# Broad-line Heavily Obscured AGN at z~2

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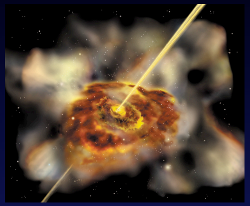
STScI

Obscured AGN conference, Seeon

June 2007

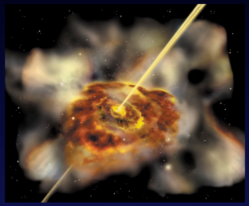
Collaborators: Michael Brown, Vandana Desai, Arjun Dey, Jim Houck, Buell Jannuzi, Emeric Le Floc'h, Tom Soifer, Dan Weedman

# Outline



- Selection of an obscured AGN population at z~2-3
  - The NDWFS multi-wavelength dataset.
  - A population of R-[24]>14 sources.
- 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

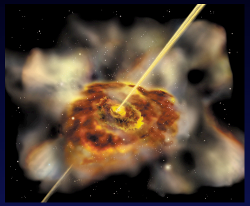



9 deg$^2$

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

PIs: A. Dey & B. Jannuzi

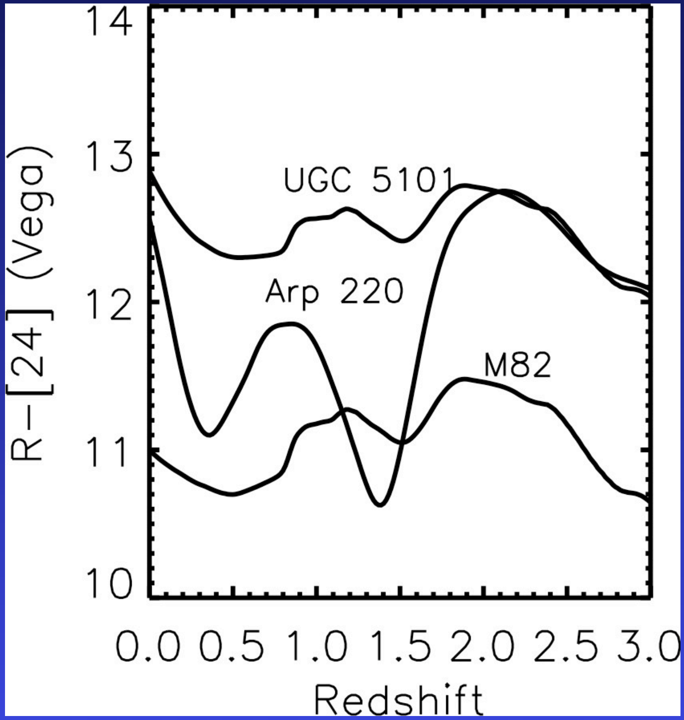
# Multi-wavelength observations in the Bootes field



| | | | | |
|---|---|---|---|---|
| VLA P-band | 90 cm | 7 sq.deg. | 100mJy | 100% complete; van Breugel, PI |
| VLA L-band | 21 cm | 1 sq.deg. | 15mJy | 100% complete; Higdon, PI |
| VLA (FIRST) | 21 cm | 9 sq.deg. | 1mJy | 100% complete; public |
| Westerbork | 21 cm | 7 sq.deg. | 8mJy | 100% complete; Rottgering, PI |
| Spitzer/MIPS | 24,70,160um | 9 sq.deg. | 3.0, 30, 100mJy | 100% complete; Jan 2004 GTO |
| Spitzer/IRAC | 3.6,4.5,5.8,8um | 9 sq.deg. | 6.4, 8.8, 51, 50mJy | 100% complete; Eisenhardt et al. |
| Spitzer/IRAC | 3.6,4.5,5.8,8um | 9 sq.deg. | 3.2, 4.4, 25, 25mJy | Stern et al. large GO5 Spitzer program |
| NOAO | J, Ks | 5 sq.deg. | 23 mag | 100% complete; Elston et al. (2005) |
| NOAO | K, Ks | 9 sq.deg. | 19.2 mag | 100% complete |
| NOAO | J, H | 9 sq.deg. | 21 mag | 40% complete |
| NOAO | $B_W$, R, I | 9 sq.deg. | 25.5-26.6 mag | 100% complete |
| NOAO | U | 9 sq.deg. | 25 AB mag | 100% complete |
| NOAO | U | 1 sq.deg. | 26 AB mag | 100% complete |
| GALEX | FUV, NUV | 1 sq.deg. | 26 AB mag | 100% complete, GTO |
| GALEX | FUV, NUV | 9 sq.deg. | 25 AB mag | in progress, GTO |
| HST | I, H | sparse | 26, 23 mag | in progress |
| Chandra | 0.5-2 keV | 9 sq.deg. | 4.7e-15 erg/s/$cm^2$ | 100% complete |
| Chandra | 2-7 keV | 9 sq.deg. | 1.5e-14 erg/s/$cm^2$ | 100% complete |
| NOAO/Keck | spectroscopy | sparse | 24 mag | in progress (500 so far) |
| MMT/Hectosp | spectroscopy | 9 sq.deg. | R~20.5 mag | completed (~20,000 redshifts) |
| Spitzer/IRS | spectroscopy | sparse | | in progress |

