LSST
Large Synoptic Survey Telescope

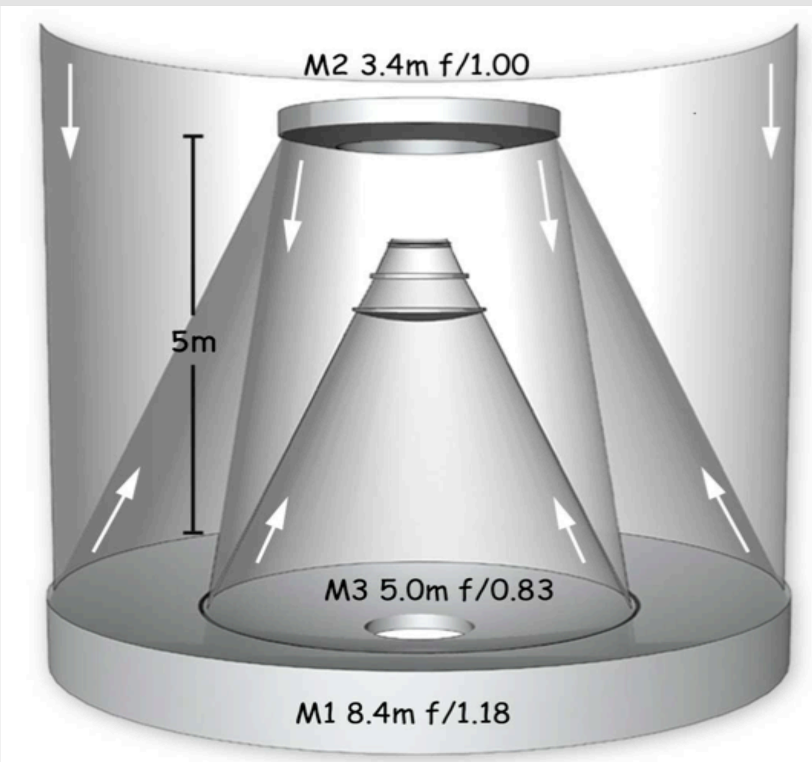
Lorentz center
Paving the Way to Simultaneous Multi-Wavelength Astronomy
Workshop: 13 – 17 July 2015, Leiden, the Netherlands

Niel Brandt (Penn State)

Quick Overview, Current Status, and Comparison to Other Variability 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.

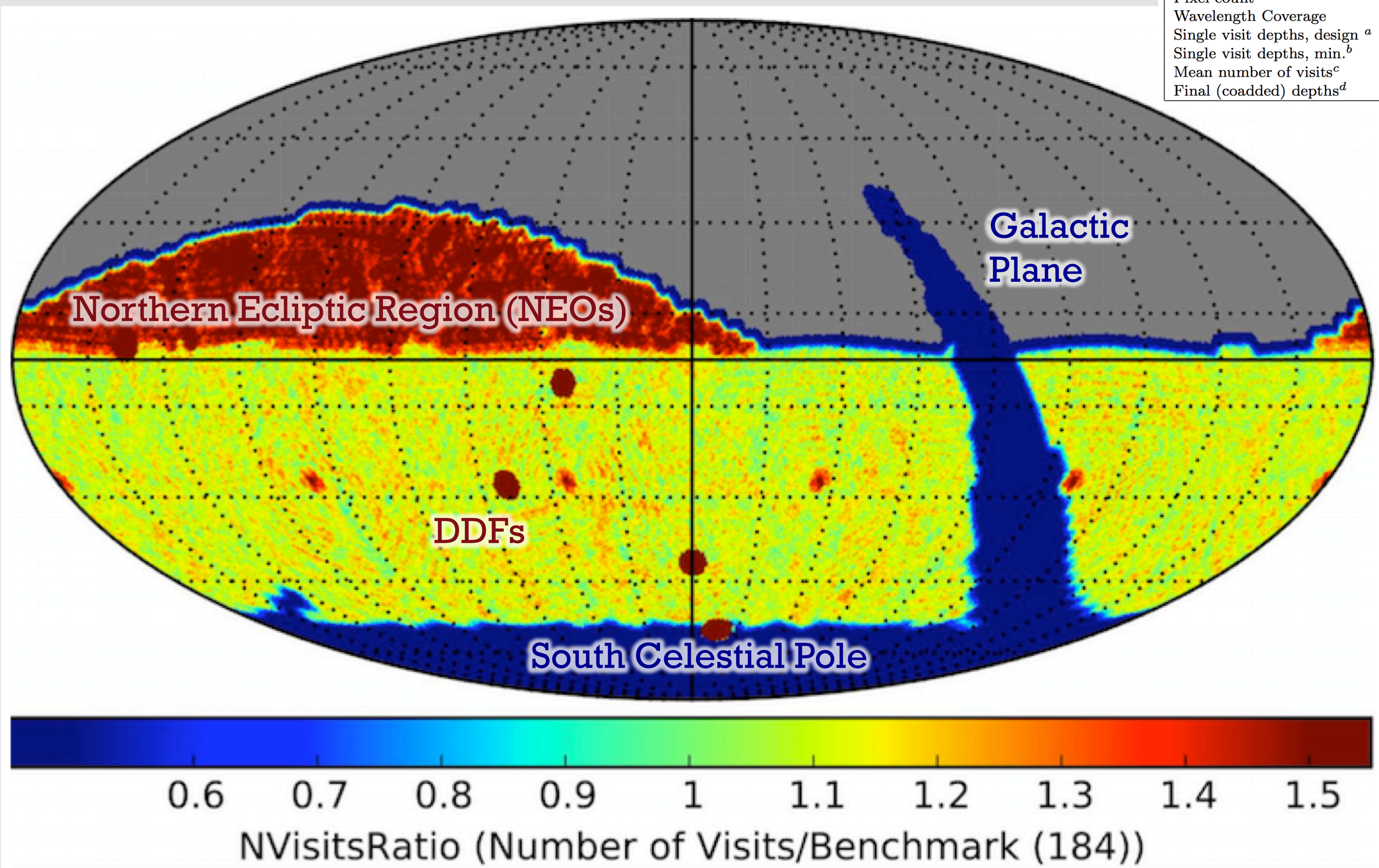
See arXiv:0805.2366 for more details.

