Nuclear obscuration in AGN: an X-ray perspective

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1993
Wada et al. (2016); See talks by K. Wada, D. Williamson, C.-H. Chan, A. Dorodnitsyn, D. Angles-Alcazar
Obscured accretion

Treister et al. (2009); see also Tasnim Ananna et al. (2018), Ueda et al. (2014), Akylas et al. (2012), Draper & Ballantyne (2010), Gilli et al. (2007)
X-ray emission of AGN

Credit: Optical: NASA/HST, X-ray: NASA/PSU
X-ray spectra of AGN
X-ray spectra of AGN
X-ray spectra of AGN
Absorption in the X-rays

\[ N_H < 10^{18} \text{ cm}^{-2} \]

- Transmitted power-law
- Reflected component
- Scattered component
- High-energy cutoff
- Thermal emission
Absorption in the X-rays

\[ N_H < 10^{18} \text{ cm}^{-2} \]

- Transmitted power-law
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- Scattered component
- Thermal emission
- High-energy cutoff
1 — Reprocessed
2 — Obscured
1 — Reprocessed X-ray radiation
The Fe Kα line

MCG–5–23–16(2)

Broad

Narrow

Nandra et al. (2007)
The Fe Kα line

Chandra/HETG

Circinus

FWHM~1700 km s⁻¹

photons cm⁻² s⁻¹ keV⁻¹

10⁻³ 2×10⁻³ 3×10⁻³ 4×10⁻³

0

5.5 6 6.5 7 7.5

Rest Energy (keV)

Shu et al. (2011), see also Shu et al. (2010)
The Fe Kα line

Shu et al. (2011), see also Shu et al. (2010)

Hitomi collaboration (2018)
The Compton shoulder

Circinus

Fe Kα

CS

Counts/sec/keV

Residuals

Energy (keV)

Bianchi et al. (2002); See C. Andonie’s talk
The Fe Kα line

Gandhi et al. (2015)
Extended Fe Kα lines

NGC 4945: Marinucci et al. (2017)
ESO428–G014: Fabbiano et al. (2017)
NGC 2110: Bauer et al. (in prep.)

See talks by G. Fabbiano, M. Elvis, F. Bauer
Extended Si Kα lines

Chandra 2.5-3 keV image of Circinus

Simulations with two different models

Fe Kα/Si Kα vs. Cos (inclination angle)

- Disk model
- Disk + wind model

Liu, Hoenig, Ricci & Paltani (in prep.)
Polar emission in the IR

Hoenig et al. (2013)

VLTI: significant mid-IR emission from polar region
(Raban+09, Hoenig+12,13, Burtscher+13, Tristram+14, Lopez-Gonzaga+16, Leftley+18)

See also talks by D. Asmus, M. Stalevski; Poster by J. Leftley
Polar emission in the IR

VISIR images of local AGN

Asmus, Honig, Gandhi (2016)
Polar emission in the IR

Stalevski, Asmus & Tristram (2017, 2019); see talks by D. Asmus, M. Stalevski; Poster by J. Lyu.
Balokovic et al. (2018); See talks by M. Balokovic, J. Buchner, N. Osorio-Clavijo; Poster by T. Kawamuro
Reprocessed radiation: spectral models and radiation transport.

*MyTORUS* (Murphy & Yaqoob 2009)

*BNTorus* (Brightman et al. 2011), *Borus* (Balokovic et al. 2017); Ikeda et al. (2009)

See talks by M. Balokovic, M. Elvis; Posters by A. Tanimoto, D. Esparza Arredondo
Reprocessed radiation: spectral models

Liu & Li (2014)  
Furui et al. (2016)

See talks by M. Balokovic, M. Elvis; Posters by A. Tanimoto, D. Esparza Arredondo
Reprocessed radiation: simulation platforms

**MONACO (Geant4)**

Odaka et al. (2011)

**RefleX**

Paltani & Ricci (2017)