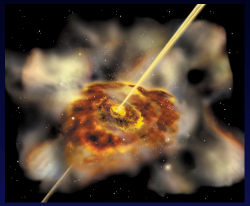
# Optically faint, luminous infrared galaxies

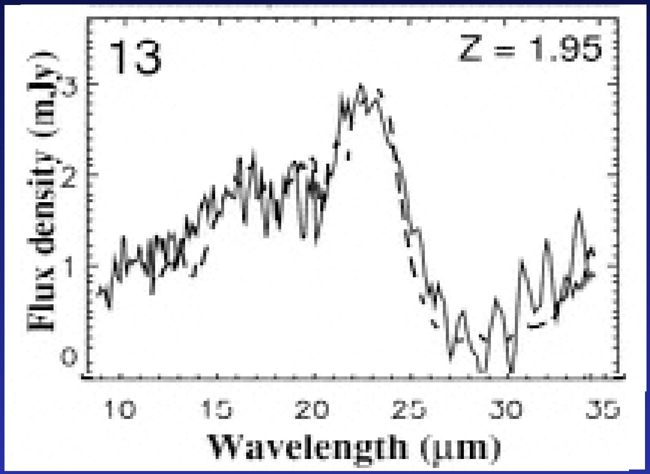
- R-[24]>14, $f_{24}$ > 0.8 mJy (R> 24-25)
- An effective method in identifying powerful but heavily obscured AGN at z~2-3.
- ~200 sources / $deg^2$
- Similar programs in FLS (Fadda et al., Yan et al., Magliocchetti et al.), SWIRE (Polletta et al.).

