Reflection and Reprocessing in Swift/BAT AGN: Evidence for a Broad Range of Covering Fractions?

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arXiv:1811:02570
What is the Distribution of AGN Covering Fractions?

Common, typical covering fraction

Large variety of covering fraction

Credit: Peter Boorman

Credit: Martin Ward

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Investigating Covering Fractions with Swift/BAT AGN

Herschel Observed Sample
313 Swift/BAT AGN at z<0.05
- PACS (Meléndez et al. 2014)
- SPIRE (Shimizu et al. 2016)
- Herschel + WISE SEDs (Shimizu et al. 2017)
Investigating Covering Fractions with Swift/BAT AGN

Herschel Observed Sample
313 Swift/BAT AGN at z<0.05
PACS (Meléndez et al. 2014)
SPIRE (Shimizu et al. 2016)
Herschel + WISE SEDs (Shimizu et al. 2017)

NuSTAR Observed Sample
95 Swift/BAT Sy2 at z<0.05
(Baloković et al. 2018)
Phenomenological Modeling

69 Obscured AGN with both

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Investigating Covering Fractions with Swift/BAT AGN

69 Obscured AGN with both

Herschel Observed Sample
AGN IR Luminosity

NuSTAR Observed Sample
Observed, Intrinsic, and Reflected X-ray Luminosities
Reprocessing across the Wavelengths

Correlation analysis using ASURV survival analysis code (Lavallely et al. 1992, Isobe et al. 1986)

Bootstrapping to determine reliability of correlation.

IDL ASURV bootstrapping code available at: https://github.com/lalanz/bootstrap_asurv

\[ \rho = 0.47 \pm 0.10 \]
\[ \log(p) = -4.0 \pm 1.4 \]

\[ \rho = 0.61 \pm 0.08 \]
\[ \log(p) = -6.3 \pm 1.5 \]
Reprocessing across the Wavelengths

X-ray Reflection

Reprocessed IR

Credit: Claudio Ricci
Reprocessing across the Wavelengths

Expected IR(X) relation from Chen et al. (2017)
Modeling Observables for Covering Fractions

ALL AGN

Covering Fraction

0.2  0.4  0.6  0.8
Modeling Observables for Covering Fractions

ALL AGN

Obscured

0.2  0.4  0.6  0.8
Covering Fraction

4995
Modeling Observables for Covering Fractions

\[ f_{\text{cov}} \rightarrow R_{\text{pex}} \rightarrow \text{IR Excess} \]

ALL AGN

<table>
<thead>
<tr>
<th>Covering Fraction</th>
<th>ALL AGN</th>
<th>Obscured</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>4995</td>
<td>10000</td>
</tr>
<tr>
<td>0.4</td>
<td>9995</td>
<td>13000</td>
</tr>
<tr>
<td>0.6</td>
<td>9995</td>
<td>13000</td>
</tr>
<tr>
<td>0.8</td>
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<td>13000</td>
</tr>
</tbody>
</table>

Log(IR Excess) vs. Log(Pex/f Reflection Parameter)
Modeling Observables for Covering Fractions

ALL AGN Obscured

0.2 0.4 0.6 0.8
Covering Fraction

Log(IR Excess)

Log(Pexrav Ref.)

Log(IR Excess)
Testing Covering Fractions Distributions

Two-dimensional Kolmogorov-Smirnov (K-S) Test

Peacock 1983; Goulding et al. 2014

Log(Probability) = -2.85±1.06
Testing Covering Fractions Distributions

20 FWHM x 21 $<f_{\text{Cov}}>$ + Uniform = 421 models
Testing Covering Fractions Distributions
Testing Covering Fractions Distributions

![Graph showing covering fraction distributions with color legend indicating inconsistency with null hypothesis.]

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Covering Fractions Distributions

(h) 

(i) 

(g) 

(j) 

Median (Log(KS Prob.))

Consistent with Null Hypothesis

Possibly Consistent with Null Hypothesis

Inconsistent with Null Hypothesis

Mean Covering Fraction

Cov. Fraction Distribution FWHM
Covering Fractions Distributions

(g) Mean Covering Fraction

(h) FWHM Distribution

(i) Uniform Distribution

Median(Log(KS Prob.))
Testing Covering Fractions Distributions

(h) Inconsistent with Null Hypothesis

(i) Possibly Consistent with Null Hypothesis

(g) Consistent with Null Hypothesis

Median(Log(KS Prob.))

Mean Covering Fraction

All AGN
Type 2 AGN

2067
7994
Comparing Covering Fractions Distributions

X-ray Absorption Properties of Large Samples $\rightarrow$ $\sim 70\%$ Obscured

e.g., Ramos Almeida & Ricci 2017
Ricci et al. 2015

IR Clumpy Torus Modeling $\rightarrow$ Broad Distributions

e.g., Mateos et al. 2016,
Ichikawa et al. 2015,
Alonso-Herrero et al. 2011
Ramos Almeida et al. 2011
Summary

• Reflected X-ray luminosity and IR AGN luminosity are correlated \( \rightarrow \) a common (or related) re-processor.

• Simple empirical model to identify distributions of covering fraction that reproduce this relation

• Broad distributions best match observations


Stat. codes: https://github.com/lalanz/bootstrap_asurv