Main Survey - Brief Details

Operations Simulation of *r*-Band Visits

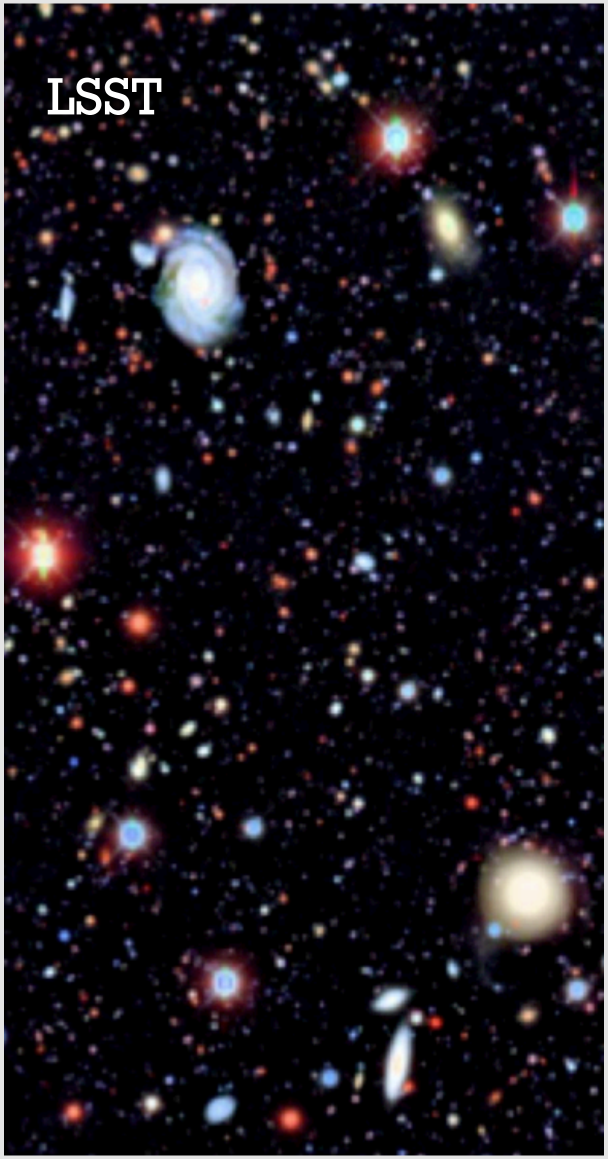
THE LSST BASELINE DESIGN AND SURVEY PARAMETERS

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 $m^2 deg^2$
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



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

Image Comparison



20 billion galaxies

and

20 billion stars

with

exquisite photometry, image quality, and astrometry.

Many millions of quasars, supernovae, asteroids, etc.

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.

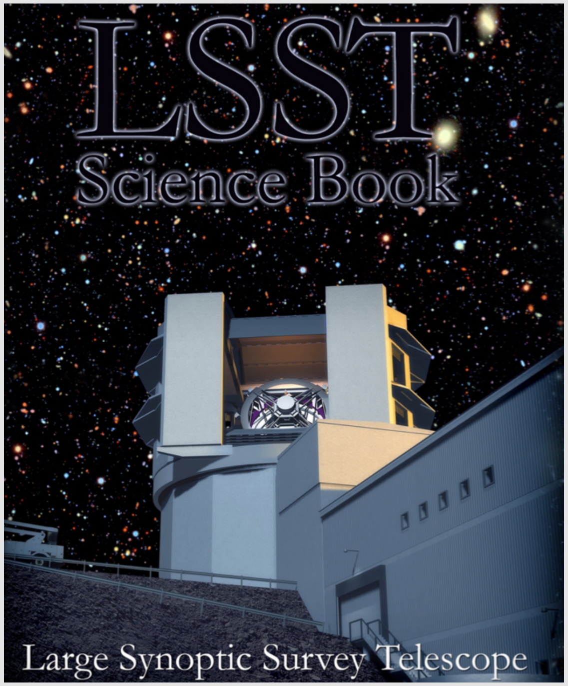
Other possible cadence programs include improved Galactic-plane coverage, denser sampling of ~ 600 deg^2, rotating "focus" fields, TOOs?

LSST Science Themes

Dark matter, dark energy, cosmology
(e.g., spatial distribution of galaxies, gravitational lensing, supernovae, quasars)

<u>Time-domain astrophysics</u>
(e.g., SMBHs, compact objects, cosmic explosions, variable stars)

Solar System structure
(e.g., near-Earth asteroids, trans-Neptunian objects)



596 pages!

Milky Way structure
(e.g., stars, star-formation regions, tidal streams)

Project Status and a Few Updates

Received Federal construction start in 2014 Aug as NSF/DOE project.

Primary/tertiary mirror polishing completed in 2015 Feb. Secondary mirror at Exelis for processing to finished polished state.

Plans for camera construction at SLAC received "Critical Decision 2" approval from DOE. Fabrication can begin after "Critical Decision 3" review in 2015 Summer.

Dome contract initiated.

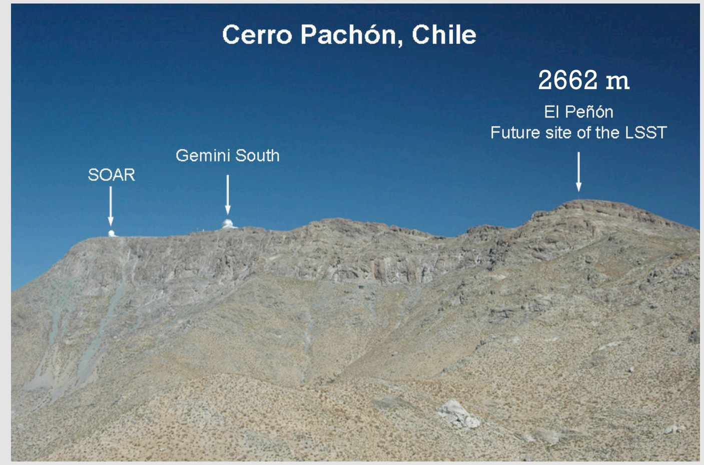
Site leveled and preparation in progress.

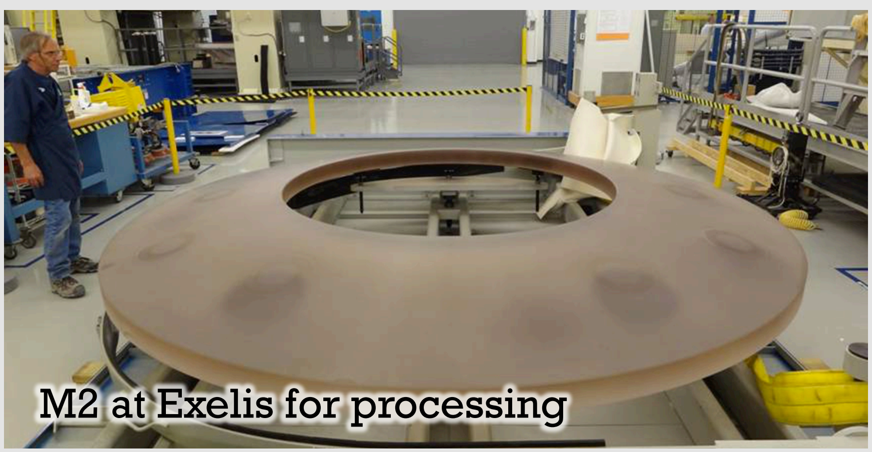
LSST Project actively hiring engineering and science staff.

Onset of science operations planned for late 2022 (2019 first light).