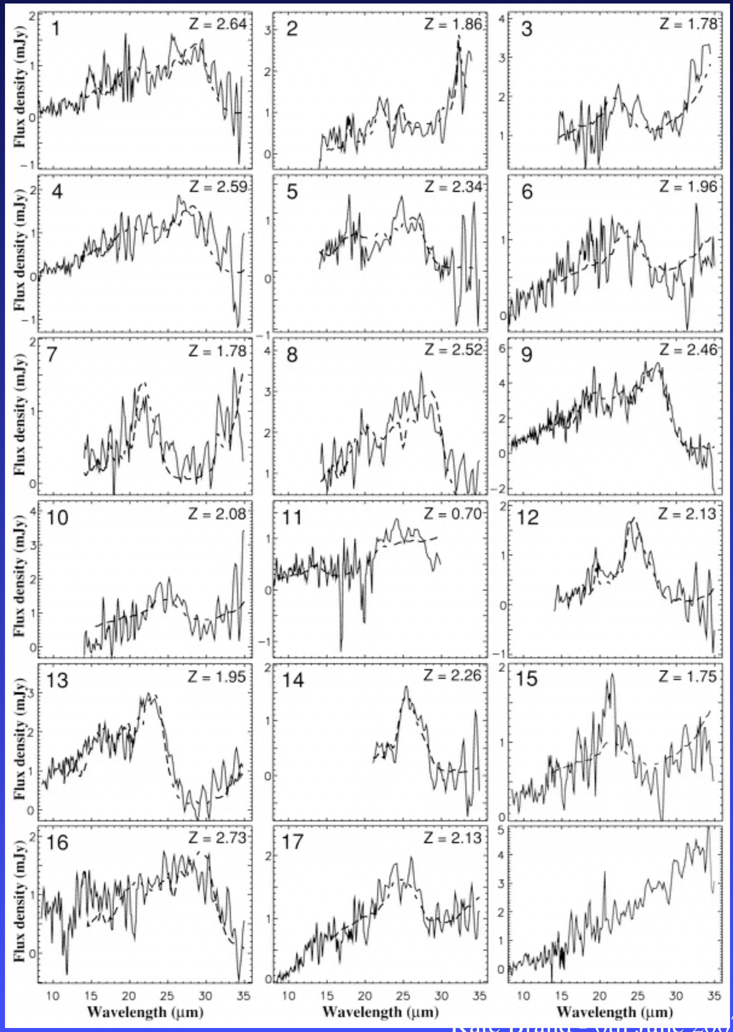



Dey et al. in prep
Desai et al. in prep

# IRS spectroscopy of heavily obscured AGN



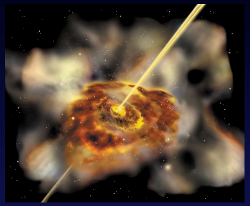


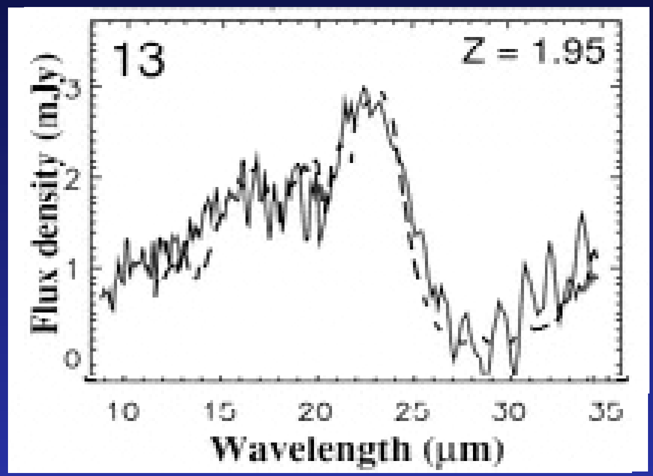



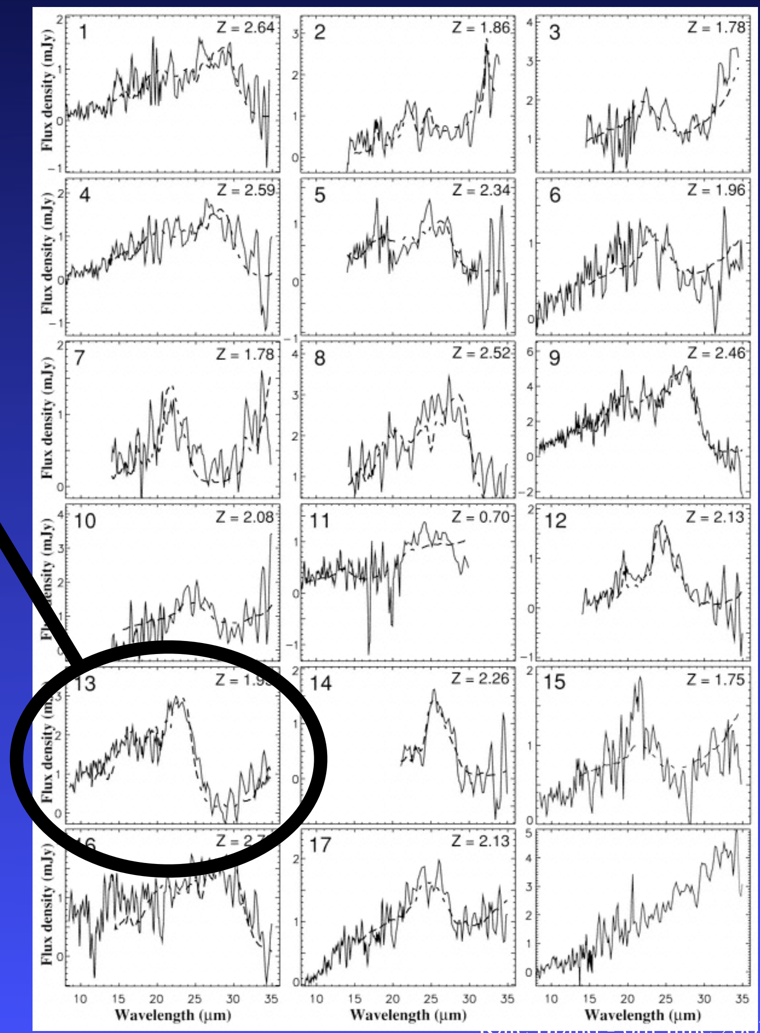

- Spitzer/IRS spectra of $f_{24}$> 0.8 mJy sources
  - redshifts determined for ~50% of sources via their silicate absorption features. z ~ 1.5 - 2.7
