Broad-line Heavily Obscured AGN at z~2

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STScI

Obscured AGN conference, Seeon

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Outline

- Selection of an obscured AGN population at z~2-3
  - The NDWFS multi-wavelength dataset.
- IRS spectroscopy of obscured AGN.
- Near-IR spectroscopy of obscured AGN.
- Interpretation: a large population of z~2-3 ‘host-obscured’ AGN.
- What are the ‘power-law’ IRS sources?
  - Weak silicate absorption or high redshift?
  - IRS spectroscopy of X-ray-bright sources.
The NDWFS Bootes field

NOAO Deep Wide-Field Survey

9 deg²
Bw, R, I, K ~ 27.1, 26.1, 25.4, 19.0 mag (Vega).

PIs: A. Dey & B. Jannuzi
### Multi-wavelength observations in the Bootes field

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Wavelength</th>
<th>Area (sq.deg.)</th>
<th>Sensitivity (Jy)</th>
<th>Completeness</th>
<th>PI/Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VLA P-band</strong></td>
<td>90 cm</td>
<td>7</td>
<td>100 mJy</td>
<td>100% complete; van Breugel, PI</td>
<td></td>
</tr>
<tr>
<td><strong>VLA L-band</strong></td>
<td>21 cm</td>
<td>1</td>
<td>15 mJy</td>
<td>100% complete; Higdon, PI</td>
<td></td>
</tr>
<tr>
<td><strong>VLA (FIRST)</strong></td>
<td>21 cm</td>
<td>9</td>
<td>1 mJy</td>
<td>100% complete; public</td>
<td></td>
</tr>
<tr>
<td>Westerbork</td>
<td>21 cm</td>
<td>7</td>
<td>8 mJy</td>
<td>100% complete; Rottgering, PI</td>
<td></td>
</tr>
<tr>
<td><strong>Spitzer/MIPS</strong></td>
<td>24, 70, 160 μm</td>
<td>9</td>
<td>3.0, 30, 100 mJy</td>
<td>100% complete; Jan 2004 GTO</td>
<td></td>
</tr>
<tr>
<td><strong>Spitzer/IRAC</strong></td>
<td>3.6, 4.5, 5, 5.8, 8 μm</td>
<td>9</td>
<td>6.4, 8.8, 51, 50 mJy</td>
<td>100% complete; Eisenhardt et al.</td>
<td></td>
</tr>
<tr>
<td><strong>Spitzer/IRAC</strong></td>
<td>3.6, 4.5, 5, 5.8, 8 μm</td>
<td>9</td>
<td>3.2, 4.4, 25, 25 mJy</td>
<td>Stern et al. large GO5 Spitzer program</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>J, Ks</td>
<td>5</td>
<td>23 mag</td>
<td>100% complete; Elston et al. (2005)</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>K, Ks</td>
<td>9</td>
<td>19.2 mag</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>J, H</td>
<td>9</td>
<td>21 mag</td>
<td>40% complete</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>B&lt;sub&gt;W&lt;/sub&gt;, R, I</td>
<td>9</td>
<td>25.5-26.6 mag</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>U</td>
<td>9</td>
<td>25 AB mag</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO</strong></td>
<td>U</td>
<td>1</td>
<td>26 AB mag</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>GALEX</strong></td>
<td>FUV, NUV</td>
<td>1</td>
<td>26 AB mag</td>
<td>100% complete, GTO</td>
<td></td>
</tr>
<tr>
<td><strong>GALEX</strong></td>
<td>FUV, NUV</td>
<td>9</td>
<td>25 AB mag</td>
<td>in progress, GTO</td>
<td></td>
</tr>
<tr>
<td><strong>HST</strong></td>
<td>I, H</td>
<td>sparse</td>
<td>26, 23 mag</td>
<td>in progress</td>
<td></td>
</tr>
<tr>
<td><strong>Chandra</strong></td>
<td>0.5-2 keV</td>
<td>9</td>
<td>4.7e-15 erg/s/cm²</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>Chandra</strong></td>
<td>2-7 keV</td>
<td>9</td>
<td>1.5e-14 erg/s/cm²</td>
<td>100% complete</td>
<td></td>
</tr>
<tr>
<td><strong>NOAO/Keck</strong></td>
<td>spectroscopy</td>
<td>sparse</td>
<td>24 mag</td>
<td>in progress (500 so far)</td>
<td></td>
</tr>
<tr>
<td><strong>MMT/Hectospec</strong></td>
<td>spectroscopy</td>
<td>9</td>
<td>R~20.5 mag</td>
<td>completed (~20,000 redshifts)</td>
<td></td>
</tr>
<tr>
<td><strong>Spitzer/IRS</strong></td>
<td>spectroscopy</td>
<td>sparse</td>
<td></td>
<td>in progress</td>
<td></td>
</tr>
</tbody>
</table>
Optically faint, luminous infrared galaxies

- $R-[24]>14$, $f_{24}>0.8$ mJy ($R>24-25$)
- An effective method in identifying powerful but heavily obscured AGN at $z\sim2-3$.
- $\sim200$ sources / deg$^2$
- Similar programs in FLS (Fadda et al., Yan et al., Magliocchetti et al.), SWIRE (Polletta et al.).
Spitzer/IRS spectra of \( f_{24} > 0.8 \) mJy sources
- redshifts determined for \(~50\%\) of sources via their silicate absorption features. \( z \sim 1.5 - 2.7 \)
- No PAH emission - AGN-dominated
- \( L_{IR} \sim 10^{13} L_\odot \)

Houck et al. (2005)
Weedman et al. (2006)
Higdon et al. in prep.
See also Yan et al. (2006)
IRS spectroscopy of heavily obscured AGN