Current Project Status

M1M3 after polishing - moved to storage at Tucson International Airport



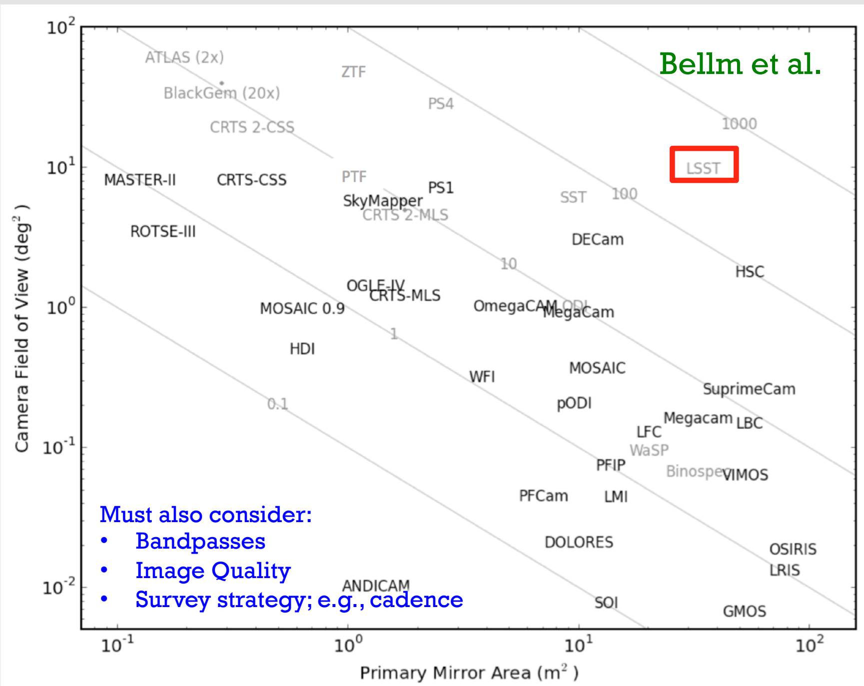


M2 at Exelis for processing

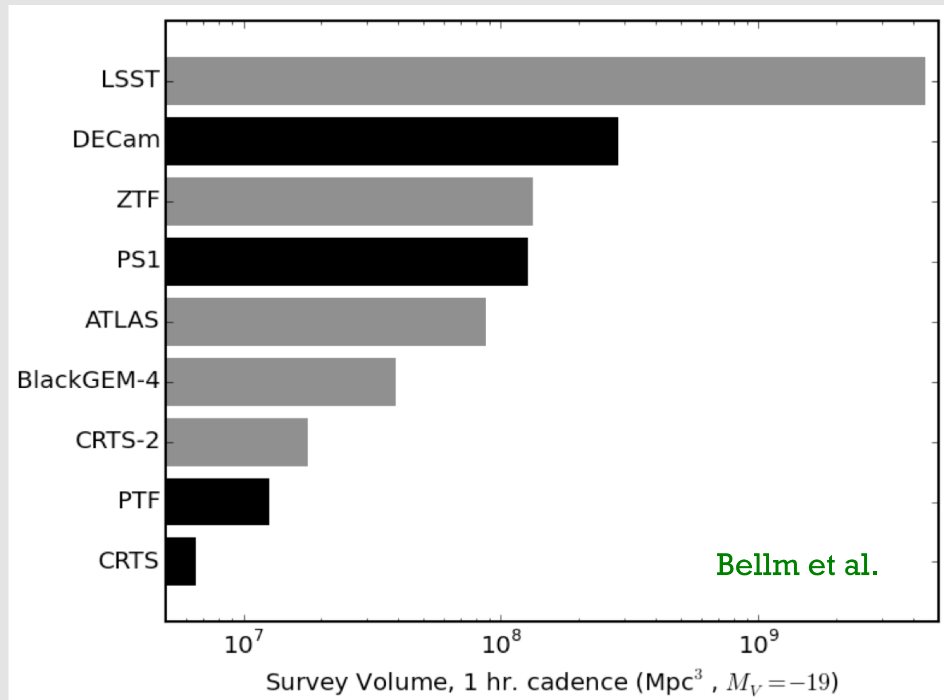
Site bedrock testing in 2015 June

Some Basic Comparisons to Other Facilities

Étendue Comparison

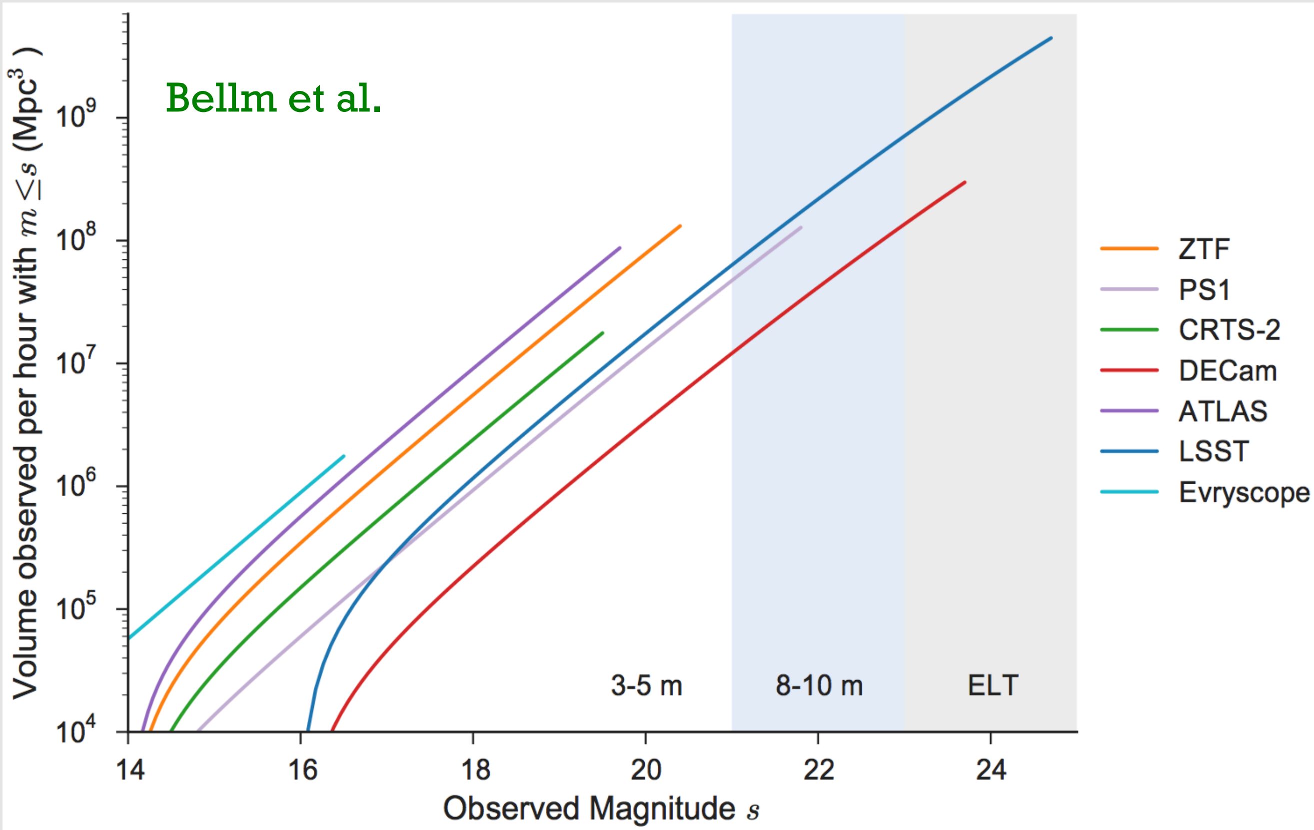


Surveying Massive Cosmic Volumes



Above an étendue of 200-300 m² deg² it becomes possible to undertake a single comprehensive multi-band survey of the entire visible sky serving most science opportunities, rather than multiple special surveys in series.

