The coronal parameters of local Seyfert galaxies

Andrea Marinucci
(Roma Tre)

on behalf of the
NuSTAR AGN Physics WG

The Extremes of Black Hole Accretion
European Space Astronomy Centre (ESAC)
June 8, 2015
Overview

• Brief introduction on high-energy cutoff measurements
  • Nearby AGN seen by NuSTAR
  • Results
• Conclusions and future perspectives
• Brief introduction on high-energy cutoff measurements

• Nearby AGN seen by NuSTAR

• Results

• Conclusions and future perspectives
Introduction

One of the main open problem for AGN is the nature of the primary X-ray emission.

It is due to Comptonization of soft photons, but the geometry, optical depth and temperature of the emitting corona are largely unknown.

Most popular models imply $E_{\text{cut}} = 2-3 \times kT_e$, so measuring $E_{\text{cut}}$ helps constraining Comptonization models.
Introduction

Since the primary X-ray radiation illuminates the disc and is partly reflected towards the observer's line of sight it is fundamental to properly take it into account: Xillver (Garcia+13), Kyreflionx (see Svoboda's poster).
Introduction

So far, we have only a handful of results based on non focusing, and therefore strongly background-dominated, satellites (BeppoSAX-PDS, Suzaku HXD-PIN, INTEGRAL, Swift-BAT)

Perola et al., 2002

De Rosa et al., 2012; Molina et al., 2013
• Brief introduction on high-energy cutoff measurements

