[type 1] AGN spectroscopy and timing

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A brief intro to X-ray emission from accreting BHs
Outline

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X-ray soft excess and (possible) interpretations
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Relativistic disc reflection and Fe K diagnostics of AGN BH spin
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The remarkable cases of 1H 0707-495 and IRAS 13224-3809
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Conclusions: do we have a template?
Accreting BHs

The two flavours of accreting BH:

- **stellar mass BHs** scattered in Galaxies (X-ray binaries)
- **supermassive BHs** in the center of Galaxies (AGN and quasars)
The accreting gas is \textit{heated by friction} and emits as a blackbody

\[ kT_{BB} = k \left( \frac{L}{A \sigma} \right)^{1/4} = k \left( \frac{L}{4 \pi R^2 \sigma} \right)^{1/4} \]

by using

\( L = L_{Edd} \approx 1.3 \times 10^{38} \left( \frac{M}{M_\odot} \right) \text{erg/s} \)

and a typical size of 20 \( r_g (=20 \text{ M in some units}) \)

we get \( \sim 0.6 \text{ keV} \) (X-rays !) for stellar mass BHs \textbf{BUT} \( \sim 0.01 \text{ keV} \) (UV) for supermassive BHs
Accreting BHs in X-rays

Soft Excess

Fe line

Compton Hump

Krongold et al 03
The X-ray soft excess

Simple definition

extrapolation of the best-fitting 2-10 keV continuum reveals
excess X-ray emission typically below ~ 1 keV

It is typically stronger and more extreme in NLS1 galaxies but
almost ubiquitous in relatively unabsorbed Seyfert 1 and QSO

has to be related to fundamental processes

Its spectral shape is remarkably uniform and closely resembles optically
thick thermal emission with typical kT ~ 150 eV and very little spread
Not only the shape is TOO uniform to be thermal, the $kT$ is also TOO hot.

This simple fact seems to rule out a thermal origin and calls for interpretations invoking physical processes with typical energies that are independent on (e.g.) BH mass.

Atomic processes may then be invoked (e.g. absorption and reflection).
Absorption:

larger opacities in the intermediate ~1-2 keV band in partially ionized gas may be responsible for a spurious soft excess

Potentially also explains the energy-dependent X-ray variability in many sources

Gierlinski & Done 04,06
The X-ray soft excess

However smearing velocities are likely too extreme and unrealistic with terminal outflow $v \sim 0.9 \, c$

Recent numerical simulation show that in realistic cases far too many sharp absorption features are seen and models cannot reproduce the observed smooth soft excesses

Schurch, Done & Proga 08
The X-ray soft excess

The sharp absorption features may be more subtle if PC is at work.

One such model was presented e.g. for the case of MCG-6-30-15 with multiple PC (5 abs zones of which 2 are global and gratings-detected).

Miller et al 08
While the model reproduces the X-ray spectra it can explain the X-ray variability of the source only by assuming that most of the X-ray variability is not intrinsic but rather associated with PC variations (covering fraction).

This implies that the properties of X-ray variability in Galactic BH and AGN are driven by very different processes (one being intrinsic the other due to intervening matter).

But we have good indication that this is not the case and that AGN variability can be scaled from GBH making use of $M$ and $M_{dot}$ only.
The X-ray soft excess
The X-ray soft excess

\[ T_B \sim \frac{M^2}{L_{bol}} \]
\[ \sim \frac{M}{\dot{M}_{Edd}} \]

which is one piece of evidence for common variability properties among accreting BHs at all scales.

It seems unlikely that variability is driven by significantly different processes in the two classes.
Relativistic disc reflection

\[ \xi = 10^4 \]

\[ \xi = 10^3 \]

\[ \xi = 10^2 \]

Fabian & GM 09 thanks to Randy Ross
Relativistic disc reflection
Relativistic disc reflection
Relativistic disc reflection
Relativistic disc reflection
Like absorption, reflection off partially ionized material can produce smooth and uniform soft excesses in AGN. The soft excess smoothness comes for free thanks to relativistic blurring and its strength is mainly dictated by the reflection fraction.
Relativistic disc reflection

Broad Fe K: not only MCG-6

Power law + disc reflection model explains soft excess and broad Fe K and a measure of the BH spin can be inferred

$\alpha \sim 0$ is excluded but just at the 3σ level
$\alpha \sim 0.998$ is excluded at more than 5σ
Relativistic disc reflection

Fairall 9 with Suzaku

Fig. 2.— The plot above shows the data/model ratio in Fe K region that results from a simple power-law fit to the data. The narrow Gaussian peak near 6.1 keV (6.4 keV in the rest frame) is due to reflection from distant gas. A broad diskline component is also clearly present. The NIS0, NIS1, and NIS2 spectra are shown in black, red, and blue, respectively.

Schmoll et al 09

5σ
Why do we care about AGN BH spin?

- **mergers only**
  - $a \sim 0.7$

- **mergers + coherent**
  - high $a$

- **mergers + chaotic**
  - low $a$

Berti & Volonteri 08
Why do we care about AGN BH spin?

A further possibility: magnetic extraction of rotational energy (BZ)?

Moderski, Sikora & Lasota 98
This is an AGN belonging to the class of NLS1 galaxies

It is remarkable in the X-rays:

- large amplitude and fast X-ray variability
- huge soft X-ray excess
- extreme spectral curvature at Fe energies (Boller et al 02)

All these properties are observed in almost all (unobscured) AGN to a much lesser extent

but Nature seems to have found one (actually two…) extreme object for us to study to perhaps infer the general properties of all of them

[see talk by A. Zoghbi for much more details]
The special case of 1H 0707-495

Two main competing interpretations:
- absorption
- reflection

but distinguishing between the two models spectroscopically is difficult if not impossible

Fabian, GM et al 04

Fabian, GM et al 04
The special case of 1H 0707-495

ratios of the data to a simple power law + BB model

time-averaged

orbit by orbit

two unambiguous features appear between 0.5-1 keV and 4-7 keV

and they can be interpreted as broad Fe L and K lines coming from the

same medium with huge reflection fraction and high Fe abundance
The special case of 1H 0707-495

Again absorption models may work, but what about variability?

The two competitors (absorption and reflection) predict very distinct properties.
The special case of 1H 0707-495

Looking for time lags between lines and continuum: the most crucial result

fast variations (< 20 min)
The special case of 1H 0707-495

Looking for time lags between lines and continuum: the most crucial result

continuum leads line by ~ 30 s on short timescales
The observed lag means that

the soft X-ray spectrum (Fe L) has to be reprocessed emission

if it was the same continuum the lag would be in the opposite direction

absorption is then ruled out

the magnitude of the lag (~ 30s) is dictated by light travel time:

the X-ray corona is very close to the BH (few $r_g$)

the BH mass is likely 3-5 x $10^6$ M$_\odot$
The special case of 1H 0707-495

Problem: why is reflection so strong?

GM & Fabian 04

\[ G_{\mu \nu} = 8\pi T_{\mu \nu} \]

graph showing trajectories of light beams around a black hole

Einstein
1879-1955

General Relativity
1916
Problem: why is reflection so strong?

GM & Fabian 04

It is a natural consequence of having a X-ray corona close to the BH as demonstrated by the ~30s lag
Well, there is another suspect: IRAS 13324-3809

Ponti et al 09, MNRAS submitted
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Ponti et al 09, MNRAS submitted
Conclusions: do we have a template?

In the standard situation and with normal exposures we are unable to detect all these features except for the soft excess (which is indeed ~ ubiquitously detected)

What a standard one would look like