LSST Transients Follow-Up Challenge

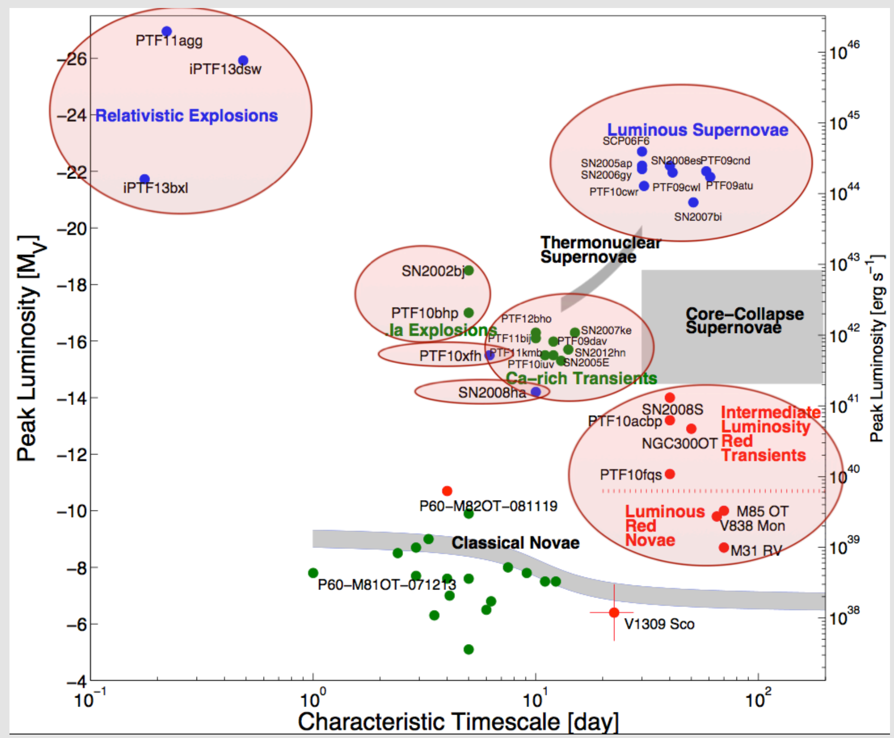


Owing to delays in funding for LSST construction, smaller projects are picking off the bright-source science in specific areas; e.g., transients.

Most of the "new discovery volume" for LSST transients in 2022 will be at faint magnitudes. Large telescopes needed for follow-up!

Some SMBH Variability Science with LSST

See, e.g., the LSST Science Book for LOTS of additional science on other classes of variable objects.



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?

Aim to select 20-40 million, or more, AGNs with LSST plus multiwavelength data.

Also ~ 2500 supernovae and ~ 5 "orphan" GRB afterglows.

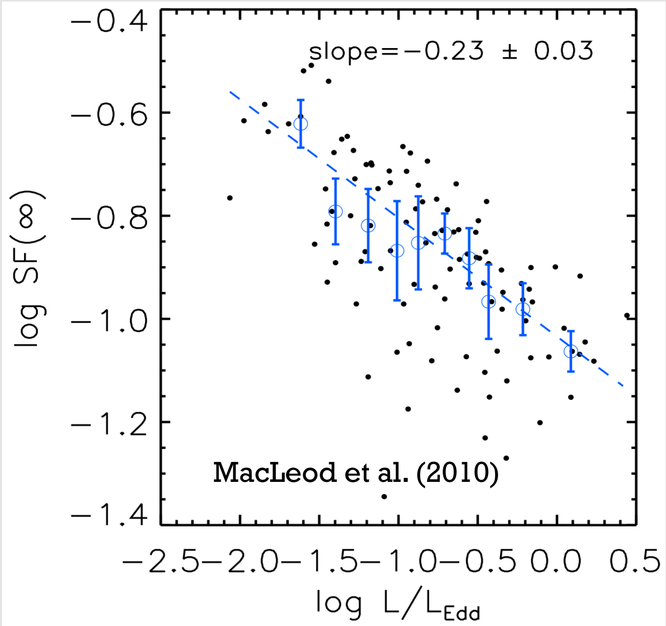
Massive AGN Variability Studies

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

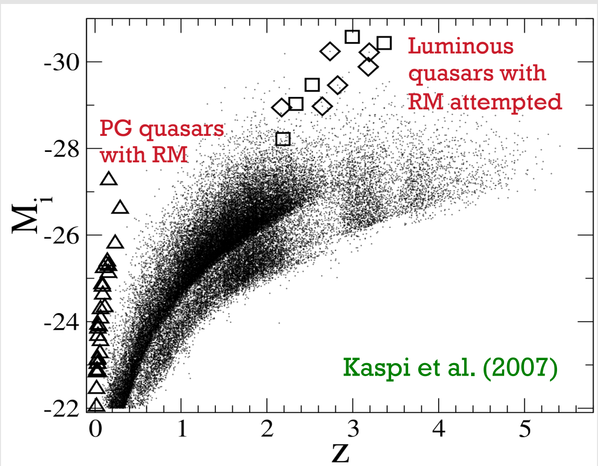


Can powerfully study general luminosity and spectral variability as a function of L, z, λ, Δt, color, radio properties, line properties, M_{BH}, L/L_{Edd} (some require one-epoch spectra).

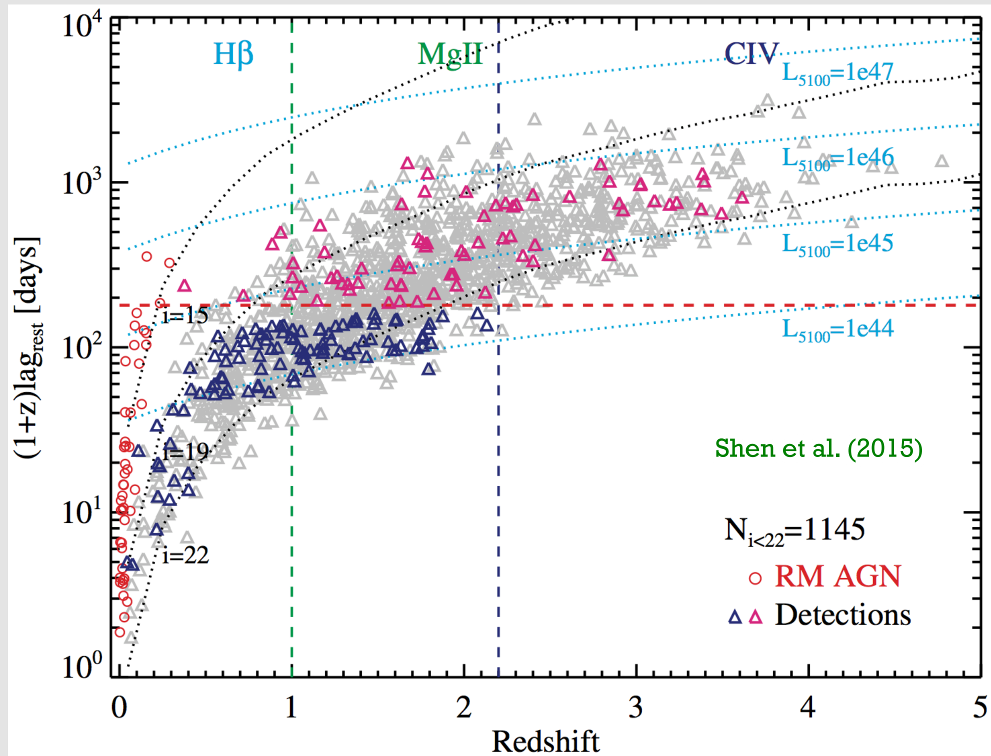
Rare but important events - large disk instabilities, strong jet flares, swan-song events, QPOs.