Liu et al. (in prep.)
Reprocessed radiation: simulation platforms

Ricci et al. (in prep.); see also Odaka et al. (2016)
See talk by C. Andonie
2 — X-ray absorption
More than 20 AGN (e.g., Risaliti+05, Bianchi+09, Marinucci+13, Miniutti+14, Rivers+15, Burtscher+15, Ricci+16b); See talk by S. Lamassa
Obscuration variability

Broad-line regions clouds?

\[ N_H \sim 10^{23} \text{ cm}^{-2} \]
\[ N_H \sim 3 \times 10^{22} \text{ cm}^{-2} \]
\[ L_{\text{tail}} > 2 \times 10^{13} \text{ cm} \]
\[ \theta < 1.2^\circ \]

Maiolino et al. (2010)

See talk by S. Lamassa, E. Sturm, M. R. Stock, A. Laor, T. Waters
Obscuration variability

NGC 1068

Marinucci et al. (2016); See talk by A. Zaino
Obscuration variability

Markowitz et al. (2014)
The sky seen from the SMBH

Optical depth in the V band

Stalevski et al. (2012); See talk by R. Nikutta, ; Poster by E. Lopez-Rodriguez
X-ray Surveys

Koss et al. (2017)
Obscured AGN in the hard X-ray band

Fraction of escaping flux

Ricci et al. (2015)

$\log N_H \ (\text{cm}^{-2})$

14-195 keV

90%
Obscured AGN in the hard X-ray band

Fraction of escaping flux vs. $\log N_H$ (cm$^{-2}$)

90% of the escaping flux

2-10 keV

14-195 keV

Ricci et al. (2015)
Obscured AGN in the hard X-ray band

Treister et al. (2009)
Obscured AGN in the hard X-ray band

Swift/BAT
(14-195 keV)

NuSTAR
(3-80 keV)
Obscured AGN in the hard X-ray band

NGC 5643

$N_H > 5 \times 10^{24} \, \text{cm}^{-2}$

IC 3639

Boorman et al. (2016)

Annuar et al. (2015)
The Covering factor of gas and dust

Annuar et al. (in prep.),
The Covering factor of gas and dust

Ramos Almeida & Ricci, Nature Astronomy 2017, see also Ricci et al. (2015); talks by P. Boorman, K. Ichikawa, S. Mateos, L. Lanz
see also Ueda et al. (2003, 2011), LaFranca+05, Sazonov+07, Hasinger 08, DellaCeca+08, Beckmann+09, Brightman+11, Merloni+14, Buchner+15, Aird+15, Sazonov+16, Georgakakis+17, Mateos+17, Ricci+17

See talks by C. Ramos Almeida, K. Ichikawa, S. Mateos, L. Lanz
Obscuration vs Eddington ratio

\begin{align*}
\text{Fraction of obscured sources} &\quad 1.0 \\
\log \lambda_{\text{Edd}} &\quad -5 \quad -4 \quad -3 \quad -2 \quad -1 \quad 0 \\
\lambda_{\text{Edd}}^\text{eff} (10^{22} \text{cm}^{-2}) &\quad \text{Expected Eddington limit for dusty gas}
\end{align*}

\text{Ricci et al. (2017c, Nature)}
Radiation-regulated unification

Low Eddington Ratio

$(10^{-4} < \lambda_{Edd} < 10^{-1.5})$

Covering factor $\sim 85\%$

Ricci et al. (2017c, Nature)
Radiation-regulated unification

Low Eddington Ratio
\( (10^{-4} < \lambda_{\text{Edd}} < 10^{-1.5}) \)
Covering factor \( \sim 85\% \)

High Eddington Ratio
\( (10^{-1.5} < \lambda_{\text{Edd}} < 1) \)
Covering factor \( \sim 40\% + \) outflows

Ricci et al. (2017c, Nature)
AGN unification

Inclination

θ

Unobscured
(broad & narrow lines)

Obscured
(narrow lines)
Radiation-regulated unification

- Inclination
- Eddington ratio
- Absorption in the X-rays
- Radiation-regulated unification

Graph showing the relationship between inclination and covering factor with Eddington ratio, with regions for unobscured, Compton-thin obscuration, and Compton-thick obscuration.
Galaxy mergers and obscuration

Blecha et al. (2018)
Galaxy mergers and obscuration

Ricci et al. (2017b)