  - No PAH emission - AGN-dominated
  - $L_{IR} \sim 10^{13} L_{\odot}$

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



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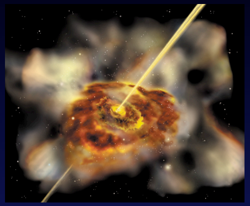
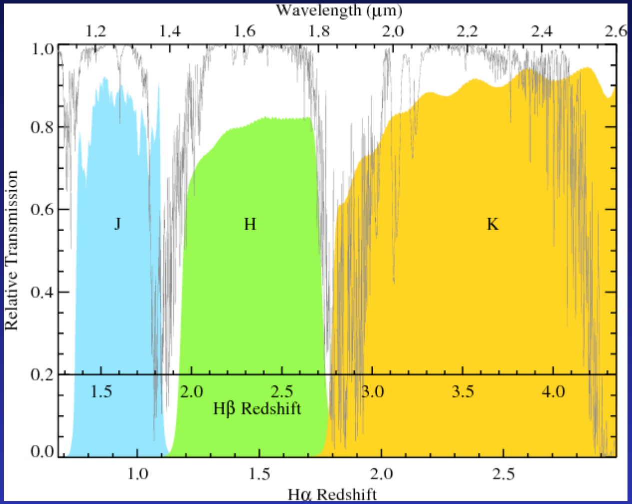
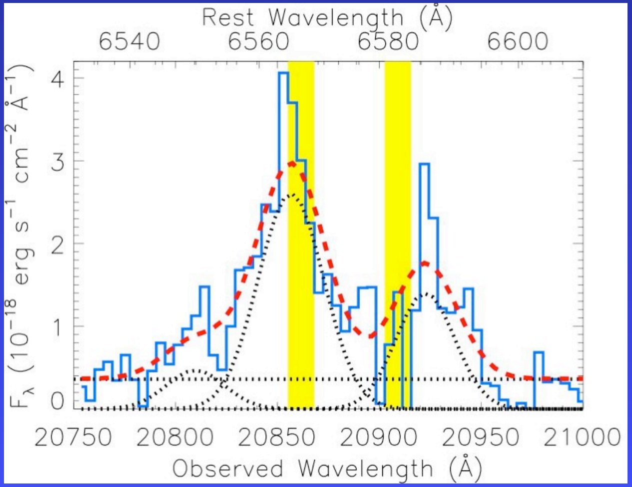
# Near-IR spectroscopy of heavily obscured AGN



- 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.