• Nearby AGN seen by NuSTAR

• Results

• Conclusions and future perspectives
Nearby AGN seen by NuSTAR

<table>
<thead>
<tr>
<th>Source</th>
<th>$z$</th>
<th>$\log(M) \quad [M_\odot]$</th>
<th>$r_{co} \quad [r_G]$</th>
<th>$F_x$</th>
<th>$E_{cut} \quad [\text{keV}]$</th>
<th>$\Gamma$</th>
<th>$\Theta$</th>
<th>$\ell$</th>
<th>Data</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 5506</td>
<td>0.006</td>
<td>$8 \pm 1$</td>
<td>10</td>
<td>2.9</td>
<td>$720^{+130}_{-190}$</td>
<td>$1.91^{+0.03}_{-0.03}$</td>
<td>$0.71^{+0.13}_{-0.06}$</td>
<td>$4^{+33}_{-3}$</td>
<td>SWIFT/NU</td>
<td>1 – 2</td>
</tr>
<tr>
<td>NGC 7213</td>
<td>0.006</td>
<td>$7.98^{+0.22}_{-0.24}$</td>
<td>10</td>
<td>0.71</td>
<td>$&gt; 240$</td>
<td>$1.84^{+0.03}_{-0.02}$</td>
<td>$&gt; 0.05$</td>
<td>$1.0^{+0.7}_{-0.4}$</td>
<td>NU</td>
<td>3 – 4</td>
</tr>
<tr>
<td>MCG-6-30-15</td>
<td>0.008</td>
<td>$6.7 \pm 0.7$</td>
<td>2.9</td>
<td>8.2</td>
<td>$&gt; 110$</td>
<td>$2.06^{+0.05}_{-0.05}$</td>
<td>$&gt; 0.04$</td>
<td>$258^{+232}_{-232}$</td>
<td>XMM/NU</td>
<td>5 – 6</td>
</tr>
<tr>
<td>NGC 2110</td>
<td>0.008</td>
<td>$8.3 \pm 1$</td>
<td>10</td>
<td>8.9</td>
<td>$&gt; 210$</td>
<td>$1.64^{+0.03}_{-0.03}$</td>
<td>$&gt; 0.07$</td>
<td>$10^{+89}_{-89}$</td>
<td>SWIFT/NU</td>
<td>7 – 8</td>
</tr>
<tr>
<td>MCG 5-23-16</td>
<td>0.009</td>
<td>$7.85 \pm 1$</td>
<td>10</td>
<td>4.2</td>
<td>$116^{+6}_{-5}$</td>
<td>$1.85^{+0.01}_{-0.01}$</td>
<td>$0.11^{+0.01}_{-0.04}$</td>
<td>$15^{+136}_{-14}$</td>
<td>NU</td>
<td>9 – 11</td>
</tr>
<tr>
<td>SWIFT J2127.4+5654</td>
<td>0.014</td>
<td>$7.18 \pm 1$</td>
<td>13</td>
<td>1.1</td>
<td>$108^{+11}_{-10}$</td>
<td>$2.08^{+0.01}_{-0.01}$</td>
<td>$0.11^{+0.01}_{-0.04}$</td>
<td>$34^{+308}_{-31}$</td>
<td>XMM/NU</td>
<td>12 – 13</td>
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<tr>
<td>IC 4329A</td>
<td>0.016</td>
<td>$8.1 \pm 1$</td>
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<td>4.9</td>
<td>$186^{+14}_{-14}$</td>
<td>$1.87^{+0.01}_{-0.01}$</td>
<td>$0.18^{+0.01}_{-0.04}$</td>
<td>$41^{+365}_{-37}$</td>
<td>SU/NU</td>
<td>14 – 15</td>
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<tr>
<td>NGC 5548</td>
<td>0.018</td>
<td>$7.59^{+0.24}_{-0.21}$</td>
<td>4.5</td>
<td>1.3</td>
<td>$70^{+40}_{-10}$</td>
<td>$1.49^{+0.05}_{-0.05}$</td>
<td>$0.07^{+0.03}_{-0.03}$</td>
<td>$88^{+35}_{-37}$</td>
<td>XMM/NU</td>
<td>15 – 17</td>
</tr>
<tr>
<td>Mrk 335</td>
<td>0.026</td>
<td>$7.42^{+0.12}_{-0.16}$</td>
<td>3</td>
<td>0.10</td>
<td>$&gt; 174$</td>
<td>$2.14^{+0.02}_{-0.02}$</td>
<td>$&gt; 0.06$</td>
<td>$36^{+19}_{-19}$</td>
<td>SWIFT/NU</td>
<td>18 – 19</td>
</tr>
<tr>
<td>Ark 120</td>
<td>0.033</td>
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<td>4.4</td>
<td>0.55</td>
<td>$&gt; 68$</td>
<td>$1.73^{+0.02}_{-0.02}$</td>
<td>$&gt; 0.06$</td>
<td>$4^{+1}_{-1}$</td>
<td>XMM/NU</td>
<td>20 – 21</td>
</tr>
<tr>
<td>1H0707-495</td>
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<td>$6.31 \pm 1$</td>
<td>2</td>
<td>0.14</td>
<td>$&gt; 63$</td>
<td>$3.2^{+0.2}_{-0.2}$</td>
<td>$&gt; 0.02$</td>
<td>$358^{+3219}_{-322}$</td>
<td>SWIFT/NU</td>
<td>22 – 23</td>
</tr>
<tr>
<td>Fairall 9</td>
<td>0.047</td>
<td>$8.41^{+0.11}_{-0.09}$</td>
<td>2</td>
<td>0.87</td>
<td>$&gt; 242$</td>
<td>$1.96^{+0.02}_{-0.02}$</td>
<td>$&gt; 0.08$</td>
<td>$12^{+3}_{-1}$</td>
<td>XMM/NU</td>
<td>20 – 24</td>
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<tr>
<td>3C390.3</td>
<td>0.056</td>
<td>$9.40^{+0.05}_{-0.06}$</td>
<td>10</td>
<td>1.6</td>
<td>$116^{+24}_{-18}$</td>
<td>$1.70^{+0.02}_{-0.02}$</td>
<td>$0.11^{+0.02}_{-0.02}$</td>
<td>$18^{+3}_{-3}$</td>
<td>SU/NU</td>
<td>25 – 26</td>
</tr>
<tr>
<td>Cyg A</td>
<td>0.056</td>
<td>$9.40^{+0.11}_{-0.11}$</td>
<td>10</td>
<td>1.1</td>
<td>$&gt; 110$</td>
<td>$1.47^{+0.06}_{-0.06}$</td>
<td>$&gt; 0.04$</td>
<td>$6^{+2}_{-2}$</td>
<td>NU</td>
<td>27 – 28</td>
</tr>
<tr>
<td>3C382</td>
<td>0.058</td>
<td>$9.2 \pm 0.5$</td>
<td>10</td>
<td>1.4</td>
<td>$214^{+167}_{-147}$</td>
<td>$1.68^{+0.03}_{-0.03}$</td>
<td>$0.21^{+0.14}_{-0.11}$</td>
<td>$12^{+25}_{-8}$</td>
<td>SWIFT/NU</td>
<td>29 – 30</td>
</tr>
</tbody>
</table>

$F_x$ is the $0.1-200 \text{ keV}$ X-ray flux in $10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$.


