Obscured AGN

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Rationale: Why obscured AGN are important (especially the Compton-thick AGN)

Obscured AGN from X-ray surveys (Chandra, XMM, Swift/BAT, Nustar)

IR+ sub-mm methods (mid-IR colours, Spectral Energy Distributions, IR spectroscopy)

future surveys
X-ray Surveys

- X-ray surveys provide the most efficient way to detect AGN

- In the CDFS 4Ms the sky density is **20,000 sq. deg.** (Xue+11) cf. with **~300/sq. deg.** in SDSS (Ross+12)

- This is because X-rays probe faint luminosities and absorbed sources

  - but see variability studies and spectroscopic studies [OIII], [NeV] e.g. Bongiorno+10, Gilli+10 -
see also Miyaji+15, Ranalli+15, Buchner+15, Fotopoulou+15 for recent derivations of the LF
Obscuration depends on redshift and luminosity

Powerful QSOs prefer not to be obscured!

AGN at high-z are more obscured
DISTRIBUTION OF ABSORPTION

Tozzi+06
Georgantopoulos+07
using spectroscopy 1Ms CDFS

Number

peaks at
\( N_h \sim 10^{23} \text{ cm}^{-2} \)
\( A_V \sim 30 \times 10^{-16} \text{ cgs} \)

\( N_H \)

CT–AGN
regime
The most obscured AGN: can X-ray surveys detect them easily?

Even the very efficient hard X-rays have difficulties penetrating column densities above $>10^{24}$ cm$^{-2}$ Compton-thick AGN.

The attenuation is because of Compton scattering on electrons and not because of photoelectric absorption.

This reduces the X-ray emission in the 2-10 keV band to a few percent of the intrinsic emission.
What does the torus look like?

not really a compact torus.
More of a cloud structure (e.g. Nekova+08)
See also the Hydrodynamical simulations of Wada+08

But the most important evidence is the VLT observations which resolve the torus in nearby AGN (Jaffe+04)
Why are heavily obscured AGN important?

They may represent a large (evasive) part of the accretion history of the Universe.

Theoretical models postulate that heavily obscured AGN represent the birth of an AGN (e.g. Hopkins+08)
Observational evidence of this scenario?

Kocevski+15
Morphology of heavily obscured sources with HST (CDFS, Aegis, COSMOS)

Fraction of mergers vs. column density $N_h$
Why do we need the most heavily obscured AGN?

An argument often mentioned is that among the nearby AGN most are Compton-thick

**Spectrum X-ray background**
X-ray background population synthesis models: Comastri+95, Gilli+07, Treister+09, Ballantyne+11, Akylas+12, Ueda+14

**Soltan argument**: The luminosity becomes BH mass
\[ \rho_{BH} = \left( \frac{k_{bol}}{\epsilon} \right) (1+z) \frac{I_0}{\langle z \rangle} \quad (\text{Soltan}82) \]

On the basis of this Iwasawa&Fabian(1999) claimed that most accretion in the Universe is heavily obscured (assuming a value for accretion efficiency \( \epsilon \))
Density of BH locally factor of 1.5 higher than LFluminosity function (e.g. Merloni & Heinz)
Most Heavily obscured AGN in X-ray surveys ($N_H \sim 10^{24}\,\text{cm}^{-2}$)

Ultra-hard X-ray surveys:
- SWIFT/BAT
- NuSTAR

Hard (2-10keV) X-ray surveys: Chandra and XMM
How do we find extreme obscuration?

X-ray spectroscopy

Looking for 3 features:

1. The absorption turnover

2. A flat spectrum with $\Gamma \sim 1$ indicative of reflection in the back side of the torus

3. An FeKα line with a high EW
SWIFT/BAT: All sky survey with coded mask imaging down to \(~10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\) (14-195 keV) and getting deeper as new scans are added. Burlon+11, Ajello+13, Baumgartner+13

1210 sources with about 700 AGN.

Heavily obscured AGN can be found only by using BAT+XRT. BAT only is not very effective because of the lack of soft energy coverage (two groups, Ricci et al, Akylas et al.)
2MASXJ08434495 +3549421

![Graph showing photon distribution vs energy](image_url)

- XRT+BAT
Number counts + comparison with models

Note the degeneracy between the reflection component and the fraction of CT AGN in the models.
Alexander+13 serendipitous fields

Civano+15 1.7deg2 COSMOS: 1 bona fide CT

Mullaney+15 eCDFS

Because of small number statistics the apparent lack of CT AGN is consistent with both Gilli+07, Treister+09, Akylas+12

We must go a factor of 3 deeper hitting the confusion limit OR wait for the serendipitous CT sources
Recent Searches for CT AGN at softer energies <10keV

0.5-8  Brightman+14 BUCHNER+15  CDF, AEGIS, COSMOS

2-10  Corral et al. CDFS 7 Ms (in prep.)

2-10 keV  lanzuisi+15 COSMOS

XMM INITIAL selection BUT  XMM+Chandra fits are performed

10 CT AGN of which 6 have EW(FeKα) ~ 1 keV

1 common CT in cosmos between the Brightman and Lanzuisi samples at z=0.125
7Ms search Compton-thick (Luo 2Ms catalogue)
there may be a hint for additional evolution of CT AGN with $z$.
IR techniques

- IR can provide insight on obscured objects as the absorbed radiation is re-emitted at IR wavelengths.