See also Kocevski et al. (2015), Lanzuisi et al. (2015), Lansbury et al. (2017b), Del Moro et al. (2016), Koss et al. (2016), De Rosa et al. (2018), Koss et al. (2018); Talks by R. Pfeifle, E. Treister, C. Carroll
Isolated galaxies

Late stages of merger

From the NASA press release; Credits: NAOJ/NASA/CXC/M. Weiss (Imanishi et al. 2006)
The drivers of obscuration

- Inclination
- Eddington ratio
- Merger stage

- Unobsured
- Compton-thin obscuration
- Compton-thick obscuration

Covering factor
• X-rays are a great probe of the circumnuclear environment of AGN
• Studies of reprocessed X-ray radiation have shown elongated emission
• More and more complex X-ray spectral models are being developed
• Absorption variability show a dynamic environment
• Hard X-ray surveys have allowed to infer the typical covering factor of local AGN
• Covering factor depends on the Eddington ratio
• Probability of observing obscured AGN is very high in close mergers
AGN in Santiago

www.agnsantiago.cl
BACK UP SLIDES
The BAT AGN Spectroscopic Survey (BASS)

X-ray spectroscopy (Ricci et al. 2017d)

Optical spectroscopy (Koss et al. 2017)

Talk by M. Koss
Intrinsic column density distribution

Fraction of $\log N_H = 24-25$ AGN: 27±4%

Ricci et al. (2015)
Covering factor of gas and dust

1) Fraction of obscured AGN
   (e.g., Ueda+03,11, Brightman+11,
   Merloni+14, Buchner+15, Aird+15)

2) Spectroscopy with torus models
   (e.g., Brightman+15, Balokovic+ prep.)
Covering factor of gas and dust

**X-rays**

1) Fraction of obscured AGN
   (e.g., Ueda+03,11, Brightman+11, Merloni+14, Buchner+15, Aird+15)

2) Spectroscopy with torus models
   (e.g., Brightman+15, Balokovic+ prep.)

**Infrared**

1) $L_{IR}/L_{Bol}$
   (e.g., Maiolino+07, Treister+08, Assef+13, Mateos+16, Ichikawa+17)

2) Spectroscopy with torus models
   (e.g., Alonso Herrero+11, Ramos Almeida+11)
Radiation pressure on dusty gas

Effective Eddington limit

\[ \lambda_{Edd}^{\text{eff}} = \frac{\sigma_T}{\sigma_i(N_H; \xi)} \]

see also Fabian+08; Fabian+09; Raimundo+10; Vasudevan+13, Ishibashi+18
Effective Eddington limit \( \lambda_{Edd}^\text{eff} = \sigma_T / \sigma_i(N_H; \xi) \)

Ricci et al. (2017c, Nature)
Radiation pressure on dusty gas

Effective Eddington limit

\[ \lambda_{\text{Edd}}^{\text{eff}} = \frac{\sigma_T}{\sigma_i(N_H; \xi)} \]

Baer et al. (2018 in prep.)
The covering factor of dust

Covering factor from $L_{\text{IR}}/L_{\text{Bol}}$; $\sim$360 BASS AGN

Ricci et al. (2018, in prep.); see also Ezhikode et al. (2017), Zhuang et al. (2018)
Luminosity dependence of obscuration - IR

Stalevski et al. (2016)

see also Maiolino et al. (2007), Treister et al. (2008), Assef et al. (2013), Ichikawa et al. (2017), talk by S. Mateos
Obscured AGN tend to reside in denser environments than unobscured AGN.
Galaxy mergers and obscuration

See also Lanzuisi et al. (2015), Lansbury et al. (2017b), Del Moro et al. (2016), Koss et al. (2016), De Rosa et al. (2018), Koss et al. (2018, submitted)
Obscuration properties of mergers
Obscuration properties of mergers

Fraction of CT AGN (%)
The Iwasawa-Taniguchi effect


Shu et al. (2010), see P. Boorman’s talk
X-ray studies of obscured AGN: the future

Talk by M. Salvato
X-ray studies of obscured AGN: the future