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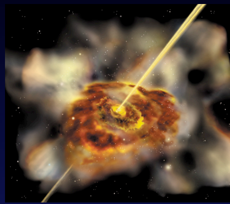
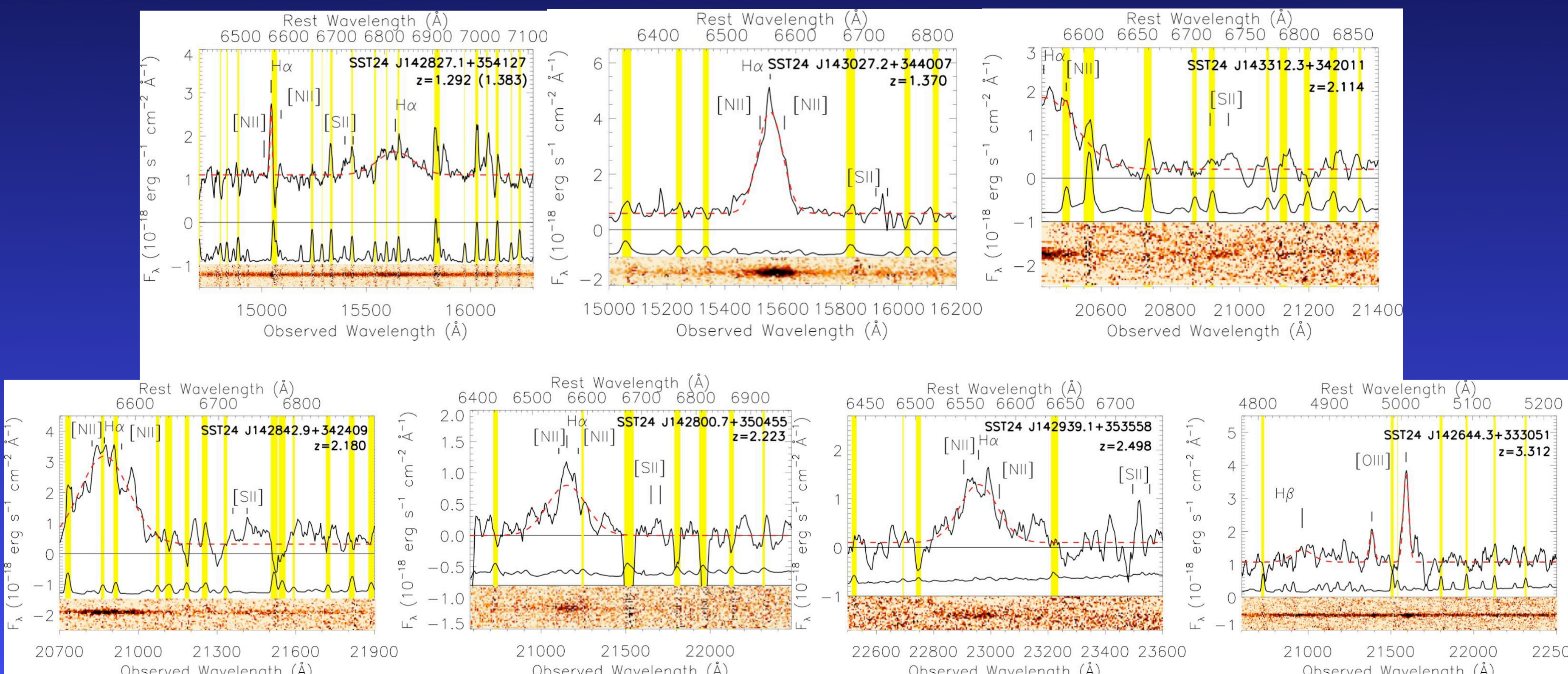
# Near-IR spectroscopy - broad-line sources

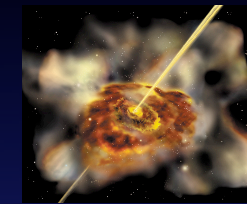


- 7/10 sources have broad (>1900 km/s) $H_\alpha$ or $H_\beta$ emission lines - AGN dominated.



