Relativistic gravity, AGN
and the next generation X-ray Observatory

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Evidence for black holes (BHs) in galactic nuclei

- non-AGN:
  - Stars around Sgr A*
  - Stars, gas around centres of nearby galaxies
  - Water maser “disc” in NGC 4258

- AGN:
  - High luminosity
  - Spatially unresolved
  - Large dL/dt: compact, efficient
  - Relativistic jets
  - Optical/UV line “Reverberation”

“Big Science”
- Do BHs exist (test prediction of GR)?
- What are the laws of physics close to BHs?
- Astrophysics of BHs
  - Accretion physics, galaxy/BH co-evolution, etc.
Observations from the BH region

Photons (mainly EUV + X-rays)

\[ r_{\text{ISCO}} \]

Spatial (x,y) – unresolved (until interferometry)
Time (t) – this talk
Energy (E) – this talk
Polarization (PA) – possible with IXO
1. Disklines
The “diskline” model

“thick” accretion flow at \( \sim \text{few } r_g \)

+ \( \text{X-rays } \sim \text{few } r_g \)

= “diskline”

Fe is our “probe” near BH

\[ \text{Kerr disk} \]

![Graph showing photon counts vs energy](image)

\[ \text{Transverse Doppler shift} \]

\[ \text{Beaming} \]

\[ \text{Gravitational redshift} \]

Fabian et al. (1989)
Loar (1991)
Fabian et al. (2000)
What could destroy the diskline(s)?

- No Fe\(^{+0}\)-Fe\(^{+25}\)
  - low abundance
  - complete ionisation
- viewing angle/covering
- electron scattering
- Thick disc truncated at \( r_{in} \gg \sim \text{few } r_g \)
- No BH/GR?

[Not just a line!]

See Ross & Fabian et al.; Nayaskshin et al.
“reverberation” - the X-ray light echo that propagates across the accretion disk due to the finite speed of light. These reverberation signatures encode detailed information about the spacetime geometry, and might allow for a quantitative test of General Relativity in the very strong field limit. (Reynolds & Nowak (2003)
Real data (energy + time)
MCG-6-30-15: the "poster child" of broad lines

Tanaka et al. (1995)
Fabian et al. (1995)
Iwasawa et al. (1996)
Nandra et al. (1997)
Inoue & Matsumoto (2001)
Wilms et al. (2001)
Fabian et al. (2002)
MCG-6-30-15 with \textit{XMM-Newton}: enough photons

\begin{center}
\includegraphics[width=\textwidth]{figure.png}
\end{center}

\textit{Fabian et al. (2002)}
How we should all be plotting our spectra

\[ C(i) = \int R(i, E) A(E) S(E) dE \]

- **Observed (ct s\(^{-1}\))**
- **Response matrix**
- **Effective area (cm\(^2\))**
- **Source spectrum (ct s\(^{-1}\) cm\(^2\) keV\(^{-1}\))**

Discrete version (channel \(i\) energy \(j\))

\[ C_i = \sum_{j=1}^{N} R_{ij} A_j S_j \]

\[ \hat{S} = \frac{C_i}{\sum_{j=1}^{N} R_{ij} A_j} \]

A “best efforts” unfolded spectrum

```plaintext
xspec> model powerlaw
   Index: 0
   Norm: 1
xspec> plot eeuf
```

for a \(vF_v\) style plot
The “poster child” at grating resolution

Young et al. (2005)

Turner et al. (2003, 2004)
Spectral-timing methods

- RMS-spectra / Fourier resolved spectra
- flux-flux relations
- difference + ratio spectra
- Flux / time – resolved fitting
- Cross-spectrum / cross-correlation (time lags, coherence)
- Principal Component Analysis (PCA)

see Vaughan & Fabian (2004)
The “consensus”

Broad lines:  
MCG-6-30-15 (Wilms et al. 2001; Fabian et al. 2002)  
MCG-5-23-16 (Braito et al. 2007)  
NGC 3516 (Turner et al. 2002)

No broad line:  
NGC 3783 (Reeves et al. 2004)  
NGC 5548 (Pounds et al. 2003)  
NGC 3516 (Turner et al. 2005) !

Nandra et al. (2007):

37 XMM-Newton observation of 26 Seyfert 1s  
~11/37 narrow line only  
~ 9/37 broad but not strong-GR  
~17/37 broad disklines

[Don’t forget GBHs – J. Miller 2007]

What next?  
Explain missing disklines  
Better disklines: CCD photons + grating res. + Hard X-rays  
Disklines in “simple” sources  
Consensus on line variability
2. Narrow, relativistically shifted lines
Narrow and shifty lines

NGC 3516
- High
- Low

Emission from disk hotspots integrated over partial orbits at tens-hundreds of $r_g$? (Turner et al 2002)
Comparing “signal” to “noise” in narrow lines

![Graph showing the relationship between EW (eV) and error(EW) (eV). The graph includes data points for X-BALs, Absorption, and Emission.]
A “funnel plot” for X-ray lines


“narrow and X-ray and line and (redshifted or blueshifted)“

Found 135 papers. 13 of these are new detections of shifted narrow lines (v/c > 0.05)
Added 13 more papers by following “paper trail” of the first 12.

Total of 38 lines, of which 36 have EW (or flux) and an uncertainty – “effect” and “precision”.

Clearly a very strong correlation between “EW” and “error” & no lines in upper-left region of plot.

Confounding factors?

• Redshift? No.
• Line energy? No.

What about publication bias?

Given ~500 spectra with ~50 spectral elements expect ~67 residuals at “>3σ”

Most of these unpublished null-results lie in the lower-right half of the figure, the published ones are the “tip of the iceberg”.

17/09/2008
Confounding factors
Post hoc reasoning

“You know, the most amazing thing happened to me tonight. I was coming here, on the way to the lecture, and I came in through the parking lot. And you won’t believe what happened. I saw a car with the license plate ARW 357. Can you imagine? Of all the millions of license plates in the state, what was the chance that I would see that particular one tonight? Amazing!”