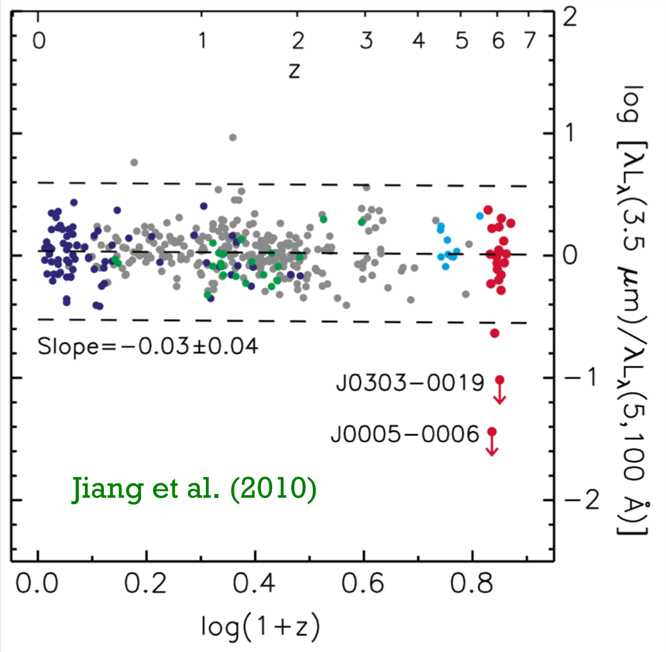
Lots of great high-z targets for multiwavelength follow-up studies.

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.



Massive Mining of Chandra and XMM-Newton Archives

Combine Chandra and XMM-Newton source catalogs, especially for deeper observations, with DES, HSC, LSST, Euclid, WFIRST, etc.

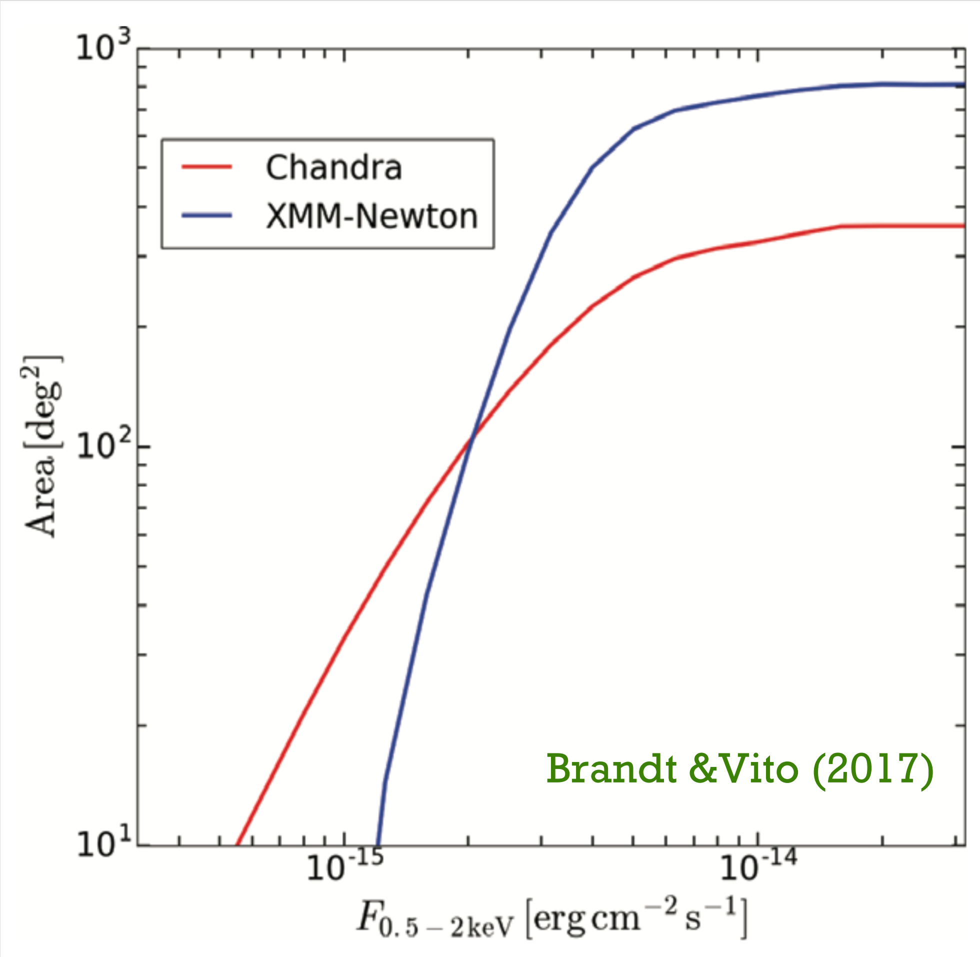
Can aim for an effective $z \sim 4$ - 8 AGN survey, *including obscured AGNs*, over ~ 1100 deg^2.

Identify X-ray sources with optical / NIR colors indicating high redshifts.

Only new cost is follow-up spectroscopy, which could use DESI, PFS, 4MOST.

Measure XLF bright end and f_{obsc} with
500-1100 sources at $z = 4$ - 6 and
10-100 sources at $z = 6$ - 8.

Solid Angle vs. Depth for a 25 yr Chandra + XMM-Newton Survey




The End