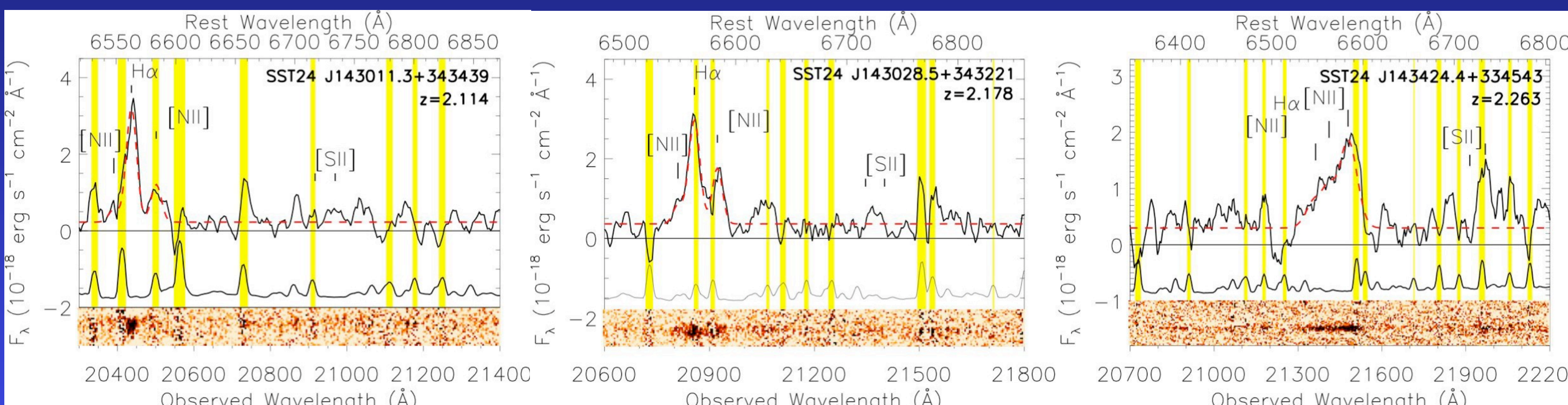

Brand et al. (2007)

# Near-IR spectroscopy - narrow-line sources



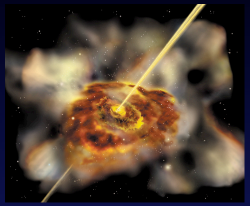
- 3/10 sources have narrow (<700 km/s) $H_{\alpha}$ or $H_{\beta}$ emission lines.

Line diagnostics and bolometric luminosities suggest they are AGN-dominated.

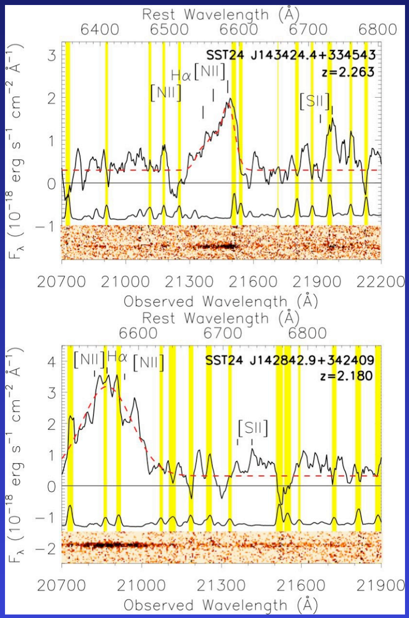



Brand et al. (2007)

# Near-IR spectroscopy - radio spectral index



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



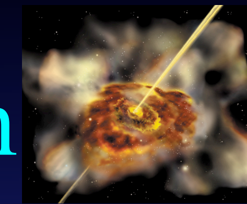

SST24 J143424.4+334543 is a narrow-line source.
Steep radio spectral index ($\alpha = 1.0$).

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).

