NuSTAR spectral analysis of the two bright Seyfert 1 galaxies: MCG 8-11-11 and NGC 6814

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From the Dolomites to the event horizon: sledging down the black hole potential well.

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**Overview**

**MCG +8-11-11**

\[ z = 0.0204 \]
\[ \log \left( \frac{M_{BH}}{M_\odot} \right) = 8.07 \pm 0.02 \]
\[ F_{2-10\text{keV}} = 5.62 \times 10^{-11} \text{ergcm}^{-2}\text{s}^{-1} \]
\[ F_{20-100\text{keV}} = 8.46 \times 10^{-11} \text{ergcm}^{-2}\text{s}^{-1} \]

Suzaku + Swift BAT (Bianchi et al., 2010; Mantovani et al., 2016): relativistic FeKα line + narrow component with no associated reflection component + Fe XXVI line emission;

ASCA and OSSE (Grandi 1998): absorbed power law, \( \Gamma=1.73 \) & \( E_c\sim250 \text{ keV} \) + reflection component + cold iron line;

BeppoSAX (Perola 2000): \( \Gamma=1.84 \pm 0.05 \) & \( E_c=169^{+318}_{-78} \) keV;

XMM-Newton (Matt et al., 2006): lack of a soft excess + a large reflection component + narrow iron line + Fe XXVI line emission.

**NGC 6814**

\[ z = 0.0052 \]
\[ \log \left( \frac{M_{BH}}{M_\odot} \right) = 6.99^{+0.32}_{-0.25} \]
\[ F_{2-10\text{keV}} = 0.17 \times 10^{-11} \text{ergcm}^{-2}\text{s}^{-1} \]
\[ F_{20-100\text{keV}} = 5.66 \times 10^{-11} \text{ergcm}^{-2}\text{s}^{-1} \]

INTEGRAL (Malizia et al., 2014): quite flat spectrum \( \Gamma=1.68 \) & \( E_c\sim190 \text{ keV} \);

XMM-Newton (Ricci et al., 2014): FeKα line with EW\~{}84 eV;

Suzaku (Walton et al., 2013): no soft excess, fairly hard photon index \( \Gamma=1.53 \), variability.
• Why? To investigate the Comptonization mechanisms acting in the innermost regions of AGN and which are believed to be responsible for the X-ray emission;
• NuSTAR (Nuclear Spectroscopic Telescopic Array) works in the band 3 - 79 keV;
• First focusing hard X-ray (10-79 keV) telescope in orbit;
• ~100 times more sensitive in the 10-79 keV band than any previous mission working in this band;
AGN in X-Rays

**X-RAYS EMISSION:**

In AGN the primary X-ray emission is due to Inverse Compton by electrons in a hot corona of the UV/soft X-ray disc photons.

**PRIMARY POWER-LAW:**

- Power-law with photon index and cutoff energy directly related to the temperature and to the optical depth of the coronal plasma.
- Most popular Comptonization models imply: $E_c = 2-3 \times kT_e$

**REPROCESSED EMISSION:**

Typical X-ray features of the reflection by cold circumnuclear material include intense Fe Kα line $\approx 6.4$ keV and the associated Compton reflection continuum peaking $\approx 30$ keV.
Both sources show variability in their light curves but since no significant spectral variation is found in the ratio between the 10-80 and 3-10 keV count rates we used **time-averaged spectra** in our analysis.
• Primary X-ray emission;
• Relativistic disk reflection;
• Cold, distant reflection;
• Narrow Fe XXVI line
• @ 6.966 keV (MCG +8-11-11)
Spectral Parameters

MCG +8-11-11

\[ \Gamma = 1.77 \pm 0.04 \]
\[ E_c = 175^{+110}_{-50} \text{ keV} \]
\[ R^{\text{refl}} = 0.25 \pm 0.12 \]

NGC 6814

\[ \Gamma = 1.71^{+0.04}_{-0.03} \]
\[ E_c = 155^{+70}_{-35} \text{ keV} \]
\[ R^{\text{refl}} = 0.27^{+0.10}_{-0.12} \]
Spectral Parameters

**MCG +8-11-11**

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**NGC 6814**

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\[ E_c = 155^{+70}_{-35} \text{ keV} \]
\[ R^{\text{refl}} = 0.27^{+0.10}_{-0.12} \]

* Relativistic FeKα line with the associated reflection component, moderately broad;
* Cutoff energy measurement;
* Narrow component of the FeKα line due to a large iron overabundance, or alternatively produced in distant Compton thin material;
Spectral Parameters

MCG +8-11-11

NGC 6814

E_{c} (keV) vs. Γ for MCG +8-11-11 and NGC 6814, showing contours at 68%, 90%, and 99% confidence levels.
The coronal temperature is expected to be related to the cutoff energy by $E_c = 2-3 \times kT_e$ (Petrucci 2000, 2001).

