Introduction

LSST will be great for AGN

Will find more AGN than any survey before by at least an order of magnitude

300+ million AGN observed

20 million identified by LSST

50+ million identified by LSST + additional data
  • Euclid, eROSITA, WFIRST, etc.
  • NEOCAM will also be great if approved
Characterizing the population

LSST will probe AGN to much fainter optical limits than any other large scale survey

Possibility to characterize AGN populations well beyond the knee of the QLF
  - Imaging is deep enough it will likely allow to characterize their environments.

AGN Identification is far from trivial
  - Only ~20% of the observed AGN will be identified by LSST

It is not the ones we see, but those we don’t that matter
Characterizing the Population

Issue is that missing AGN are not random
  • Missing specific populations can have important effects on conclusions about AGN
  • Particularly important for galaxy evolution
  • Need to at least understand if not solve

Main biases that need to be considered:
  • Confusion with stellar locus
  • Obscuration – Reddened type 1 and type 1.8/1.9/2 AGN
  • Host Dilution
Confusion with the Stellar Locus

Great issue for optical color selection
  • E.g., Fan et al. (1999), Richards et al. (2006)

Happens at z of about 2-3

Variability selection will help
  • Time dilation lowers the light curve duration
  • Highest L QSOs may not vary enough in 10 years to detect variability in all bands

Lack of astrometry should be enough to identify them.
Host Dilution

Likely one of the biggest issue for AGN studies in LSST

Color identification criteria works because AGN are different than galaxies

• Flipside is that AGN need to dominate the SED to be identified
• Need to trade completeness with reliability

Dominating over the host in the optical is a function of

• AGN Luminosity
• Host Stellar Mass
• Host Unobsured Star-Formation Rate
• Redshift
• Obscuration of the AGN
Templates from Assef et al. (2010)
MIR Experience – Host Dilution

MIR Experience – Obscuration and z

Luminosity Ratio Bias

In the mid/near-IR, the emission of the host galaxy is more related to the stellar mass than to the SFR

At these $\lambda$, $L_{\text{Host}}$ is related to $M_{\text{BH}}$ so $L_{\text{AGN}} / L_{\text{host}}$ is a proxy for the Eddington ratio $= L_{\text{AGN}} / L_{\text{Edd}}$

IR criteria are biased against low Eddington ratios.
- Effectively biased against low-L AGN, but because of low $L/L_{\text{Edd}}$ and $B/T$

Importance of bias depends on the selection criteria, redshift and obscuration
- Need to consider all when analyzing selection function effects
AGN vs Host Luminosity Bias

are detected by IRAC but do not meet either the Stern et al. or Donley et al. criteria. Many X-ray AGNs that are not IRAC detected have high specific accretion rates. These sources are primarily found in red, massive galaxies (M \textsubscript{stellar} \gtrsim 3 \times 10^{10} \text{ M}_\odot), which may be due to contamination of star-forming galaxies. The fraction of galaxies with Stern et al. AGNs is lower than the X-ray AGN sample, this is dominated by the emission from the AGN with high specific accretion rates and high stellar masses. The fraction of red galaxies with Stern et al. or Donley et al. AGNs decreases with stellar mass. Following Aird et al. (2012), we define the specific accretion rate from the bolometric luminosity derived from L_{bol} = 3 \times 10^{38} \text{ erg s}^{-1}, where L_{bol} is the bolometric luminosity. The X-ray sources with IRAC detections consist primarily of sources at low stellar masses and high specific accretion rates. These sources are selected by either the Stern et al. or Donley et al. IR-AGN techniques tend to identify higher specific accretion rate sources relative to the X-ray AGN sample. We include the X-ray completeness corrections for the X-ray-detected sources. Stern et al. IR-AGNs by star-forming galaxies.

In Figure 3, we also show Stern et al. or Donley et al. IR-AGN sources as red squares or blue diamonds, respectively. The gray dashed line shows the approximate fraction at low masses, which may be due to contamination of galaxies with Stern et al. AGNs is much slower than for red galaxies. The vast majority of Donley et al. IR-AGNs also satisfy the Stern et al. IR-AGN selection criteria. The sources that are IRAC detected but not identified by either selection technique are low-luminosity sources that have low specific accretion rates and high stellar masses. For the hard X-ray-selected sample, this is dominated by the emission from the AGN with high specific accretion rates.

