Modelling the X-ray Spectra of AGNs with a Relativistic Reflection Model

Chia-Ying Chiang\textsuperscript{1}, Andy Fabian\textsuperscript{1}, Rubens Reis\textsuperscript{1,2}, Dominic Walton\textsuperscript{1}, Dirk Grupe\textsuperscript{3}, and Sachiko Tsuruta\textsuperscript{4}

\textsuperscript{1}Institute of Astronomy, University of Cambridge
\textsuperscript{2}Department of Astronomy, University of Michigan
\textsuperscript{3}Department of Astronomy and Astrophysics, Pennsylvania State University
\textsuperscript{4}Department of Physics, Montana State University

IoA seminar, 09 November 2011
Geometry & Spectrum

- Hot corona
- Soft disc photons
- Reflected photons
- Black hole

Log $v f(v)$ vs. Log $v$
Reflected Spectrum

(Reynolds, PhD thesis, 1996)
Relativistic Effects

(Fabian et al. 2000)
Broad Fe Kα Line

- Broad iron line first discovered in *ASCA* observation of Type I AGN MCG-6-30-15
- Confirmed by *BeppoSAX*, *XMM-Newton*, *Chandra*, and *Suzaku*
- Spin parameter $a \sim 0.989$ (Reynolds et al. 2005)

(Tanaka et al. 1995)
Unlike 1H0707-495, the spectrum of MCG-6-30-15 is seriously modified by warm absorbers.
Disconnection of Variability

(Fabian et al. 2002)
Reflection-Dominated Model

- Extremely **broad** iron line
- Variability from the **powerlaw** component
- Gravitational light-bending model
- using only full-covering absorbers

- Gravitational light-bending effects can explain the invariability of the iron line (Miniutti & Fabian 2004)
- 30s soft lag detection in MCG-6-30-15 (Emmanoulopoulos et al. 2011)
### Absorption-Dominated Model

- **Narrow** iron line
- Partial covering clumpy absorbers
- Long-term variability from the *warm absorbers* due to changing covering factors

- Warm absorbers can mimic the broad line profile (Inoue & Matsumoto 2003)
- Hard excess is absorption-dominated (Miller et al. 2009)
- Difficult to explain variability $< 1$ ks
Simple Case - CBS 126

- Broad-Line Seyfert I Galaxy ($\text{H}/\beta$ FWHM = $2980 \pm 200$ km s$^{-1}$)
- $z = 0.079$
- $N_H = 1.38 \times 10^{20}$ cm$^{-2}$
- Soft Excess
- Variability
- $M_{\text{BH}} \sim 7.6 \times 10^7$ M$_{\odot}$
CBS 126

Spectra

Suzaku Fl XIS
Suzaku Bl XIS
Suzaku PIN
Swift

Normalized Counts s^{-1} keV^{-1}

Ratio

Energy (keV)
Fitting

Galactic absorption\(^{*}\)(powerlaw + blurred reflection + distant reflection)
Fitting

Galactic absorption* (powerlaw + blurred reflection + distant reflection)

$A_{Fe} \sim 10$
Difference Spectra

XIS

count rate (ct s⁻¹)

Time (sec)

0 5.0×10^4 1.0×10^5 1.5×10^5

high flux

low flux

CBS 126 Difference Spectra

Ratio

Energy (keV)

1 2 5 10
Difference Spectra

![Graph showing high and low flux in XIS and CBS 126 Difference Spectra](image)
RMS Spectrum

![RMS Spectrum graph](image-url)
Galactic absorption*(powerlaw_{high} + reflection_{high}) -
Galactic absorption*(powerlaw_{low} + reflection_{low})
= Galactic absorption*Δpowerlaw

