The AGN-star formation connection

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Overview of this talk

Star formation measurements:
infrared – traces intense dust-obscured star formation

Focus on AGN-SF connection of distant X-ray AGNs (bulk of BH and galaxy growth)

Kalfountzou talk on AGN-SF connection for radio-loud AGN
Motivation for studying AGN-SF connection
Broad connection from AGN and SF cosmic histories

Factor $\sim 1500x$ offset between BH accretion and SFR cosmic histories in broad agreement with $M_{BH}-M_{sph}$ relationship
Relic evidence from $M_{\text{BH}}-M_{\text{sph}}$ relationship

[BH mass] Driver: AGN activity

[Spheroid mass] Driver: Star formation (gas accretion)

Why this seems crazy: huge difference in size scales

Black-hole-galaxy: $\sim 10^9$ difference in size scale (grape-Earth)
Radius of influence of the black hole: $< 10^{-3}$ that of the galaxy

This suggests some sort of regulation between AGN activity and star formation
Regulation: outflow - the AGN as the driver/boss

The winds/outflows from the AGN could provide an “arm” for the black hole to orchestrate kpc-scale star formation

(e.g., Di Matteo et al. 2005; Granato et al. 2004; Hopkins et al. 2006; Lapi et al. 2014)
Regulation: inflow - the galaxy as the driver/boss

Regulated gas inflow?

Star-formation regulated growth?

Can be challenging to distinguish between all these scenarios due to uncertain gas inflow/outflow timescales

(i.e., driven by same gas supply)

Alexander & Hickox (2012)
Measuring star-formation rates in the far-IR waveband
Both emit strongly at infrared wavelengths.

Ideally, decompose the SED but often just the far-IR luminosity is used (e.g., Herschel), which is typically star-formation dominated unless a luminous AGN.
Key message: AGN contaminate/increase average SFR over 250um photometry by >2 for luminous/dominant AGN – can be higher for individual sources and shorter wavelengths
The AGN-SF connection of X-ray AGNs
SF in distant AGNs tracks SF galaxies – on average

Increase in average SFR of AGNs with redshift tracks that seen for SF galaxies

Increase in the average sSFR of AGNs with redshift also tracks that seen for SF galaxies: the “main sequence”

Specific SFR (sSFR=SFR/mass): relative growth rate

Mullaney et al. (2012)

Also Lutz et al. (2010), Mullaney et al. (2010); Shao et al. (2010); Rosario et al. (2012, 2015); Harrison et al. (2012); Santini et al. (2012)
ALMA reveals similar SF extent in FIR bright AGN

High resolution (~1-3 kpc) ALMA 870um data of some z>1.5 X-ray AGNs and star-forming galaxies (SMGs)

No clear differences in galaxy wide SF environment – SF extent and surface density for X-ray AGNs comparable to SF galaxies. Caution: only a few FIR-bright AGN observed.
What about the $L_{SF} - L_{AGN}$ relationship?

Early Herschel results of mean $L_{SF}$ for $L_{AGN}$ bins showed a large amount of diversity.

Positive relationship

Negative relationship (at high $L_X$)

Predominantly flat relationship

Differences often driven by low source statistics, cosmic variance (small fields), wide redshift ranges, and/or AGN contamination (e.g., Harrison et al. 2012)
Now clear the mean $L_{\text{SF}}$-$L_{\text{AGN}}$ relationship is flat

Mean $L_{\text{SF}}$ for $L_{\text{AGN}}$ bins for X-ray AGN: remarkably flat relationship

At first this seemed an absurd result – how can a flat $L_{\text{SF}}$-$L_{\text{AGN}}$ relationship be consistent with the $M_{\text{BH}}$-$M_{\text{sph}}$ relationship?
Key to understanding this: changes in accretion rate

AGNs likely vary on short timescales when compared to and star formation – so the observed $L_{\text{AGN}}$ can vary substantially for a (relatively) constant $L_{\text{SF}}$

A fluorescent bulb at 1000 frames per second

Mullaney et al. (2012); Hickox et al. (2014)

SF: comparatively constant with time
AGN: more variable with time
Expectations from simple accretion variability model

Mean $L_{\text{SF}}$ for $L_{\text{AGN}}$ bins for X-ray AGN

Model tracks plotted

Simple model: assume AGN vary based on Aird et al. (2012) Eddington-ratio distribution and hosts are SF galaxies

Not convinced? If instead calculate mean $L_{\text{AGN}}$ for $L_{\text{SF}}$ bins using SF galaxies (i.e., selected on more stable quantity) then a remarkably tight relationship is seen

See also Aird et al. (2010, 2015), Mullaney et al. (2012), Chen et al. (2013), Rodighiero et al. (2015)
So when take account of mass, redshift, and AGN variability all X-ray AGN reside in SF galaxies – right?

No this is only for the mean SFR – need to calculate a more refined quantity: SFR distributions, which requires deeper data.
Using ALMA to constrain the SFR distribution

Few X-ray AGN detected by ALMA but upper limits valuable: updated SFRs place them below typical star-forming galaxies

Mullaney et al. (2015); Scholtz et al. (in prep); Stanley et al. (in prep)
Key message: a **typical** X-ray AGN does not appear to reside in a SF galaxy

**Interpretation?** AGN suppressing SF (gas outflows)? Or delays in gas inflow from galaxy/star formation?

We are starting to distinguish using (1) ALMA data for factor ~3 more X-ray AGN and (2) VLT-KMOS IFU data to connect gas outflows to SFR constraints

See Bongiorno talk for complementary constraints
Key messages from this talk

Measuring accurate SFRs in AGN can be challenging, particularly when AGN:SF ratio is high

- Most critical for high-luminosity or low-z AGN (where SF low)

**Mean** SFRs for X-ray AGN consistent with typical SF galaxies

- Need to take into account redshift, mass, and AGN variability

But tentative differences found in the distribution of SFRs – many X-ray AGN reside in more quiescent galaxies

- However, it is unclear what is the driver – regulation from AGN gas outflows or galaxy/SF gas inflow timescale to get to BH?