The fraction of X-ray sources that are not identified as IR-AGNs: those that are not detected by IRAC and those that detect X-ray without IRAC detection. The fraction of X-ray with IRAC detection. For the hard X-ray-selected sample, this is dominated by the emission from the AGN with high specific accretion rates.

(b) Specific accretion rate (\lambda)diistribution for the X-ray, Stern et al. and Donley et al. AGN sample. Stern et al. and Donley et al. sources that are open green circles. Sources with IRAC detections that are solid green circles and the sources without IRAC detections are black circles. (c) specific accretion rate (\lambda)distribution for the X-ray, Stern et al. and Donley et al. AGN sample. Stern et al. and Donley et al. sources that are solid green circles and the sources without IRAC detections are black circles. The gray dashed line shows the approximate fraction at low masses, which may be due to contamination of galaxies with Stern et al. AGNs is much slower than for red galaxies.
Host Dilution in the Optical

It is a more complicated case than in the IR

Optical color selection is biased against low Eddington ratios

- This needs to be fully modeled and taken into account for galaxy evolution studies
- Somewhat better for optical than IR because host peaks in the NIR

Additionally, host dilution in the optical means

- Bias against AGN in SF galaxies
  - Could have significant impact in gal evol studies where both are important

- Bias against reddening
  - Light reddening can already have an impact
How to Solve it?

• Variability should be able to help, at least in nearby objects
  • Lower time dilation
  • Fainter
  • Variability amplitude is higher for L/Ledd (Macleod et al. 2010)

• X-rays
  • Notably insensitive to this issue
  • Unfortunately eROSITA is rather shallow

• SED fitting
  • Not as efficient to do without other anchoring data points in the IR
  • Should be easy to implement with Euclid or WFIRST or Deep drilling fields
  • $L_{\text{AGN}}/L_{\text{Host}}$ notably independent of redshift accuracy (more or less)
Figure 14. Top panels: the long-term rms variability $SF_\infty$ (left) and characteristic timescale $\tau$ (right) are shown as colors on a grid of redshift and absolute $i$-band magnitude $M_i$. The $SF_\infty$ parameters are normalized to a fixed rest wavelength using the fitted power-law dependences of $(\lambda_{RF}/4000 \text{ Å})^B$ with $B = -0.479$ and 0.17 for $SF_\infty$ and $\tau$, respectively. The lines of constant variability (dashed) show that $SF_\infty$ is independent of redshift. Bottom panels: as in the top panels but with black hole mass $M_{BH}$ on the $x$-axis.

Figure 15. Left: the Eddington ratio for S82 quasars (estimated using masses and bolometric luminosities from Shen et al. 2008) is shown as colors on a grid of $M_i$ vs. $M_{BH}$, with dashed lines of constant $L/L_{Edd}$ over-plotted. Right: long-term rms variability (corrected for wavelength dependence) is shown as a function of $L/L_{Edd}$ (open circles are medians in each bin). The slope of the linear fit to the medians is listed on the panel.

Therefore, using this naive scaling, we are not able to relate the observed $\tau$ to either a thermal or viscous timescale of the radius associated with the wavelength of the variability. However, in reality there is a range of radii, which corresponds to a range in timescales, contributing to the observed flux in each band, and this will cause some degree of smoothing. Also, the radial regions might overlap for each band, causing a single radius to contribute flux in multiple bandpasses, and this...
Examples of AGN SED Fitting

Assef et al. (2010)
Decomposition not very sensitive to $z$

Estimates of $L_{\text{AGN}}/L_{\text{Host}}$ ratio are independent of $z_{\text{phot}}$ accuracy.