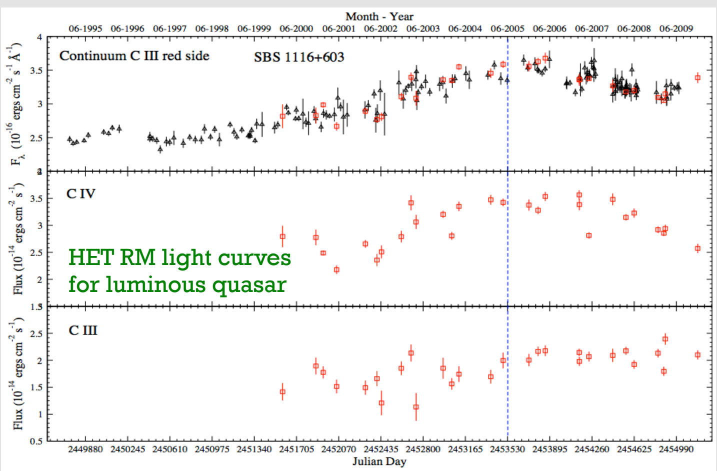
Triggered Spectroscopic Follow-Up: RM

Strong Quasar Continuum Variations Can Trigger Reverberation Mapping Follow-Up



Multi-Object AGN Reverberation Mapping with SDSS

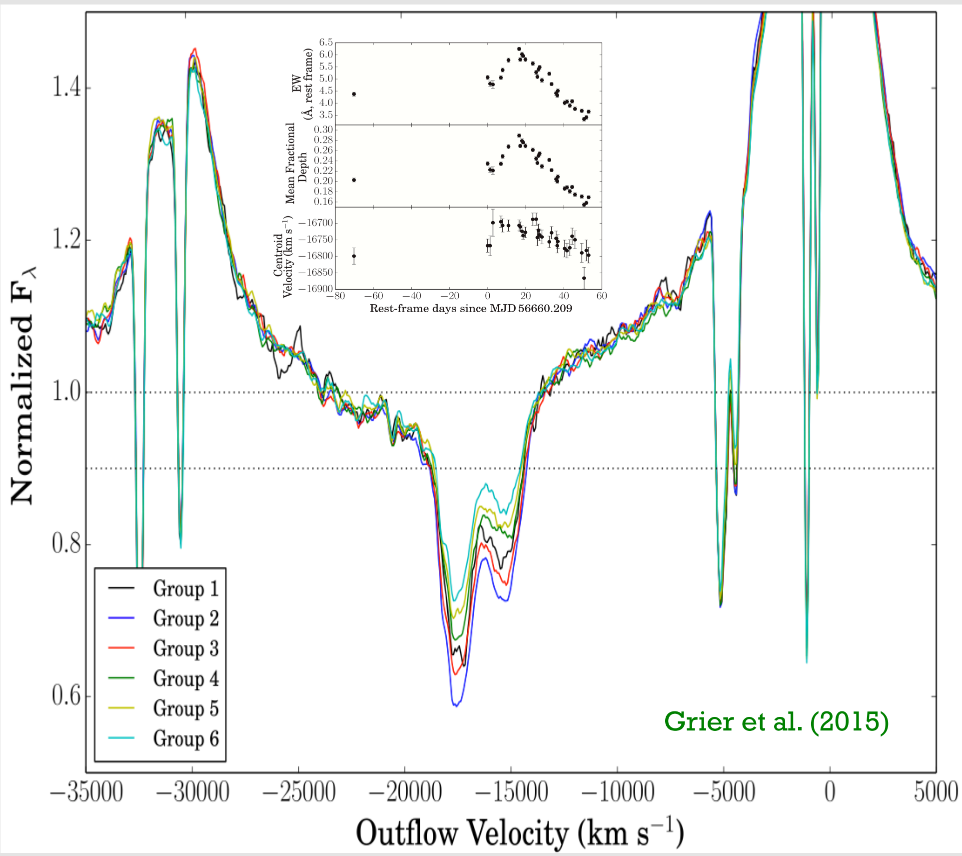


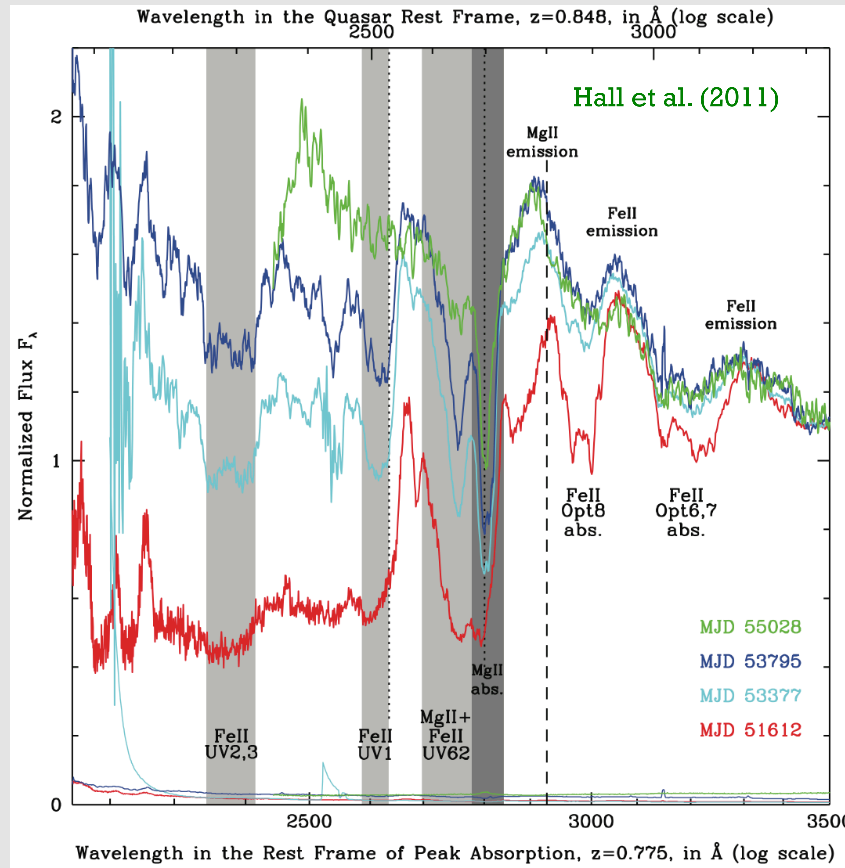


Potentially also photometric RM (Chelouche et al. 2012, 2014).

Triggered Spectroscopic Follow-Up: BALs

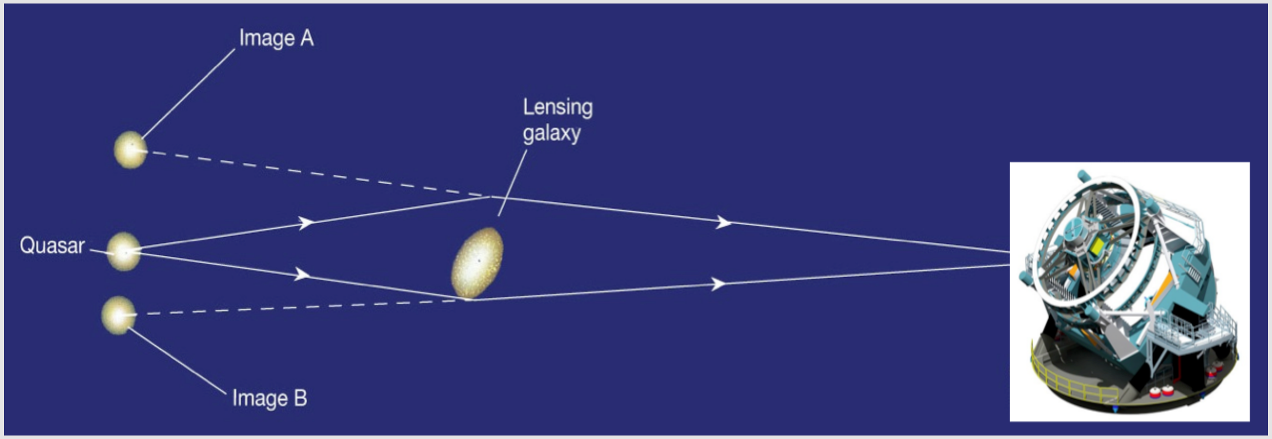
Color Changes Will Trigger Spectroscopic Follow-Up of Strong BAL Variations