…and now for something a (bit) different
**X-SERVS: New X-ray survey of the LSST/DES Deep-Drilling Fields**

**X-SERVS Fields**

- **COSMOS**: 2 deg$^2$
- **XMM-LSS**: 4.5 deg$^2$
- **W-CDF-S**: 4.1 deg$^2$
- **ELAIS-S1**: 3 deg$^2$

- 1.3 Ms allocated!

**Expected Source Yields**

**Ultimate aim**: 14 deg$^2$ solid-angle coverage in total – factor of ~ 7 improvement over COSMOS alone (4.5 deg$^2$ allocated so far). Reduces cosmic variance and allows robust studies of large-scale structures.

**Observations**: can be done with XMM-Newton and/or Chandra – aiming for 50 ks XMM-Newton depth, so that we sample the AGN populations producing the bulk of cosmic accretion power.

**Overall**: expect 11,000 AGNs and 760 X-ray groups/clusters. **Contact**: me or email niel@astro.psu.edu
Primary Science Goals for X-SERVS

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

Links between SMBH accretion and star formation.

Improved measurements of the $z \sim 4-7$ AGN space density.

Constraints upon $z > 10$ direct-collapse black holes via X-ray/NIR cross correlation.

Rare and luminous sources – e.g., luminous type 2 quasars, extreme X-ray/optical sources, intrinsically X-ray weak AGNs, SMBH pairs, X-ray bright but radio-faint jets.

Cosmology with clusters and groups.
Incredible Legacy Value: Likely the Best Multiwavelength Fields for Decades

Fantastic Current/Scheduled X-SERVS Multiwavelength Coverage

Coverage of an AGN Spectral Energy Distribution

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Table 1: Current/Scheduled 1–10 deg² Multiwavelength Coverage of X-SERVS

<table>
<thead>
<tr>
<th>Band</th>
<th>Survey Name</th>
<th>Coverage (W-CDF-S, ELAIS-S1, XMMLSS)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td>Australia Telescope Large Area Survey (ATLAS)¹</td>
<td>3.7, 2.7, 1. deg²; 15 μJy rms depth at 1.4 GHz</td>
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<tr>
<td></td>
<td>MIGHTEE Survey (Scheduled)²</td>
<td>4.5, 3, 4,5 deg²; 1 μJy rms depth at 1.4 GHz</td>
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<tr>
<td>FIR</td>
<td>Herschel Multi-tiered Emiss wave Survey (HerMES)³</td>
<td>0.6-18 deg²; 5-60 mJy depth at 100-500 μm</td>
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<tr>
<td>MIR</td>
<td>Spitzer Wide-area IR Emiss wave Survey (SWIRE)⁴</td>
<td>8.2, 7.6, 9.4 deg²; 0.04-30 mJy depth at 3.6-100 μm</td>
<td></td>
</tr>
<tr>
<td>NIR</td>
<td>Spitzer Emiss wave &amp; Vol Survey (SERVS)⁵</td>
<td>4.5, 3, 4,5 deg²; 2 μJy depth at 3.6 and 4.5 μm</td>
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<td></td>
<td>VISTA Deep Emiss wave Obs Survey</td>
<td>4.5, 3, 4,5 deg²; ZY JHK; to mₜₕₜₜₜₜ ≈ 23.5-25.7</td>
<td></td>
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<tr>
<td>Optical</td>
<td>Dark Emiss Survey (DES)⁶</td>
<td>9, 6, 9 deg²; Multi-band depth, mₜₜₜₜ = 27 co-added</td>
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<tr>
<td>Photometry</td>
<td>Hyper Suprime-Cam (HSC) Deep Survey⁷</td>
<td>λ = 1.3 deg²; griz to mₜₜₜₜ = 23.5-27.5</td>
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<td></td>
<td>Pan-STARRS1 Medium-Deep Survey (PS1MD)⁸</td>
<td>λ = 6.4 deg²; Multi-band depth, mₜₜₜₜ = 23.5-27.5</td>
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<td></td>
<td>VST Optical Imaging of CDF-S and ESI (VOICE)⁹</td>
<td>λ = 6.4 deg²; Multi-band depth, mₜₜₜₜ = 23.5-27.5</td>
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<td></td>
<td>SWIRE optical imaging³</td>
<td>λ = 6.4 deg²; Multi-band depth, mₜₜₜₜ = 23.5-27.5</td>
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<tr>
<td>Optical/IR</td>
<td>LNSI deep-drilling field (Planned)³</td>
<td>λ = 6.4 deg²; Multi-band depth, mₜₜₜₜ = 23.5-27.5</td>
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<td>Spectroscopy</td>
<td>Carnegie-Spitzer-DMACS Survey (CDS)³</td>
<td>λ = 6.4 deg²; 140,000 redshifts, 3.6 μm selected</td>
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<td></td>
<td>PRIMl Multi-object Survey (PRIMUS)⁰</td>
<td>λ = 6.4 deg²; 70,000 redshifts to zₜₜₜₜ = 23.5</td>
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<tr>
<td>UV</td>
<td>GALEX Deep Imaging Survey²</td>
<td>λ = 6.4 deg²; Depth mₜₜₜₜ = 25</td>
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References: