The search for heavily obscured AGN in the Chandra Deep Fields, and prospects for SPICA

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The quest for obscured AGN at different cosmic times

Obscured SMBH growth as a key phase in AGN/galaxy life

Needs for a complete AGN census

X-ray surveys  Combined mid-IR/opt/X-ray  Optical spectroscopy

The strength of deep X-ray spectroscopy and SED fitting (including the mid-IR/far-IR) – SPICA

see review talk by Comastri
Phase with obscured AGN growth coupled to powerful star formation

AGN likely either Compton thick ($N_H > 10^{24} \text{ cm}^{-2}$) or heavily obscured in this phase

C-thick AGN at $z>0.1$ invoked to explain the 30 keV XRB: they are expected to contribute from ~10 to 30%, depending on the models (Gilli+07, Treister+09) – see also recent results from Ueda+14 and Ballantyne…

Much of the mass growth of SMBH occurs during the heavily obscured phase? (e.g., Treister+10)

Strong winds/outflows (=feedback) expected in the “blowout” phase
Recently, on the very obscured AGN issue
Compton-thick AGN in the COSMOS survey

Searching for the most obscured AGN
Almost complete X-ray spectra coverage

Typically, low-SNR X-ray spectra, careful modeling needed
HR selection may be not appropriate if a soft component is present at low z

$z = 0.1 - 2.5$
$log L_{2-10\text{keV}} \approx 43.5 - 45$

see also Del Moro et al. 2015 in the Chandra Deep Fields, and Buchner et al. 2015

Lanzuisi+15a
The most obscured AGN in the COSMOS (field) – I.

The power of combining X-ray vs. mid-IR information (from SED fitting)

\[ L_{\text{BOL}} \text{(SED fitting)} \]

\[ L_{\text{2-10keV}} \text{(intrinsic)} \]

\[ N\text{-AGN} \]

\[ B\text{L-AGN} \]

\[ \text{galaxies} \]

\[ z=0.35 \text{ ULIRG in COSMOS} \]

Similar to DOGs (MIR/O>1000) but at much lower z

The measured \( L_X \) is too low compared to \( L_{\text{BOL}} \) assuming a “standard”

\[ k_{\text{BOL}} = \frac{L_{\text{BOL}}}{L_{\text{2-10keV}}} \]

Typically, low-SNR X-ray spectra, careful modeling needed
The most obscured AGN in the COSMOS (field) – II.

Checks with different models to account for obscuration (MYTorus, etc.)

Strong soft X-ray emission may ‘hide’ the Compton-thick nature of the sources in case of simple hardness ratio analysis

"diagnostic" diagrams

Log $N_H$ vs.
$\frac{L_{\text{obs}}^{(2-10\text{keV})}}{L([\text{NeV}])}$

Log $L_{\text{obs}}^{(2-10\text{keV})}$ vs.
Log $\lambda L_{\lambda}(5.8\mu\text{m})$
Using *Chandra* Deep Field data
Delvecchio et al. (2015): *Herschel*-selected galaxies in GOODS and COSMOS (goal: to study BHAR vs. SF as a function of cosmic time via SED fitting)

- X-ray detection in 4Ms CDF-S and 2Ms CDF-N catalogs (Xue+11; Alexander+03)
- Likely presence of an AGN from SED decomposition (using modified MAGPHYS)

X-ray spectral analysis to constrain $N_H$ and derive intrinsic $L_X$

Intrinsic $L_X$ predicted from $L_{BOL}$ (SED fitting) + $k_{BOL} > 10 \times L_{X,observed}$

\[ S_{[\text{Jy}]} = \text{goodSN: ID=12930, z=3.406 (spec) CID=330} \]

Not a complete selection
CDF-S
29 obscured AGN candidates

CDF-N
10 obscured AGN candidates

z=0.07-3.51
<z>≈0.8

Red + blue datapoints: 115 (CDF-S) and 79 (CDF-N) sources with X-ray detections and AGN apparently required in the mid-IR (SED fitting)

Intrinsic \( L_X \) predicted assuming \( L_{\text{BOL}} \) from SED fitting and Marconi+04 \( k_{\text{bol}} \)

10x

Obscured AGN candidates

Difference likely ascribed to obscuration

Heavily obscured AGN candidates

Recently available 7Ms data CDF-S + 2Ms data CDF-N

Fit with a simple transmission model + iron line leaves strong residuals

More physical modeling needed
Using appropriate “torus” modeling

Example of an AGN at $z=0.68$ with $N_H \approx 10^{24} \text{ cm}^{-2}$

BNtorus modeling (Brightman & Nandra 2012)
Checks with MYTorus (Murphy & Yaqoob 2009)
ongoing

- Powerlaw
- Reflection
- Total emission
Modeling the X-ray spectra. II

Heavily obscured AGN candidates

- $z=0.31$: $N_H > 3 \times 10^{24} \, \text{cm}^{-2}$
- $z=0.68$: $N_H > 1.8 \times 10^{24} \, \text{cm}^{-2}$
- $z=0.23$: $N_H \approx 1.3 \times 10^{24} \, \text{cm}^{-2}$
Column density distributions

CDF-S

CDF-N

9 sources (6+3) with $N_H > 10^{23}$ cm$^{-2}$
X-ray luminosity distributions

CDF-S

CDF-N

AGN
SF
AGN

Low $L_X$

High $L_X$

$L_{2-10\text{keV}} = 10^{42} \text{ erg/s}$

$10^{39}$ $10^{40}$ $10^{41}$ $10^{42}$ $10^{43}$ $10^{44}$ $10^{45}$ $10^{46}$

Number of sources

$10^{39}$ $10^{40}$ $10^{41}$ $10^{42}$ $10^{43}$ $10^{44}$ $10^{45}$ $10^{46}$

$10^{39}$ $10^{40}$ $10^{41}$ $10^{42}$ $10^{43}$ $10^{44}$ $10^{45}$ $10^{46}$
Combining the mid-IR information with the strength of X-rays
Comparison of the X-ray luminosity with the AGN 12.3µm luminosity (from SED fitting)

Original selection seems to pick up also “hybrid” sources, where the AGN is not dominant.
Comparison of the X-ray luminosity with the AGN 12.3µm luminosity (from SED fitting)

Original selection seems to select also “hybrid” sources, where the AGN is not dominant.
Example of a source originally selected as having an AGN in mid-IR but with low X-ray luminosity (Log$L_X \approx 41.4$)
X-ray emission from the heavily obscured AGN candidates: clear accretion dominance

For the heavily obscured AGN candidates, X-ray emission is due to accretion [SFR(X-ray) too high]. AGN + SF for the other sources

| XID | $L_{0.5-8keV}^X$ | $L_{8-1000\mu m}^{IR}$ | $SFR_X$ converted from $L_X$ | $SFR_{IR}$ converted from $L_{(8-1000\mu m)}$
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| ID  | $L_{0.5-8keV}^X$ | $L_{8-1000\mu m}^{IR}$ | $SFR_X$ converted from $L_X$ | $SFR_{IR}$ converted from $L_{(8-1000\mu m)}$
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Mimeo+14 (see also Ranalli+03)  
Kennicutt98
Results: the most obscured AGN

Heavily obscured AGN candidates

$N_H > 3 \times 10^{24} \text{ cm}^{-2}$

$z = 0.31$

$N_H > 1.8 \times 10^{24} \text{ cm}^{-2}$

$z = 0.68$

$N_H \approx 1.3 \times 10^{24} \text{ cm}^{-2}$

$z = 0.23$
Need for mid-IR + far-IR facilities!
Obscured AGN: Prospects for SPICA

SMI-LRS (low-resolution spectrometer, R=50, 17–36 µm)

will allow detection of obscured AGN via mid-IR continuum (torus) emission and mid-IR/optical selection (e.g., DOGs, HotDOGs)

SMI-MRS (medium-resolution spectrometer, R≈1000–2000, 18–36 µm)

more “detailed” physics and selection for AGN/SF & modeling via [NeV]$_{14.3}$, [NeV]$_{24.3}$, [OIV]$_{25.9}$ mid-IR emission lines (see Spinoglio & Malkan 1992, Gruppioni+16) as with Spitzer/IRS

Safari (grating spectrometer, R=300, 34–210 µm)

will allow extension of AGN studies to high redshifts

Overall, potentially strong synergies with X-ray surveys (e.g., Athena)