1 Multiplicative component
Ex: Edge, Warm absorbers...etc.
## Results

**Table:** Model A: reflection model; Model B: reflection model with an absorption edge

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time-averaged</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \Gamma )</td>
<td>2.01 ± 0.01</td>
<td>2.16 ± 0.01</td>
</tr>
<tr>
<td>( E_{\text{edge}} )</td>
<td>-</td>
<td>0.89 ± 0.01</td>
</tr>
<tr>
<td>( A_{\text{Fe}} \rangle )</td>
<td>&gt; 9.04</td>
<td>(1.0)</td>
</tr>
<tr>
<td>index</td>
<td>7.21 ± 0.80</td>
<td>&gt; 6.37</td>
</tr>
<tr>
<td>( R_{\text{in}}(R_g) )</td>
<td>2.98 ± 0.63</td>
<td>1.68 ± 0.33</td>
</tr>
<tr>
<td>( \phi )</td>
<td>27.1 ± 19.5°</td>
<td>50.5 ± 5.1°</td>
</tr>
<tr>
<td>( \chi^2/\nu )</td>
<td>1766.6/1577</td>
<td>1762.1/1576</td>
</tr>
</tbody>
</table>
Flux Evolution

\[ \xi = \frac{L}{nR^2} \]
Complex Case - MCG-6-30-15

warm absorber

![Graph showing energy vs. normalized counts and ratio]
Papers Over Last Few Years

- **The absorption-dominated model for the X-ray spectra of type I active galaxies: MCG-6-30-15**, Miller et al., MNRAS, 2009
- **Spectral Variation of the Seyfert 1 Galaxy MCG-6-30-15 Observed with Suzaku**, Miyakawa et al., PASJ, 2009
- **Negative X-ray reverberation time delays from MCG-6-30-15 and Mrk 766**, Emmanoulopoulos et al., MNRAS, 2011
- **Modelling the broad-band spectra of MCG-6-30-15 with a relativistic reflection model**, Chiang et al., MNRAS, 2011
### Datasets

*Table:* The table lists the summary of all datasets used in this work.

- **XMM-Newton**
  - Epic PN: 2.2-10 keV;
  - XMM-Newton RGS: 0.4-1.7 keV;

- **BeppoSAX**
  - 13-200 keV;

- **Suzaku**
  - XIS: 0.5-12 keV;
  - PIN: 14-45 keV;

- **Chandra**
  - MEG: 0.5-5 keV;
  - HEG: 0.8-7.5 keV

<table>
<thead>
<tr>
<th>Observation</th>
<th>Date</th>
<th>ObsID</th>
<th>Exposure (ks)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>XMM-Newton</strong></td>
<td>31/07 - 01/08, 2001</td>
<td>0029740101</td>
<td>55.2</td>
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<tr>
<td></td>
<td>02/08 - 03/08, 2001</td>
<td>0029740701</td>
<td>85.5</td>
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<td></td>
<td>04/08 - 05/08, 2001</td>
<td>0029740801</td>
<td>86.8</td>
</tr>
<tr>
<td><strong>Beppo-SAX</strong></td>
<td>31/07 - 05/08, 2001</td>
<td>51346001</td>
<td>49.6</td>
</tr>
<tr>
<td><strong>Suzaku</strong></td>
<td>09/01 - 14/01, 2006</td>
<td>700007010</td>
<td>143.3</td>
</tr>
<tr>
<td></td>
<td>23/01 - 26/01, 2006</td>
<td>700007020</td>
<td>98.5</td>
</tr>
<tr>
<td></td>
<td>27/01 - 30/01, 2006</td>
<td>700007030</td>
<td>96.7</td>
</tr>
<tr>
<td><strong>Chandra</strong></td>
<td>19/05 - 27/05, 2004</td>
<td>4759-4762</td>
<td>497.1</td>
</tr>
</tbody>
</table>
Light Curves

XMM-Newton

Suzaku

Chandra
Difference Spectra

Energy (keV) vs Ratio

- PN
- XIS0/XIS2/XIS3
- MEG/HEG

The graph shows the ratio of energy (in keV) for different detectors (PN, XIS0/XIS2/XIS3, MEG/HEG). The ratio values range from 0.5 to 1.5 on the y-axis, with energy from 0.5 to 10 keV on the x-axis.
Fast Component

- Highly ionized (log $\xi > 3.5$) fast component (Sako et al. 2003; Turner et al. 2004; Young et al. 2005; McKernan et al. 2007; Holczer et al. 2010)
- Fe XXV & Fe XXVI absorption lines
- $v \sim 2000$ km s$^{-1}$
Slow Component & Others

- Slow component with two different ionization states (Lee et al. 2001; Sako et al. 2003; Turner et al. 2004; McKernan et al. 2007; Holczer et al. 2010)
- Absorption features $< 2$ keV
- $\nu \sim 100 \text{ km s}^{-1}$

