Finding Elusive AGN in the (mid)-Infrared

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Recent evidence for missing AGN in X-ray (<10keV) surveys

A non-negligible fraction of luminous, heavily obscured (high covering factors) type-2 AGN X-ray detection (at energies < 10keV) are missing:

• NuSTAR Serendipitous Survey

• Comparison of optical fraction of type 1/type 2 of X-ray selected AGN with the modelled distribution of torus geometrical covering factors

Landsbury+2017

Mateos+2017
SEDs of Type 1 and Type 2 AGN are different, but mostly in near-IR (see also e.g., Alonso-Herrero et al. 2001, 2003).

For AGN accretion disk emission and dust emission, see the following references:

- Hernán-Caballero et al. 2016
- Elvis et al. 1994, 2012
- Glikman et al. 2006
- Richards et al. 2001, 2006
- Hill et al. 2014
- Kim et al. 2015

For normal galaxy thermal IR continuum emission of radio quiet AGN, see:

- Popescu et al. 2011

For Seyfert 1s and Seyfert 2s, see:

- Ramos Almeida et al. 2011
- Ichikawa et al. 2016

Elvis et al. 1994, 2012
Glikman et al. 2006
Richards et al. 2001, 2006
Hill et al. 2014
Kim et al. 2015
Ichikawa et al. 2016
Infrared lines in AGN

Brightest AGN lines in the mid-IR spectral range:

- $\text{[NeV]}$ at 14.3$\mu$m and 24$\mu$m (91.7eV)
- $\text{[OIV]}$ at 25.9$\mu$m (54.9eV)

Spinoglio & Malkan 1992

Tommasin+2010
The X-ray vs. mid-IR correlations

Asmus+2011,2015, see also Gandhi+2009, Levenson+2009, Mason+2012 and many more

García-Bernete+2017

Kohei Ichikawa’s talk
The $[O\text{ IV}]$ line at $25.89\mu m$: AGN and/or SF indicator

- Type 1s
- Type 2s Compton thin
- Compton-thick
- Unknown $N_H$

**Rigby+2009**
This line could be used potentially to estimate the AGN power in very obscured and Compton-thick AGN and ULIRGs

**See also Melendez+2008, Diamond-Stanic & Rieke 2009**

**Pereira-Santaella+2010**
This line can also be excited by SF activity. However, SF excitation important when SF is about x20 more luminous than the AGN.
AGN fraction in nearby galaxies using the [NeV] $14.3\mu$m line

Nearby galaxies: AGN fraction $\sim$27% (+8/-6%)
- 50% of these are not identified in the optical
- Strong SF activity and/or moderate extinction (a few Av)

LINERs [NeV] detection rate $\sim$40%, many without other signs of AGN activity

Bulge-less nearby galaxies AGN incidence in Sd/Sdm drops significantly. No an Av effect but due to lack of AGN

Goulding & Alexander 2009, see also Satyapal+2008, Dudik+2009
High excitation lines to identify AGN in (U)LIRGs

Local LIRGs: 50-70% with [OIV] detections and 22% with [NeV] detections

Local ULIRGs: 25-50% with [OIV] detections and 25-50% with [NeV] at 14.3 μm

Farrah+2009, see also Armus+2006, 2007, Veilleux+2009

Alonso-Herrero+2012 and also Petric+2011
Spectral/SED decomposition methods to identify AGN

**Local ULIRGs:**
70% IR AGN detection rate

- Mrk231 AGN dominated
- Mrk273 SB dominated

**Local LIRGs:**
50% IR AGN detection rate

- MCG+12-02-001 SB dominated
- NGC7469
- IC4518W AGN dominated

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Alonso-Herrero+2012
Elusive AGN in local (U)LIRGs

IR indicators provide the fraction of buried (non-Seyfert) AGN in local (U)LIRGs that are not identified by X-rays and/or optical spectroscopy.

Local LIRGs: Fraction of elusive (=non-Seyfert) AGN is 20-25%
Local ULIRGs: Fraction of elusive (=non-Seyfert) AGN is 50-70%

X-rays: Maiolino+2003
IR power law emission as a method to select AGN

In cosmological fields with deep IRAC observations

Detection in all 4 IRAC bands with a power law continuum \( f_\nu \sim \nu^\alpha \) in (U)LIRGs and spectral indices \( \alpha < -0.5 \) over 3.6-8\( \mu \)m

Needs good estimates of photometric errors

Alonso-Herrero+2006, and see also Donley+2007, 2008
IR color selection of AGN using IRAC data

Can be contaminated by star forming galaxies in very deep IRAC exposures

log (S_{5.8}/S_{3.6}) vs log (S_{8}/S_{4.5})

Power law line

Lacy+2004, Stern+2005 and figures from also Donley+2008
IR power-law AGN selection using IRAC colors

This is a more restrictive wedge which takes into account:
- typical uncertainties photometric uncertainties
- avoids contamination by high z SF galaxies in deep IRAC observations

Donley+2012

New wedge + monotonically rising $f_v$
IR power-law AGN selection using WISE colors

Mateos+2012, 2013 and see also Jarret+2012, Stern+2012, Assef+2013 for other WISE selections
Selecting AGN/QSO from AllWISE catalog

Sample of 1,354,775 AGN selected from AllWISE using Mateos+2012 criteria of which 1.1 million of these were previously uncataloged

Probability of correctly identifying a known AGN/QSO is at least 84% for AGNs brighter than a limiting magnitude of $R < 19$

**WISE+SDSS AGN: Secrest+2015**, see also Mateos+2013 for detection of SDSS [OIII] selected type 2 QSO
Optical follow-up of WISE selected QSO

Of 40 targets (moderate redshifts), only 13% do not have evidence of hosting an AGN

Hainline+2014. See also eg Lacy+2007 for follow-up of IRAC selected AGN
IR power-law AGN color selection vs. X-rays

**Strong dependence on depth of X-ray data**

IR power law galaxies detected in X-rays

X-ray sources that are IR power law galaxies

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**Flux limit at IRAC 5.8\(\mu\)m (\(\mu\)Jy)**


**WISE selection:** Mateos+2012, see also Assef+2013
Completeness of IR power-law AGN selection

WISE colors - IR power law AGN selection using Mateos+2012 compared to a 4.5-10keV selection:

- Highly complete for luminous type 1 AGN (Lx > 10^{43}-10^{43.5} erg/s)
- Moderately complete for type 2s with Lx > 10^{44} erg/s

Landsbury+2017: NuSTAR serendipitous survey

Mateos+2012: XMM BUXS survey selected in 4.5-10keV band
Host galaxy dilution

IRAC/WISE selections most likely to miss X-ray and optically selected AGNs:

- luminous hosts (i.e., massive host galaxies)
- AGN emission is itself obscured.

Donley+2012 for IRAC selection
Mateos+2013 for WISE selection

See also e.g., Lazy+2007, Alonso-Herrero+2008, Hickox+2009, Mendez+2013, Messias+2014, Azadi+2017
Do mid-IR criteria select obscured luminous AGN?

20 candidates to heavily obscured AGN from combination of XMM-SDSS-WISE + SED decomposition. The majority meet the MIR-selection criteria of Stern+2012 and Mateos+2012.

~ 70% of SDSS QSO 2 which are also CT candidates are in Mateos+2012 wedge.

See also Landsbury+2014 for optical CT QSO2 candidates.
Hardness ratios of IRAC selected AGN

HR = 0.31 ± 0.13, column densities of log NH(cm\(^{-2}\)) = 23.5 ± 0.4.

HR = −0.31 ± 0.13, column densities of log NH(cm\(^{-2}\)) = 22.4 ± 0.4.

COSMOS cosmological field with Chandra data

Donley+2012, see also Alonso-Herrero+2006
Looking for IR power law emission using SED decomposition

GOODS-South and Chandra 4Ms X-ray catalog:

- At $z<1.5$ 3/4 of the X-ray AGN are identified with this method
- At $z>1.5$ only 44% of X-ray AGN are identified
- $\sim50\%$ of the selected galaxies at $1<z<1.5$ are not identified in X-rays

**Caputi+2013**, see also e.g., Daddi+2007

Chris Carroll’s talk
JWST photometric filters

NIRCam Filters

NIRISS Filters

MIRI Filters

Credit: JWST webpage at STScI
Deep surveys with JWST to select AGN

Combination of NIRCam F200W and F444W and MIRI F770W and F1800W to select AGN at $z \sim 1-2.5$

Credit: Frontier Fields webpage and G. Snyder & Z. Levay (STScI)

Messias+2014

Fabio Panucci’s talk: detection of DCBH
JWST/NIRSpec Multi-Object Spectroscopy

NIRSpec/MOS provides multiplexing 0.6–5.3 μm spectroscopy capabilities over a 3.6' × 3.4' field of view using configurable shutters.

Credit: JWST webpage at STScI
JWST/NIRISS slitless spectroscopy

The wide field slitless spectroscopy mode of NIRISS enables low-resolution ($R \approx 150$) spectroscopy over the wavelength range 0.8–2.2μm for all objects within a 2.2’ × 2.2’ field of view.

Simulated images of a lensing cluster observed with the NIRISS F115W filter and the GR150C grism and F115W blocking filter

Credit: JWST webpage at STScI
JWST sensitivity and angular resolution

Filters:
- F356W
- F444W
- F560W

Credit: Frontier Fields webpage and G. Snyder & Z. Levay (STScI)
Spatially-resolved AGN selection with JWST

HST observations taken in the UDF

JWST simulations
## JWST Integral Field Units

### NIRSpec

- **NIRSpec Spectrum Resolving Power**
  - Graph showing the resolving power of NIRSpec as a function of wavelength.
  - Key wavelengths highlighted:
    - G140H
    - G235H
    - G395H
    - G140M
    - G235M
    - G395M
    - PRISM

- **JWST NIRSpec IFU Field**
  - Image showing the field of view (FoV) of the NIRSpec IFU.
  - 3" FoV highlighted.

### MIRI

#### Channel Band Table

<table>
<thead>
<tr>
<th>Channel</th>
<th>Band</th>
<th>Nr. slices</th>
<th>Wavelength Range [µm]</th>
<th>Spectral Resolution</th>
<th>FoV [arcsec]</th>
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</tbody>
</table>

**Credit:** JWST webpage at STScI
Conclusions

IR offers a large number of tools to identify elusive AGN: emission lines, line ratios, color-color selection, SED/spectra decomposition

MIR diagnostics do not provide a complete selection of AGN but:

• High excitation lines can identify faint/buried AGN in local galaxies

• Color-color selections are highly reliable to identify luminous AGN ($L_x > 10^{43.5}$ erg/s) and possibly Compton-thick AGN

• WISE color-color selections provide large catalogs of QSO

**JWST provides ALL these IR diagnostics with much higher sensitivity and angular resolution using all observing modes:**

• Imaging with NIRCam, NIRISS, MIRI
• MOS with NIRSpec
• Slit-less spectroscopy with NIRISS
• IFU with NIRSpec and MIRI