**CompTT** (Titarchuk et al., 1994) convolved with the **REFLECT** model in XSPEC (reflection from neutral material according to the method of Magdziarz & Zdziarski, 1995)

**MCG +8-11-11**

- $kT = 170^{+150}_{-70} \text{ keV}$
- $\tau = 0.17 \pm 0.1$

**NGC 6814**

- $kT = 165^{+100}_{-50} \text{ keV}$
- $\tau = 0.2^{+0.30}_{-0.15}$

**SLAB**

**SPHERE**

- $kT = 150^{+80}_{-70} \text{ keV}$
- $\tau = 0.7^{+0.7}_{-0.3}$

- $kT = 110^{+100}_{-70} \text{ keV}$
- $\tau = 1.1^{+0.3}_{-0.8}$
\( \Theta \) electron temperature normalized to the electron rest energy

\[ \Theta_e = \frac{kT_e}{m_e c^2} \]

\( \ell \) the dimensionless compactness parameter

\[ \ell = \frac{L}{R} \frac{\sigma_T}{m_e c^3} \]

Summary of the theoretical understanding of the \( \Theta-\ell \) plane.

\( \Theta-\ell \) distribution for \textit{NuSTAR} observed AGN (blue points) and BHB (red points)
\( \Theta \) electron temperature normalized to the electron rest energy

\[
\Theta_e = \frac{kT_e}{m_e c^2}
\]

\( \ell \) the dimensionless compactness parameter

\[
\ell = \frac{L \sigma_T}{R m_e c^3}
\]

Summary of the theoretical understanding of the plane.

Extrapolated 0.1-200 keV Luminosity of the power-law component
\[ \Theta_e = \frac{kT_e}{m_e c^2} \]

\[ \ell = \frac{L}{R} \frac{\sigma_T}{m_e c^3} \]

Summary of the theoretical understanding of the \( \Theta-\ell \) plane.

Radius of the spherical corona. We assume \( R = 10R_g \)
Summary of the theoretical understanding of the $\Theta$-$\ell$ plane.

- **MCG +8-11-11**
  \[
  \Theta_e = 0.28^{+0.28}_{-0.11}, \quad \ell = 27 \pm 12(R_{10})^{-1}
  \]

- **NGC 6814**
  \[
  \Theta_e = 0.22^{+0.15}_{-0.12}, \quad \ell = 14.5 \pm 4.5(R_{10})^{-1}
  \]

$\Theta$-$\ell$ distribution for *NuSTAR* observed AGN (blue points) and BHB (red points).
Looking for correlations