- Spitzer/IRS spectra of $f_{24} > 0.8$ mJy sources
  - redshifts determined for $\sim 50\%$ of sources via their silicate absorption features. $z \sim 1.5 - 2.7$
  - No PAH emission - AGN-dominated
  - $L_{\text{IR}} \sim 10^{13} L_{\odot}$

Houck et al. (2005)
Weedman et al. (2006)
Higdon et al. in prep.
See also Yan et al. (2006)
Near-IR spectroscopy of heavily obscured AGN

- R-[24]>14 sources with IRS spectroscopy
- Near-IR spectroscopy is painful!
  - High sky background
  - Very faint sources (blind offsetting, no continuum flux or redshift information in some cases)
- Found 10 sources with $H\alpha$/[NII] and/or $H_\beta$/[OIII] emission lines
- Fitted Gaussian models to the 1-D spectra - simultaneous fitting.
Near-IR spectroscopy - broad-line sources

- 7/10 sources have broad (>1900 km/s) H\(\alpha\) or H\(\beta\) emission lines - AGN dominated.

Brand et al. (2007)
Near-IR spectroscopy
- narrow-line sources

- 3/10 sources have narrow (<700 km/s) $\text{H}_\alpha$ or $\text{H}_\beta$ emission lines. Line diagnostics and bolometric luminosities suggest they are AGN-dominated.

Brand et al. (2007)
Near-IR spectroscopy
- radio spectral index

- 2/10 sources are detected at 325MHz and 1.4GHz

SST24 J143424.4+334543 is a narrow-line source.
Steep radio spectral index ($\alpha = 1.0$).

SST24 J142842.9+342409 is a broad-line source.
Shallower radio spectral index ($\alpha \sim 0.5$).

Results consistent with ‘torus’ model in which broad-line source is seen face on and radio jet is directly towards us whereas narrow-line source is seen side-on and radio jet is not directly towards us (cf. Best, Martinez-Sansigre).

Radio flux densities supplied by S. Croft, W. de Vries, W. van Breugel
Near-IR spectroscopy - extinction to emission-line region

**Broad-line AGN**
- Broad-line source:
  - $H_\alpha/H_\beta > 15.7$
  - $E(B-V) > 1.6$
  - $A(H_\alpha) > 3.8$
  - $H_\alpha$ luminosity $> 33x$ lower than would be if no extinction.

**Narrow-line AGN**
- Narrow-line source:
  - $H_\alpha/H_\beta > 8.5$
  - $E(B-V) > 1.0$
  - $A(H_\alpha) > 2.4$
  - $H_\alpha$ luminosity $> 9x$ lower than would be if no extinction.

Brand et al. (2007)
Implications

- Both broad-line and narrow-line region are extincted → some fraction of the extinction must be taking place on scales larger than that of the narrow-line region → large-scale dust.

- Fraction of broad to narrow-line sources is similar to that expected from receding torus models of bolometrically luminous sources → large-scale dust.

- If hosted by large, starbursting galaxy, would expect to see this in optical → light from AGN is attenuated by dust on kpc scales.

(cf talks by Polletta, Martinez-Sansigre, Donley)
How common are these obscured AGN?

- Brown et al. (2006): 140 $f_{24} > 1 \text{ mJy}$ quasars with $17.2 < R < 21.7$ and $z > 1.3$ in Bootes field (from AGES spectroscopic survey).

- There are $\sim 300$ sources with $R-[24] > 14$ and $f_{24} > 1 \text{ mJy}$. Assuming these are all AGN-dominated sources at $z > 1.3$ (as suggested from IRS and near-IR spectroscopy of a small sub-sample), space densities are $\sim 2x$ that of optically bright type I AGN with similar redshifts and bolometric luminosities.
What are the featureless IRS sources?

- ~50% of R-[24]>14 sources followed up with IRS exhibit featureless mid-IR spectra.
  - z > 2.5?
  - lack of silicate absorption feature?
- 4/10 of near-IR spectra have featureless IRS spectra.
  - in 3/4 sources, lack of silicate absorption feature explained by high z.
  - One source has no silicate absorption feature despite heavy extinction (A(H\(\alpha\)) > 3.8)

9.7\(\mu\)m silicate absorption feature expected here.

IRS spectrum from Weedman et al. (2007)
A clue from obscured sources with powerful X-ray emission

  - 10/16 sources have redshifts 0.9<z<2.6 from weak silicate absorption.
  - 6/16 sources have featureless power-law IRS spectra.

- The featureless IRS sources are also the brightest X-ray sources - if at z>2.5, would have $L_x>2x10^{45} \text{ erg s}^{-1}$ (among most powerful quasars known).

Suggests that silicate absorption feature can be weak in heavily absorbed sources - geometry of dust clouds (e.g. Levenson et al. 2007)?

Brand et al. in preparation
Summary

- R-[24]>14 is an efficient method for identifying powerful but obscured AGN at high z.
- IRS spectroscopy of ~60 sources shows that ~50% exhibit deep silicate absorption, ~50% are featureless. Lack of PAH emission suggests they are AGN-dominated.
- Near-IR spectroscopy of 10 sources shows that 7/10 are broad-line AGN and 3/10 are narrow-line AGN.
- There is strong extinction along the line-of-sight to both the broad- and narrow-line regions, suggesting that much of the attenuation is contributed by dust on large scales.
- The ‘power-law’ IRS sources are likely to be a combination of z>2.5 sources and sources with no silicate absorption features.
- R-[24]>14 sources may be examples of ‘host obscured’ AGN, with space densities twice that of optically luminous type 1 AGN.
The End