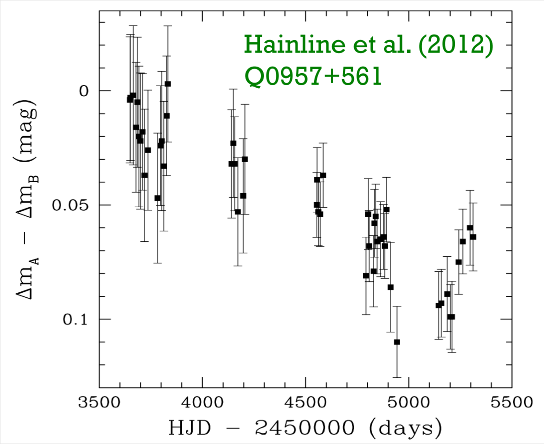




Also other absorption changes; e.g., variable dust reddening.

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

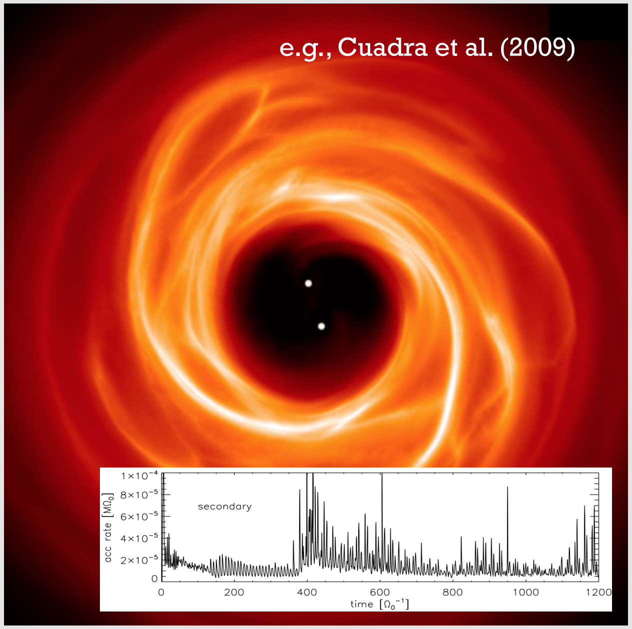
For SMBHs to move from pc to 10^{-3} pc separations, likely need gas accretion to remove binary angular momentum.

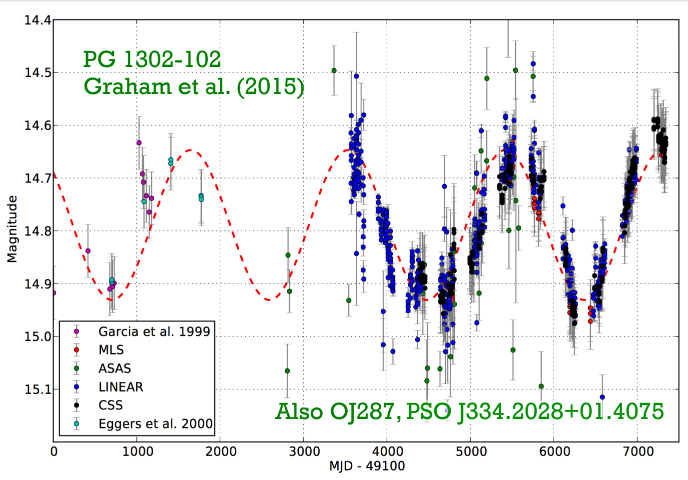
Accretion rate onto both SMBHs may vary on timescales of the binary period.

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

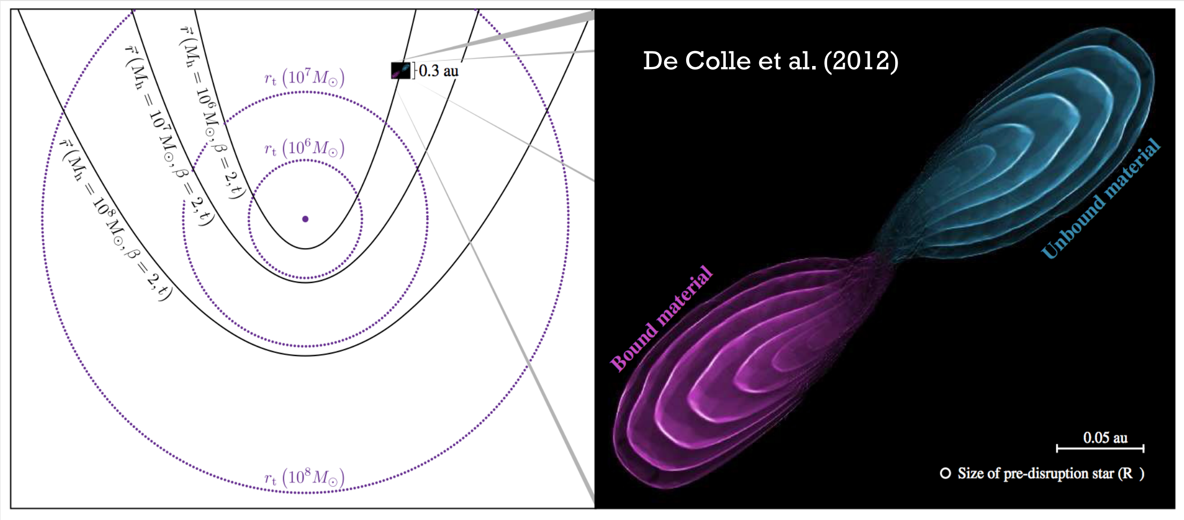
Massive LSST variability survey can find or usefully constrain the uncertain frequency of 10^{-2} pc binary SMBHs.

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

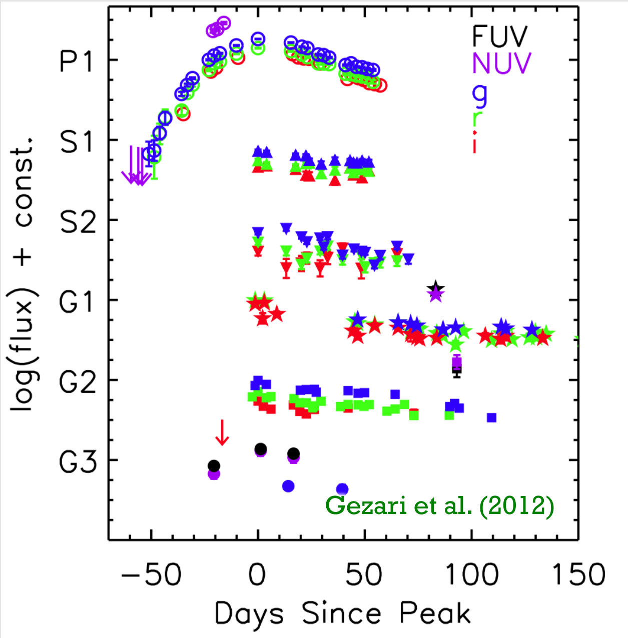




Transient Fueling of Dormant SMBH



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.