Plot shows the ratio of the bolometric luminosities of the AGN to Host components assuming the best fit photo-$z$ and the spec-$z$. 
Obscured AGN in LSST

• >50% of AGN are obscured
  • Might depend on AGN luminosity
  • Non-trivial at the highest luminosities

• LSST will be limited in identifying reddened AGN
  • Y-band photometry will give it a significant edge over SDSS
  • Unlikely to identify type 2 AGN

• Will need identification from other surveys
  • Euclid and WFIRST will add the NIR to help identify mildly obscured AGN
  • (un)WISE will help some with type 2, but rather shallow. NEOCAM?
  • eROSITA will help also with type 2 AGN, but also shallow
  • Deep drilling fields
LSST - Hosts

• While not able to identify them, LSST will see the host galaxies

• Important to characterize the host galaxies
  • Unobscured SFRs and Stellar Mass
  • AGN and galaxy evolution
  • AGN feedback

• Improved photometric redshifts
  • Stability and depth of LSST photometry will help enormously with photo-zs
  • Inherently bad for type 1 QSOs, but work well for type 2
  • Spectroscopy much easier for type 1
Cross-Correlation Function of Obscured vs. Unobscured AGN

- Cross correlation find that type 2 AGN cluster more tightly than type 1 AGN
  - Although see Mendez et al. (2016)
  - Suggest that there is a population of highly obscured type 2 AGN with a high clustering fraction.

- LSST could allow to test this when coupled with eROSITA
  - NEOCAM
  - Possibly with Euclid too

- Analysis only needs $P(z)$ to first order
  - Would be great to have more redshifts, but unlikely
  - Use variability to get $P(z)$?
4.4.1 Photometric properties of AS- and AW-selected quasars

In Section 2, many similarities between the AS- and AW-selected AGNs were discussed. The number densities are similar in SDSS. Simple power-law fits of the form \( \theta^2 \) were used to calculate the bias with the halo mass of \( M/M_* \). While the DR2–DR2 auto-correlation suggests that there is more correlated noise in the DR1 map, the DR2 map contains significantly less correlated noise, while still being consistent with the unobscured sources.

Figures 6 and 11 compare the measured bias via CMB lensing cross-correlations (left) and the quasar autocorrelation (right), using various data sets. In particular, Figure 13 illustrates that the optical difference between the AW and AS subsamples, as well as the difference between the AW and AS quasar samples, are not shown as they are generally null. The second row of Figure 13 compared to the literature results for optically selected unobscured quasars.

Donoso et al. (2014) and Di Pompeo et al. (2016) note that Hickox et al. (2009, 2011) used different prescriptions described in Section 4.4.1. They point out that there might be a difference in samples selected from the two catalogues. The fundamental difference in samples selected from the two catalogues is significant at higher redshifts for the best-fit model (thick blue line), as well as for the fundamental difference in samples selected from the two catalogues.

To understand the clustering result of our red and blue AGNs, we investigate how this reflects the properties of these samples in more detail here. We also note that Hickox et al. (2016) and Assef et al. (2010) used different prescriptions described in Section 2.5. The similarity in the distributions of the WISE AGNs is slightly larger than both our value and previous results from Hickox et al. (2011).

The AW sample shows a subtle shift towards brighter magnitudes for objects that are selected from both WISE and SDSS, as well as for their obscured quasar counterparts brighter than 12 magnitudes. Note that Hickox et al. (2016) and the authors field with the templates of Assef et al. (2016). The WISE hosts are indicated by solid, thick lines.

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Overdensities Around Luminous QSOs

Euclid + LSST (+NEOCAM) can help characterize galaxies around luminous AGN

- Photo-z
- Unobscured SFR
- Stellar mass

Assef et al. (2015)
Conclusions

LSST will have a major impact in AGN studies

Problem: Need to control for selection biases
  • Primarily host dilution
  • Biased against low Eddington ratios
  • Biased against AGN in star forming galaxies

Combined with other surveys, LSST will be great for characterizing obscured AGN
  • Need Euclid, eROSITA, and/or NEOCAM
  • Impact will be limited for LSST alone
Backup Slides
Kozlowski et al. (2010)
Overdensities Around Luminous QSOs

Euclid + LSST (+NEOCAM) can help characterize galaxies around luminous AGN (\(z_{\text{phot}}\), SFR, stellar mass)

Roberto J. Assef - UDP January 2017 - AAS - LSST AGN 26

Assef et al. (2015)

Graphical representation of over-densities around QSOs (W0831, W1136, W1603, W1835, W2216, W2246) with coordinates (+0140, +4236, +2745, +4355, +0723, -0526).
Covering fractions

Mateos et al. (2016)
WISE AGN Maps

R90 Sample, S/N>5 in W2

4.5M AGN (90% reliability) – Assef et al. (in prep)
Credits: ESA/NASA, the AVO project and Paolo Padovani
Templates from Assef et al. (2010)