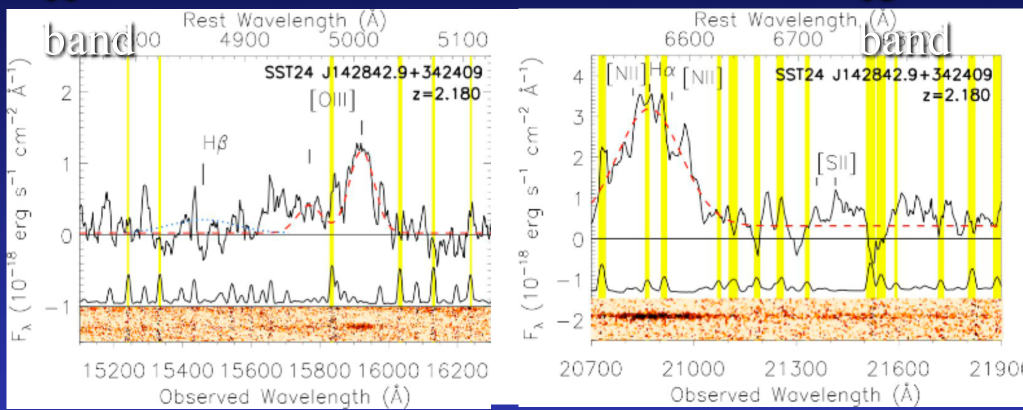
Radio flux densities supplied by S. Croft, W. de Vries, W. van Breugel

# Near-IR spectroscopy - extinction to emission-line region

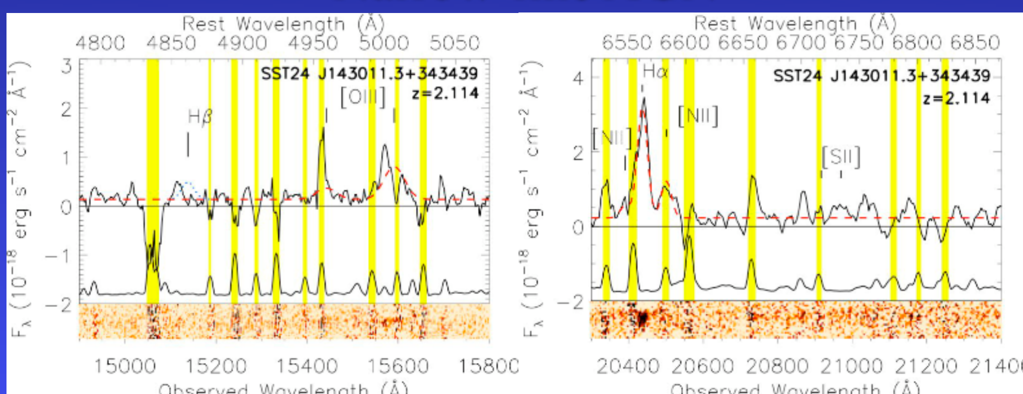


## Broad-line AGN

H-band K-band




## Narrow-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 source:

$H_\alpha/H_\beta > 8.5$

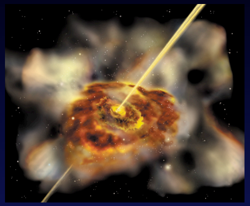
$E(B-V) > 1.0$

$A(H_\alpha) > 2.4$

$H_\alpha$ luminosity > 9x lower than would be if no extinction.

Brand et al. (2007)

# Implications

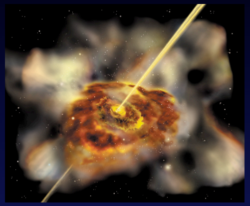


- Both broad-line and narrow-line region are extincted → some fraction of the extinction must be taking place on scales larger than that of the narrow-line region

  → 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.

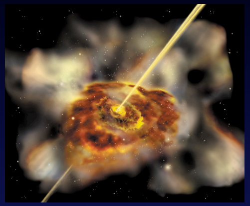
  (cf talks by Polletta, Martinez-Sansigre, Donley)

# How common are these obscured AGN?



- Brown et al. (2006): 140 $f_{24}$> 1 mJy quasars with $17.2<R<21.7$ and z>1.3 in Bootes field (from AGES spectroscopic survey).
- There are ~300 sources with R-[24]>14 and $f_{24}$>1mJy. 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 ~2x that of optically bright type I AGN with similar redshifts and bolometric luminosities.