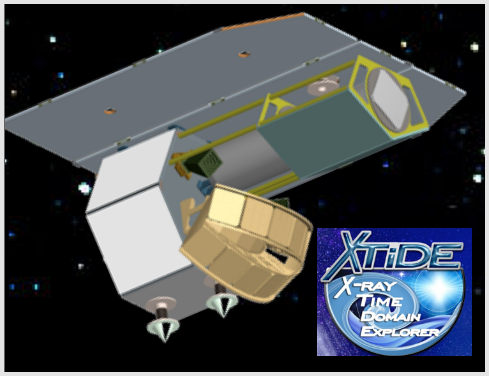
Determine fraction with jets via radio follow-up and comparison with radio transient surveys (e.g., VAST, ThunderKAT, LOFAR transients).

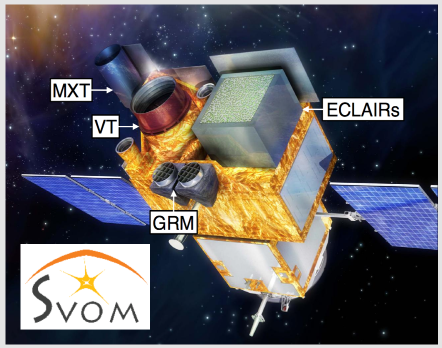
Understand diversity of these events ($L_{\rm Bol}$, kT, jet power)

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

LSST Synergy with Multiwavelength Satellite Missions

Very Wide-Field Missions for X-ray Transients Being Pursued



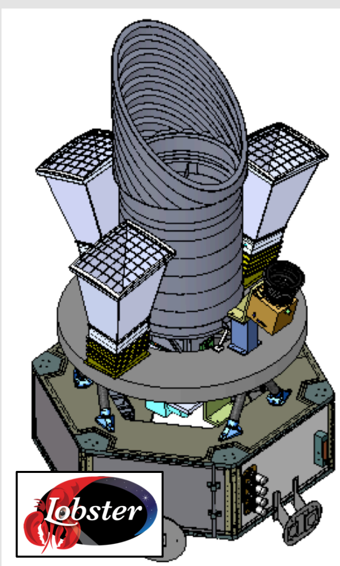


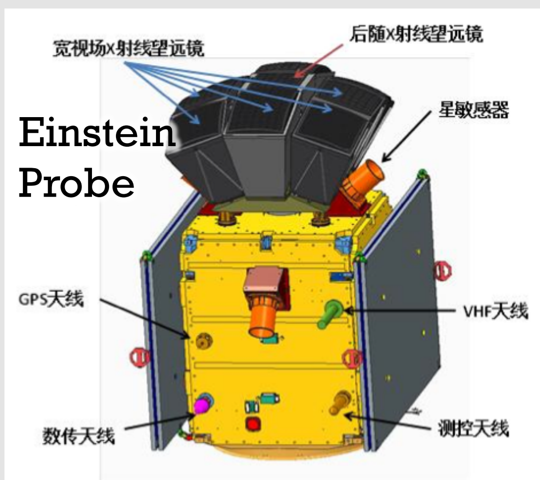
Several missions put forward, and hopefully will succeed. Need something post-Swift!

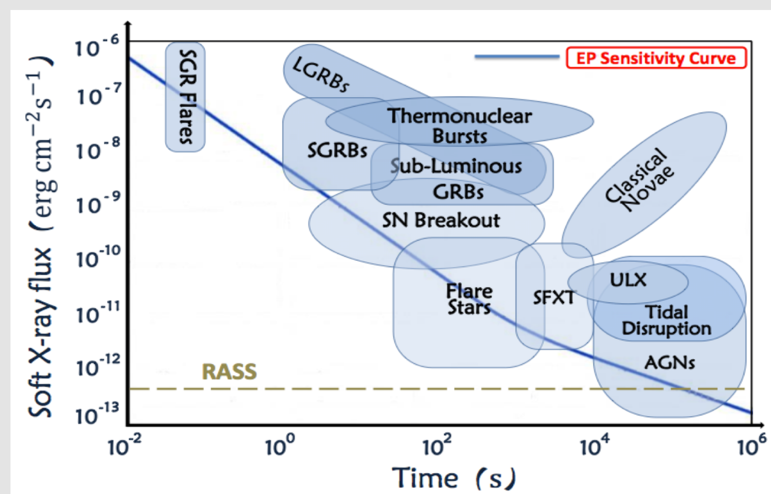
Utilize coded-mask and/or lobster-eye optics for up to ~ 5 sr coverage – some with fast pointing of narrow-field instruments.

Generally cannot match LSST depths, but great for bright transients.

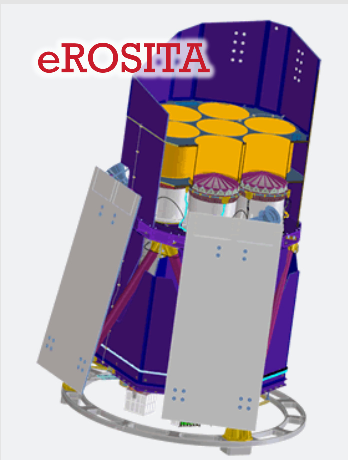
Adding other wavelengths tough on NASA SMEX budget (e.g., X-ray + UV/IR).

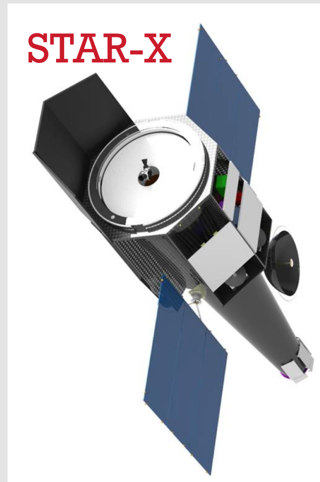






Wide-Field X-ray Imaging Missions with Transients Capabilities





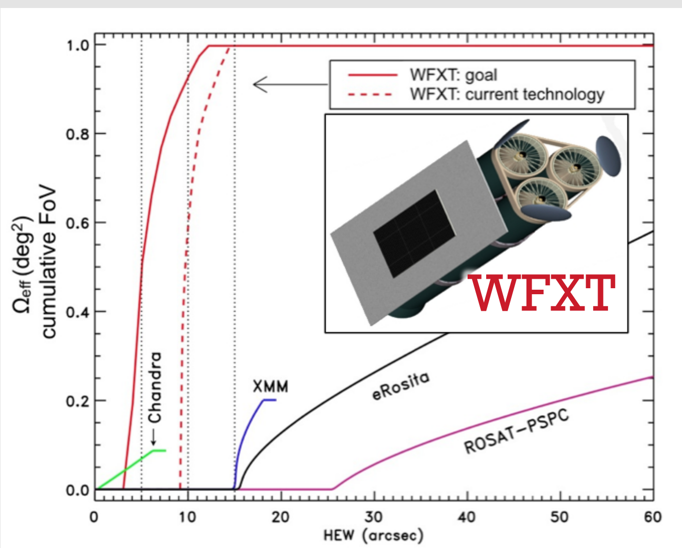
eROSITA and Athena moving forward, and other great mission concepts put forward.

