X-ray Reflection as a Probe of Accreting Black Holes

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Outline

1. X-rays from accreting black holes
2. X-ray reflection and the emissivity profile
3. Locating the corona
4. Variability and Reverberation
5. Variability in the corona
The X-ray Spectrum

Fabian et al 2009, Zoghbi et al 2010
The X-ray Spectrum

Fabian et al 2009, Zoghbi et al 2010

Disc Thermal Continuum
The X-ray Spectrum

- **Power Law Continuum**
- **Disc Thermal Continuum**

Fabian et al 2009, Zoghbi et al 2010
The X-ray Spectrum

Energy (keV)

keV^2 (Photons cm^{-2} s^{-1} keV^{-1})

Reflection from Disc
Power Law Continuum
Disc Thermal Continuum

Fabian et al 2009, Zoghbi et al 2010
The X-ray Spectrum

Reflection from Disc
Power Law Continuum
Iron Kα Line
Disc Thermal Continuum

Fabian et al 2009, Zoghbi et al 2010
The X-ray Spectrum

Reflection from Disc

Power Law Continuum

Iron Kα Line

Disc Thermal Continuum

Galactic Absorption

Energy (keV)

Fabian et al 2009, Zoghbi et al 2010
The ‘Lamppost’ Model
Relativistic Emission Lines

Fabian et al 1989, Laor 1991
Relativistic Emission Lines

Fabian et al 1989, Laor 1991
Relativistic Reflection

Ross & Fabian 2005
Relativistic Reflection

Ross & Fabian 2005
Resolving the Accretion Disc

Wilkins & Fabian 2011, MNRAS 414, 1269-1277

*Image description: A graph showing normalized counts per second per kiloelectron volt against energy in keV. The graph includes a sum of energy bins from 1.235\(r_g\) to 10\(r_g\) and individual bins from 1.235\(r_g\) to 20\(r_g\). The x-axis represents energy in keV, ranging from 0 to 10, and the y-axis represents normalized counts per second per kiloelectron volt, ranging from 0 to 1000.*
Emissivity Profiles

IH 0707-495

\( \frac{\epsilon}{\text{arbitrary units}} \) vs. \( \frac{r}{r_g} \)

- \( q = 7.8 \)
- \( 3 - 10 \text{ keV} \)
- \( 3 - 5 \text{ keV} \)

Wilkins & Fabian 2011, MNRAS 414, 1269-1277
Emissivity Profiles

IH 0707-495

IRAS 13224-3809

Wilkins & Fabian 2011, MNRAS 414, 1269-1277
Ray Tracing Simulations

• Trace rays from source to disc, then to observer
• Photons follow null geodesics in Kerr spacetime
• Codes run on GPUs (NVIDIA CUDA) for high performance
Theoretical Emissivity Profiles

Theoretical Emissivity Profiles

Extended Source: $h = 10r_g$, $0 \leq x < 25r_g$

Point source: $h = 10r_g$, $x = 25r_g$

X-ray Variability

IH 0707-495
January 2008

- Total
- 0.3-1 keV
- 1-4 keV
X-ray Reflection and Time Lags

Variability in reflected component should lag behind that in primary continuum
X-ray Reflection and Time Lags

Variability in reflected component should lag behind that in primary continuum
X-ray Reflection and Time Lags

Variability in reflected component should lag behind that in primary continuum
The Lag Spectrum of 1H 0707-495

Zoghbi et al 2010, Kara et al 2012
The Lag Spectrum of 1H 0707-495

Simulating Lag Spectra

\[ [t] = \frac{GM}{c^3} \]

Calculate cross spectrum and lag spectrum as for real observations in MATLAB
Source Height

Wilkins & Fabian 2013
IH 0707 in January 2011

![Graph showing normalized counts vs energy (keV) for IH 0707 in January 2008 and January 2011.](image)

**Normalized counts s$^{-1}$ keV$^{-1}$**

**Energy (keV)**

- **January 2008**
- **January 2011**

IH 0707 in January 2011

![Graph showing the normalized counts per second per keV for IH 0707 in January 2008 and January 2011.](image)

- January 2008
- January 2011

Energy (keV) vs. normalized counts s⁻¹ keV⁻¹
Into a Low State...
Into a Low State...
What is Varying?

Source Radius

Continuum Spectrum

Wilkins et al 2014 in prep.
The Future: Energy-Resolved Timing

\[ \frac{\tau}{\mu c} \]

Energy (keV)

Lag

Energy (keV)

Kara+2013

IH0707-495
IRAS 13224-3809
Ark 564
Mrk 335
Conclusions

• Detailed analysis of X-ray spectrum and variability
• Locate the X-ray corona through reflection spectrum and variability
• The corona increases in volume as the luminosity increases, causing the extreme variability we see
• Understand how some of the most luminous objects in the Universe are powered by combining observations of spectra and variability with theory