# What are the featureless IRS sources?



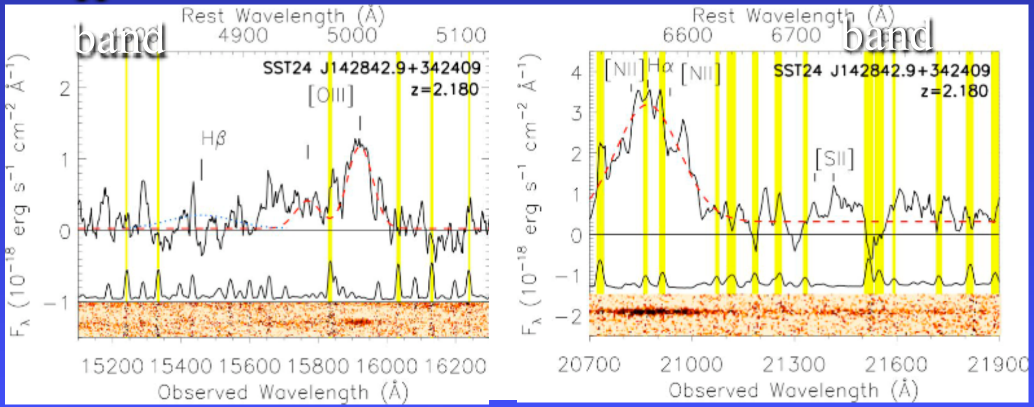
- ~50% of R-[24]>14 sources followed up with IRS exhibit featureless mid-IR spectra.
  - z > 2.5?
  - lack of silicate absorption feature?
- 4/10 of near-IR spectra have featureless IRS spectra.
  - in 3/4 sources, lack of silicate absorption feature explained by high z.
  - One source has no silicate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

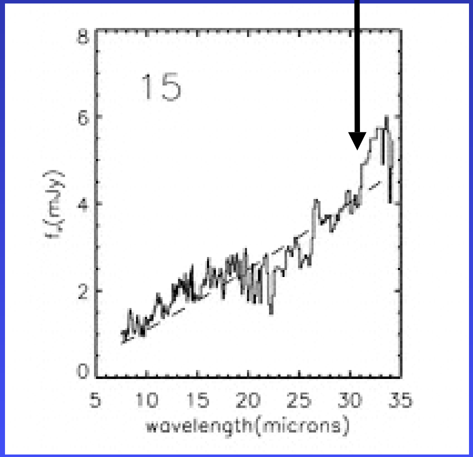
9.7um silicate absorption feature expected here.

Broad-line AGN

H-band

K-band

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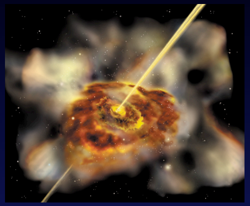
IRS spectrum from Weedman et al. (2007)

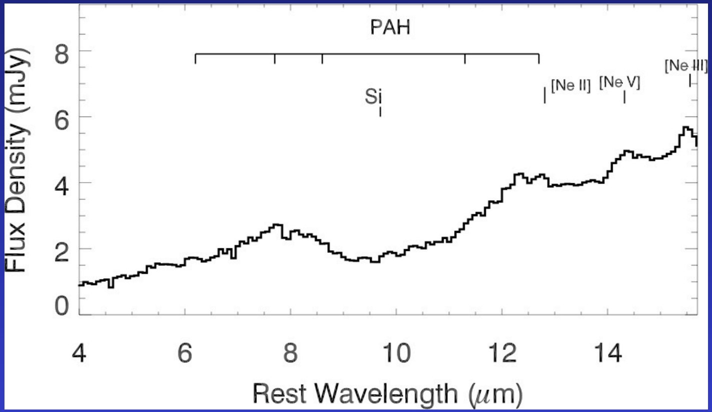
# A clue from obscured sources with powerful X-ray emission



- IRS spectroscopy of 16 R-[24]>13 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 $L_x>2\times10^{45}$ erg $s^{-1}$ (among most powerful quasars known).

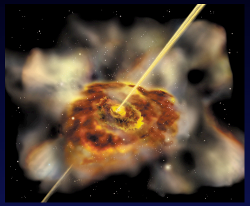
Stacked IRS spectrum of 10 sources with IRS redshift




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