Utilize grazing-incidence optics to cover 0.4-1 deg^2.

Do a much better job at matching LSST depths over limited area; e.g., could do a great job on LSST DDF transients.

Some have fairly good agility.

New mission concepts require a large NASA Explorer or probe-class mission.



Quantity	Survey		
	Deep	Medium	Wide
Ω (deg^2)	100	3000	20,000
Exposure time	400 ks	13 ks	2 ks
Total time	1.67 yr	1.66 yr	1.67 yr
S_{min} (point-like) (*)	3×10^{-17}	5×10^{-16}	3×10^{-15}
Total AGN detected	5×10^{5}	4×10^{6}	1×10^{7}
S_{min} (extended) (*)	1×10^{-16}	1×10^{-15}	5×10^{-15}
Total clusters/groups	3×10^{4}	2×10^{5}	3×10^{5}

(*) Flux limit in erg cm^2 s^{-1} (0.5-2 keV band) at 5σ detection

UV Satellite Prospects

Band of Operation	220--280 nm
Field of View	210 sq degrees
FWHM of PSF	25 arcsec (1 pixel=8.5 arcsec)
Basic Frame time	3x300 s
5-sigma sensitivity	21.5 AB mag
Orbit	Geo-synchronous + 300 km
TOO capable	Yes
Launch	2021
Prime phase	2 years

Would provide complementary UV data to LSST from 220-280 nm.

Continuous data streaming and real-time analysis, covering 210 deg^2 patches in NEP and SEP.

Aiming to investigate

- Supernova shock breakouts
- AGNs (RM and disk tomography)
- Tidal disruption events
- Stellar activity
- Relativistic explosions
- Exoplanets


The End

Extra Slides

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

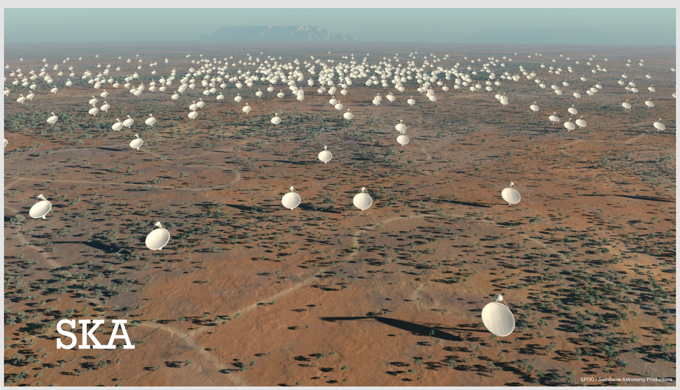
- 55-185 samplings per band over 10 yr
- Highly effective complement to color selection
- Still need effectiveness assessments when $L_{\mathrm{AGN}} \sim L_{\mathrm{host}}$

Astrometry - Lack of proper motion and differential chromatic refraction

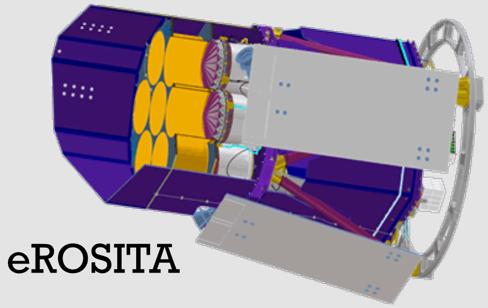
- Will reach ~ 1 mas yr^{-1} at $r \sim 24$
- Minimizes confusion with stars

Multiwavelength Selection

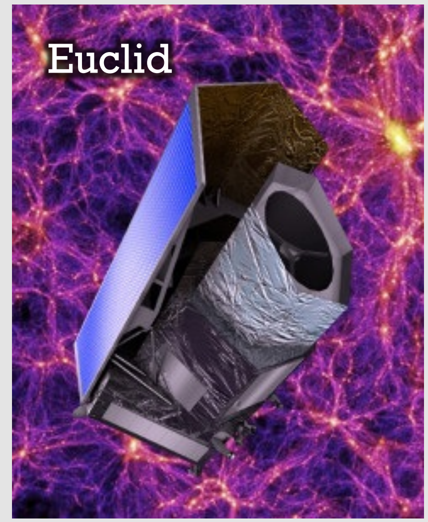
L_R, T_b, morphology



L_X and Γ_X

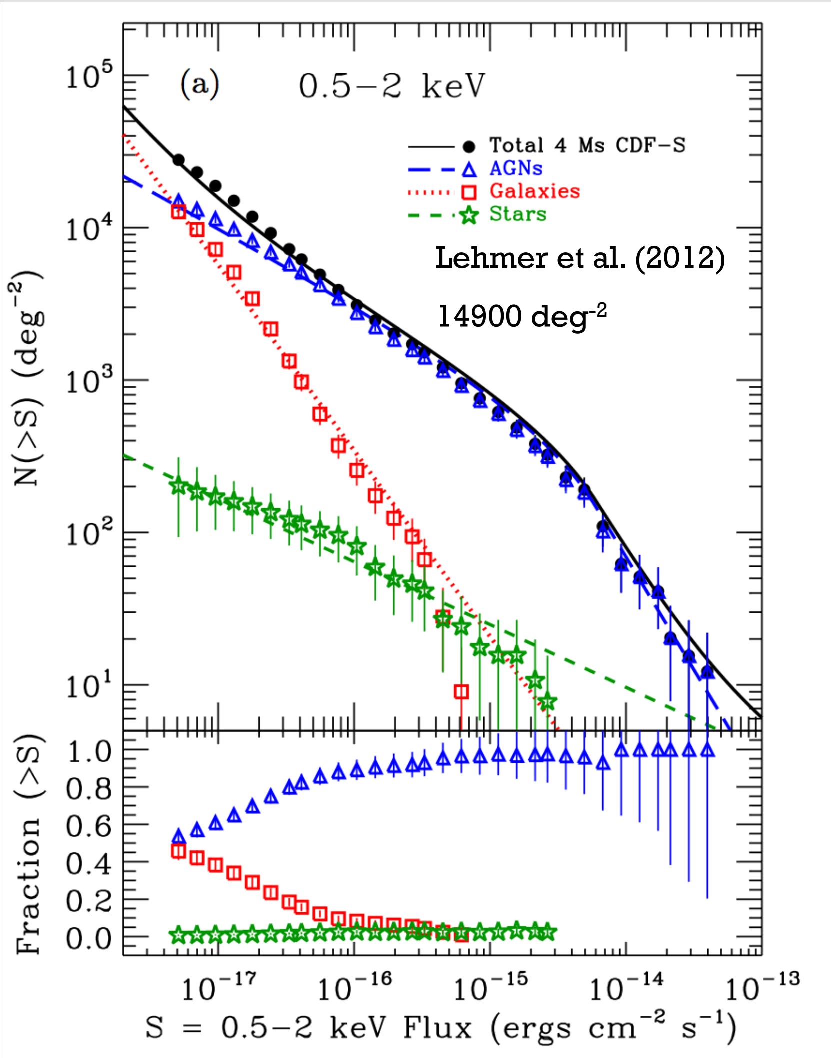


Infrared-optical colors



Plausible AGN Yields

Chandra Deep Field-South Number Counts



Will have detections for 150 million AGNs in 10000 deg^2 primary LSST survey area.

Obscuration and host-galaxy dilution will hinder AGN selection.

Confidently can select 10 million.

Hope to select 20-40 million, and likely more - especially as multiwavelength data accumulate.

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.