In the IR you get both SFR and accretion and the task is to separate one from the other.
AGN SEDs

Lx/L6μm ratio

Dust Obscured Galaxies (R/24μm)

IR spectroscopy (Si Absorption)
X-ray to 6μm (or 12μm) luminosity ratio introduced by Alexander+08

X-ray obscuration relative to the torus emission is an excellent diagnostic as for heavily obscured AGN, **X-rays DECREASE while the torus emission remains constant.**

Rovilos+14 applied this technique in the WISE survey using 3XMM data.
Dust obscured galaxies (DOGs)

High $f_{24\mu m}/f_R < 1000$ ratio

see e.g. Pope+08

Fiore+08, Georgantopoulos+08, Fiore+09 applied this method in the CDFS.

Some sources are detected in the X-rays: Corral+16

6Ms Chandra+3Ms XMM

14 sources: 9 heavily absorbed (at least 1 CT)
Spectral Energy Distributions

SEDs may provide a more refined way to find the AGN

del Moro+2015 derive SEDs (Herschel & Spitzer) in the CDFS for the most luminous mid-IR sources ($L_{6\mu m}>10^{44.8}$), redshift $z=1-3$.

From the SEDs of the luminous AGN, 70% are obscured with $N_H>10^{22}$ cm$^{-2}$, some unobscured while for the non-detected ones it is assumed that they are CT.
Mid-IR spectroscopy: 9.7 Si absorption feature

NGC4945: Spitzer IRS spectra from nearby galaxies Brandl+06
Spitzer IRS observations of the 12μm sample: Wu+09

but see Goulding+12

Note that column density from τ is always lower than $10^{24}$cm$^{-2}$
Concluding Remarks

The LF of obscured AGN has been extremely well defined (fraction of obscured AGN evolution with redshift, Luminosity) (e.g. Ueda+14, Buchner+14)

Statistically complete samples of CT AGN are found at both high redshift and low redshift in the last couple of years (Akylas+16, Ricci+15, Brightman+14, Buchner+14)

The number of CT AGN is rather low (~15-20% in the local Universe with the exact value depending on reflection but may evolve with redshift)

Comastri+15 point out that the local BH density is higher than previously thought. This can be explained by either non efficient accretion OR a population of very low luminosity Compton-thick AGN. These are very hard to detect even in deep surveys and they play no role to the X-ray background (remember the high density of nearby CT AGN)
**Future (X-ray + IR)**

**eROSITA** (3,000,000 AGN). A large number of heavily obscured AGN is expected even in the soft band (a few thousand). The tasks is to identify them. Combination of **ART-XC** and **eROSITA** are or **eROSITA** and **WISE** are two routes.

Till then the **3XMM** catalogue provides an invaluable resource. There are many added value products: **XMMFITCAT** provides spectra for 120,000 sources. A prerequisite is the derivation of phot-z. **ARCHES** is the obvious step to exploit this resource. **JWST** near IR spectroscopy to find the Si absorption feature.

**JWST** is a mid-IR telescope and e.g. Si 9.7μm

**ATHENA** will be able to find a very large number of heavily obscured AGN (see white paper by the WG)
THE END
Colours are used as a thermometer of the dust: hot dust is heated by the AGN.

Spitzer boxes: Donley, Stern, Lacy
comparison with X-ray Barmby+06, Georgantopoulos+08, Castelo-Mor+12
Similar boxes in WISE: Stern+12, Mateos+12 (Secrest+15)

Yan+13 propose r-[4.5] colour to select the obscured ones
The X-ray surveys have provided a good knowledge of the AGN luminosity function (LF) and its evolution (a few thousand cf. tens of thousand in the optical)

e.g. Aird+11, Aird+15, Ueda+14, Miyaji+15, Buchner+15, Ranalli+15 see also Vito+14, 15, Georgakakis+15 present the high-z (z>3) LF

Of particular interest for this talk: Buchner+15 present the LF and its evolution as a function of the column density
HST vs Chandra 2 Ms

Just to be fair: optical surveys can sample low luminosities using optical spectroscopy (Bongiorno+10, Heckman+09 vs Georgantopoulos+10, Gilli+10)

Also variability studies [e.g. Vilforth+11, Palanque+10]

An underlying sea of galaxies most of which contain BH remain undetected

N. Brandt
PennState
Molecular lines as a probe of highly obscured AGN

Papadopoulos+10 (observing ULIRGS from HERCULES Legacy Spitzer survey)
Proposed that high Dust obscuration can be probed with CO flux ratios

Obscuration is that high (AV~4000, NH~10^{25}) that can absorb sub-mm wavelengths!!
COMPARISON WITH MODELS: 2-10 keV

Note that the Gilli model gives lower numbers of CT AGN (2-10 keV) despite the fact that it assumes a higher fraction of CT AGN.
These massive star-forming systems at z>2 have been proposed as sites where SFR and BH galaxy growth simultaneously take place with the majority being candidate CT sources. (Alexander et al 2005) Laird+11 in the CDFN challenged these claiming a low number of AGN. Similar results were claimed in the CDF-S (based on LABOCA sub-mm sources Georganopoulos+11 matched via 24 Spitzer) The AGN fraction was found less than 20%. Wang+13 using ALMA observations made a step forward finding an AGN fraction of 17%.