Fabian+15
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Swift J2127.4+5654

NLS1 with a relativistically broadened Fe Kα emission line \((a=0.6\pm0.2)\), a steep continuum \((\Gamma=2-2.4)\), \(E_c=30-90\) keV, \(L_{bol}/L_{Edd}\sim0.18\) (Miniutti+09, Malizia+08, Panessa+11, Sanfrutos+13)

It was observed simultaneously with XMM-Newton for \(~300\) ks and both a strong Compton Hump and a broad Fe Kα line are present.
When a model composed of a primary continuum, relativistic and distant reflection components is applied to the data the only residuals are above ~25 keV
When a model composed of a primary continuum, relativistic and distant reflection components is applied to the data the only residuals are above ~25 keV.

The inclusion of relxill model (Garcia & Dauser +14) allows us to measure a cutoff energy $E_c = 108 \pm 10$ keV and to infer the contribution of the disk to the Compton hump.
Using compTT (Titarchuk+94) with two different geometries we get:

**SLAB**

\[
\begin{align*}
    kT_e &= 68^{+37}_{-32} \text{ keV} \\
    \tau &= 0.35^{+0.35}_{-0.19}
\end{align*}
\]

**SPHERE**

\[
\begin{align*}
    kT_e &= 53^{+28}_{-26} \text{ keV} \\
    \tau &= 1.35^{+1.03}_{-0.67}
\end{align*}
\]
Balokovic+15

- absorbed power law
- reflection, no cutoff
- reflection, with cutoff
- compTT, sphere (×1.1)
- compTT, slab (×0.9)
MCG-05-23-16

Balokovic et al. 2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{FPMB}$</td>
<td>1.032 ± 0.002</td>
<td>1.045 ± 0.005</td>
</tr>
<tr>
<td>$E_{line1}$</td>
<td>6.43 ± 0.05</td>
<td>6.5$^{+0.2}_{-0.1}$</td>
</tr>
<tr>
<td>$\sigma_{line1}$</td>
<td>0.46 ± 0.06</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>EW$_{line1}$</td>
<td>80 ± 10</td>
<td>80 ± 20</td>
</tr>
<tr>
<td>EW$_{line2}$</td>
<td>40 ± 10</td>
<td>50 ± 20</td>
</tr>
</tbody>
</table>

**Phenomenological continuum model: pexrav**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$</td>
<td>1163</td>
<td>687</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>1.85 ± 0.01</td>
<td>1.83 ± 0.02</td>
</tr>
<tr>
<td>$R$</td>
<td>0.87 ± 0.04</td>
<td>1.1 ± 0.1</td>
</tr>
<tr>
<td>$E_{cut}$</td>
<td>$116^{+6}_{-5}$</td>
<td>$119^{+16}_{-13}$</td>
</tr>
</tbody>
</table>

**Comptonized continuum model: refl(compTT)**

<table>
<thead>
<tr>
<th>Assumed geometry: slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$</td>
</tr>
<tr>
<td>$R$</td>
</tr>
<tr>
<td>$kT_e$</td>
</tr>
<tr>
<td>$\tau_e$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumed geometry: sphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$</td>
</tr>
<tr>
<td>$R$</td>
</tr>
<tr>
<td>$kT_e$</td>
</tr>
<tr>
<td>$\tau_e$</td>
</tr>
</tbody>
</table>
High values/lower limits

In other bright sources, high values or lower limits to the cutoff energy have been found, suggesting the presence of a very hot corona surrounding the accretion disc.

NGC 5506  
Matt+2015

NGC 2110  
Marinucci+2015

NGC 7213  
Ursini+subm., see Tortosa's poster

The next step is to build a small catalog and to start looking for correlations between the coronal temperature and other physical properties (e.g. black hole mass, accretion rate).
A larger view

\begin{center}
\begin{tabular}{c}
\begin{tabular}{c}
\textbf{NuSTAR} \\
\includegraphics[width=0.5\textwidth]{nustar.png}
\end{tabular} \\
\textbf{INTEGRAL} \\
\includegraphics[width=0.5\textwidth]{integral.png}
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{c}
\begin{tabular}{c}
\textbf{Swift-BAT} \\
\includegraphics[width=0.5\textwidth]{swift.png}
\end{tabular} \\
\textbf{ALL} \\
\includegraphics[width=0.5\textwidth]{all.png}
\end{tabular}
\end{center}

\textbf{Fabian+15}
A larger view

NuSTAR

INTEGRAL

Swift-BAT

ALL

Fabian+15

Tortosa et al., in prep.
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Conclusions

• High energy cut-off have been measured in a number of AGN with NuSTAR (more are yet to come!)
  • They are not ubiquitous

• The hard X-ray band (3-80 keV) is fundamental for testing and discriminating between different Comptonization models

• Further observations will help us in understanding the nature of the primary continuum, such as the relation between the accretion rate and the cutoff energy and the link between the disc reflection and the extension of the hot corona.