Unobscured nearby Seyfert Galaxies observed by *NuSTAR*

| Source      | $\Gamma$  | $E_c$ [keV] | log($M_{bh}/M_\odot$) | $L_{bol}/L_{Edd}$ | $L_{2-10keV} \times 10^{44}$ ergs s$^{-1}$ | Ref.
|-------------|-----------|-------------|---------------------|-------------------|------------------------------------------|------
| NGC 5506    | 1.91 ± 0.03 | 720$^{+130}_{-190}$ | 8.0 ± 0.2 | 6.21 × 10$^{-3}$ | 0.0526 | 1 - 2
| MCG 5-23-16  | 1.85 ± 0.01 | 166$^{+66}_{-5}$ | 7.2 ± 0.2 | 3.73 × 10$^{-2}$ | 0.166 | 3 - 4
| SWIFT J2127.4+5654 | 2.08 ± 0.01 | 108$^{+11}_{-10}$ | 7.2 ± 0.2 | 1.02 × 10$^{-1}$ | 0.133 | 5 - 6
| IC4392A     | 1.73 ± 0.01 | 184 ± 14 | 8.2 ± 0.1 | 9.8 × 10$^{-2}$ | 0.626 | 7 - 8
| 3C390.3     | 1.70 ± 0.01 | 116$^{+24}_{-25}$ | 9.04 ± 0.4 | 5.17 × 10$^{-2}$ | 1.8 | 9 - 10
| 3C 382      | 1.68$^{+0.03}_{-0.02}$ | 214$^{+14}_{-7}$ | 7.7 ± 0.5 | 5.06 × 10$^{-2}$ | 2.3 | 11 - 12
| GRS 1734-292 | 1.65 ± 0.05 | 53$^{+11}_{-8}$ | 8.5 ± 0.1 | 3.3 × 10$^{-2}$ | 0.056 | 13
| NGC 6814    | 1.71$^{+0.04}_{-0.03}$ | 135$^{+70}_{-35}$ | 7.2 ± 0.05 | 1.22 × 10$^{-2}$ | 0.0204 | 9 - 14
| MCG +8-11-11 | 1.77 ± 0.04 | 175$^{+40}_{-35}$ | 8.07 ± 0.02 | 9.59 × 10$^{-2}$ | 0.513 | 14 - 15
| Ark 564     | 2.27 ± 0.08 | 42 ± 3 | 6.4 ± 0.5 | 1.1 | 0.39 | 16 - 17
| PG 1247+267 | 2.35$^{+0.09}_{-0.08}$ | 89$^{+134}_{-34}$ | 8.3$^{+0.17}_{-0.15}$ | 1.16 × 10$^{-2}$ | 0.15 | 18 - 19
| NGC 7213    | 1.84 ± 0.03 | > 140 | 8.0 ± 0.2 | 1.03 × 10$^{-3}$ | 0.012 | 20 - 21
| MCG 6-30-15  | 2.06 ± 0.01 | > 110 | 6.2 ± 0.1 | 1.20 × 10$^{-1}$ | 0.02 | 22 - 23
| NGC 2110    | 1.65 ± 0.03 | > 210 | 8.3 ± 0.2 | 9.78 × 10$^{-5}$ | 0.004 | 24 - 25
| Mrk 335     | 2.14$^{+0.02}_{-0.04}$ | > 174 | 7.1 ± 0.01 | 2.32 × 10$^{-1}$ | 0.18 | 26 - 27
| Ark 120     | 1.73 ± 0.02 | > 190 | 8.2 ± 0.1 | 1.25 × 10$^{-1}$ | 0.56 | 26 - 28
| Fairall 9   | 1.96$^{+0.01}_{-0.02}$ | > 242 | 6.8 ± 0.02 | 7.57 × 10$^{-2}$ | 0.77 | 26 - 29
| Mrk766      | 2.22$^{+0.02}_{-0.03}$ | > 441 | 6.8$^{+0.05}_{-0.06}$ | 8.34 × 10$^{-2}$ | 0.046 | 30 - 31
| PG1211+143  | 2.51 ± 0.02 | > 124 | 8.16$^{+0.11}_{-0.16}$ | 4.76 × 10$^{-2}$ | 0.35 | 26 - 32

Looking for correlations

**Photon Index**

**Eddington ratio**
Looking for correlations

Fitting only the sources with cutoff measurements, with a simple linear relation:

**Photon Index**

\[ y = a \cdot x + b \]

- \(a = -97.47 \pm 96.91\)  
- \(b = +361.69 \pm 180.19\)  
- Spearman corr -0.36  
- significance 0.28

**Eddington ratio**

\[ y = a \cdot x + b \]

- \(a = -159.63 \pm 77.29\)  
- \(b = 201.11 \pm 62.75\)  
- Spearman corr -0.25  
- significance 0.45
Looking for correlations

Fitting only the sources with cutoff measurements, with a simple linear relation:

**Photon Index**

\[
\begin{align*}
    a &= -97.47 \pm 96.91 \\
    b &= +361.69 \pm 180.19 \\
    \text{Spearman corr} &= -0.36 \\
    \text{significance} &= 0.28
\end{align*}
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**Eddington ratio**

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\begin{align*}
    a &= -159.63 \pm 77.29 \\
    b &= 201.11 \pm 62.75 \\
    \text{Spearman corr} &= -0.25 \\
    \text{significance} &= 0.45
\end{align*}
\]
Conclusion

- Cutoff measurements;
- Relativistic broadened FeKα line with disk reflection component;
- Narrow FeKα line due to a large iron overabundance, or alternatively produced in distant Compton thin material;
- Estimated Eddington ratio $\eta=0.01$ for MCG +8-11-11 and $\eta=0.09$ for NGC 6814;
- Both sources are located against the pair runaway line like most of the sources among those analyzed by Fabian et al.;
- The observation of the two sources could help to understand the physics of the corona-accretion disk system and its geometry, enriching our sample;
- Next step: fitting with the cutoff lower limits.
THANK YOU!