Black hole spin measurements with NuSTAR

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on behalf of the
NuSTAR AGN Physics WG

The 7th FERO Meeting
Finding Extreme Relativistic Objects
Krakow, 28th-30th August 2014
Outline

- Brief introduction about scientific goals
  - Radio-quiet AGN seen by NuSTAR
    - Results
    - Conclusions
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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 $E_{\text{cut}} = 2-3 kT$, so...
Light bending model: much of the flux is bent onto the disk giving a constant, strong RDC
Introduction – Relativistic reflection

Spin alters shape of Fe Kα line and Compton hump in predictable, measurable ways.
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The NuSTAR satellite

Nuclear Spectroscopic Telescope Array

1 Ms Sensitivity
3.2 x 10^{-15} \text{ erg/cm}^2/\text{s} (6 - 10 \text{ keV})
1.4 x 10^{-14} \text{ erg/cm}^2/\text{s} (10 - 30 \text{ keV})

Imaging
- HPD 58”
- FWHM 18”
- Localization 2” (1-sigma)

Spectral response
- energy range: 3-79 keV
- DE @ 6 keV: 0.4 keV FWHM
- DE @ 60 keV: 1.0 keV FWHM

Target of Opportunity
- response <24 hr
- typical 6-8 hours
- 80% sky accessibility

Harrison et al., 2013

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The NuSTAR satellite

The combination of NuSTAR high effective area and low background yields ~100x better S/N versus Suzaku HXD-PIN.

MCG-6-30-15: 125 ks net exposure time and same 15-70 keV flux ($6.5 \times 10^{-11}$ erg/cm$^2$/s).

Marinucci et al., 2014a

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# Radio-quiet AGN observed by NuSTAR

<table>
<thead>
<tr>
<th>Target</th>
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<td>130 ks</td>
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<tr>
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The soft excess in Ark 120

Most AGN show soft X-ray emission in excess of the extrapolation of the hard primary emission.

In many sources the soft excess is well explained by ionized reflection from the accretion disk (e.g. Walton et al. 2013)

However, there are sources in which another component is required (Patrick et al. 2012, Lohfink et al. 2012, Petrucci et al. 2013)

Ark 120 is one of them (Matt et al. 2014)
The soft excess in Ark 120

No obvious evidence for a relativistic Iron line (differently from a previous Suzaku observation, Nardini et al. 2011)

The broad-band best fit is with a Comptonization model for the soft excess. Optxagnf (Done et al. 2012) is a disk/corona emission model which assumes a thermal disk emission outside the coronal radius, and soft and hard Comptonization inside.
The soft excess in Ark 120

Fluxes from the Optical Monitor on board XMM-Newton support an intermediate value for the black hole spin.

<table>
<thead>
<tr>
<th></th>
<th>$a$</th>
<th>$L/L_{Edd}$</th>
<th>$R_c$ ($R_G$)</th>
<th>$kT$ (keV)</th>
<th>$\Gamma$</th>
<th>$E_c$ (keV)</th>
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<tr>
<td>0</td>
<td>0</td>
<td>0.16$^{+0.16}_{-0.08}$</td>
<td>11.5$^{+3.4}_{-3.4}$</td>
<td>0.33$^{+0.02}_{-0.02}$</td>
<td>1.73$^{+0.02}_{-0.02}$</td>
<td>$&gt;190$</td>
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<tr>
<td>0.5</td>
<td>0.50</td>
<td>0.05$^{+0.01}_{-0.01}$</td>
<td>31.3$^{+16.6}_{-16.8}$</td>
<td>0.32$^{+0.01}_{-0.01}$</td>
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<tr>
<td>0.99</td>
<td>0.99</td>
<td>0.04$^{+0.03}_{-0.01}$</td>
<td>24.9$^{+16.0}_{-15.2}$</td>
<td>0.32$^{+0.02}_{-0.01}$</td>
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First broad Fe Ka line ever observed (Tanaka+95) and interpreted as originating from a rapidly spinning BH (Iwasawa+96)
Residuals to a power-law are qualitatively similar to those seen in previous epochs, as is overall flux state.
Relativistic reflection in MCG—6-30-15

The source has been observed in a very bright and variable state in 2013 during the XMM+NuSTAR campaign (Marinucci et al. 2014a)
The different spectral shape in the time intervals considered is explained in terms of the interaction between the primary continuum and the accretion disk.
Relativistic reflection in MCG—6-30-15

- XMM best fit value
- Disk $\xi$
- $N_{H1}$
- $\Gamma$

Marinucci et al. 2014a
Spin, disk inclination, iron abundance linked between different intervals.

90% confidence: $a = 0.91 - 0.98$

vs. XMM only, Suzaku: $a > 0.97$
Mrk 335 was observed by NuSTAR and Swift in a very faint state, allowing us to study the reflection properties of the source.

Once relativistic effects are taken into account, a black hole spin of $a > 0.97$ is measured.
When flux-resolved states are considered a maximally rotating black hole spin is measured.
Black hole spin in NGC 1365

NGC 1365: a source in which both absorption and relativistic reflection play a major role in the X-rays

The first NuSTAR published paper is the spin measurement in NGC 1365

Risaliti et al. 2013, Nature
NGC 1365 was observed by XMM and NuSTAR four times. Despite large variations in the absorbers, no variations in the reflected components are found, demonstrating the robustness of the result.
Black hole spin in NGC 1365

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Relativistic reflection in SWIFT J2127.4

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, $L_{\text{bol}}/L_{\text{Edd}}\sim0.18$ (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.

Marinucci et al. 2014b
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.
Relativistic reflection in SWIFT J2127.4

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 $E_c = 10^{8}\pm10$ keV and to infer the contribution of the disk to the Compton hump.
Using compTT (Titarchuk+94) with two different geometries we get:

**SLAB**
- $kT_e = 68^{+37}_{-32} \text{ keV}$
- $\Gamma = 0.35^{+0.35}_{-0.19}$

**SPHERE**
- $kT_e = 53^{+28}_{-26} \text{ keV}$
- $\Gamma = 1.35^{+1.03}_{-0.67}$
Thanks to the broad (0.5-80 keV) spectral coverage, we confirmed the intermediate spin value in this source, discarding non-spinning solutions with a significance $>3\sigma$.

Marinucci et al. 2014b

$a=0.58^{+0.11}_{-0.17}$
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Conclusions

• The recent NuSTAR observational campaign of Radio-quiet AGN allowed us to study:

  - First measurements of the coronal parameters $T$ and $t$
  - Warm Comptonization in Ark 120
  - (in addition to reflection?)

• Bringing the two pieces of information together we have an unprecedented power to investigate the hot reflection model (discrimination between disk) of the nucleus

  - Black hole spin measurements in a number of sources