- Local component at $z = 0$ (Holczer et al. 2010)
XSTAR Grids

- XSTAR is a computing program for calculating the spectra of photoionised gas.
- \( L = 2 \times 10^{43} \text{ erg s}^{-1} \) (Young et al. 2005)
- Powerlaw spectrum shape
- Gas density = \( 10^{12} \text{ cm}^{-3} \)
- \( C_v = 1.0 \)
- \( v_{\text{turb}} = 100, 500, 1000 \text{ km s}^{-1} \)
- \( T = 10^4, 3 \times 10^4, 10^5 \text{ K} \)
- Variable iron and oxygen abundances

Model: Galactic absorption*(4 xstar grids)*(powerlaw + blurred reflection + distant reflection)
Fitting Results

Chandra MEG + HEG

Normalized Counts s$^{-1}$ keV$^{-1}$ vs. Energy (keV)

Ratio
Fitting Results

![Suzaku plot](image-url)
Fitting Results

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Model

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

<table>
<thead>
<tr>
<th>Reflection</th>
<th>Powerlaw</th>
<th>Warm Absorbers</th>
</tr>
</thead>
</table>

Energy (keV)
**Fitting Parameters**

*Table:* $N_H$ is given in $10^{21}$ cm$^{-2}$, temperature in Kelvin, and $\xi$ in erg cm s$^{-1}$.

<table>
<thead>
<tr>
<th>Absorber</th>
<th>fast</th>
<th>slow (1)</th>
<th>slow (2)</th>
<th>local</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T$ (K)</td>
<td>$3 \times 10^4$</td>
<td>$10^4$</td>
<td>$3 \times 10^4$</td>
<td>$10^4$</td>
</tr>
</tbody>
</table>

**Chandra**

- $N_H$: $209.4^{+36.9}_{-33.8}$
- $\log \xi$: $(3.82)$
- $T$: $3 \times 10^4$
- $N_H$: $3.43^{+0.31}_{-0.42}$
- $\log \xi$: $1.71 \pm 0.03$
- $T$: $10^4$
- $N_H$: $0.27^{+0.20}_{-0.13}$
- $\log \xi$: $2.47^{+0.03}_{-0.16}$
- $T$: $10^4$

**XMM + BeppoSAX**

- $N_H$: $27.4^{+9.5}_{-14.0}$
- $\log \xi$: $(3.82)$
- $T$: $3 \times 10^4$
- $N_H$: $2.72^{+0.63}_{-0.28}$
- $\log \xi$: $1.68^{+0.05}_{-0.03}$
- $T$: $10^4$
- $N_H$: $0.99^{+0.46}_{-5.30}$
- $\log \xi$: $2.49^{+0.01}_{-0.10}$
- $T$: $10^4$

**Suzaku**

- $N_H$: $38.9^{+10.4}_{-8.1}$
- $\log \xi$: $(3.82)$
- $T$: $3 \times 10^4$
- $N_H$: $8.99^{+0.87}_{-0.91}$
- $\log \xi$: $1.61^{+0.03}_{-0.04}$
- $T$: $10^4$
- $N_H$: $0.14^{+0.12}_{-0.14}$
- $\log \xi$: $1.73^{+0.11}_{-0.13}$
- $T$: $10^4$

(0.406)
### Fitting Parameters

<table>
<thead>
<tr>
<th>parameter</th>
<th>Chandra HETGS</th>
<th>XMM + BeppoSAX</th>
<th>Suzaku</th>
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<tbody>
<tr>
<td>$\Gamma$</td>
<td>$1.97 \pm 0.00$</td>
<td>$2.00^{+0.00}_{-0.01}$</td>
<td>$1.98 \pm 0.01$</td>
</tr>
<tr>
<td>index</td>
<td>$8.00^{+0.00}_{-0.16}$</td>
<td>$3.78^{+0.05}_{-0.08}$</td>
<td>3.09</td>
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<tr>
<td>$R_{\text{in}}(R_g)$</td>
<td>$1.31^{+0.08}_{-0.00}$</td>
<td>$1.57^{+0.13}_{-1.57}$</td>
<td>2.50</td>
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<tr>
<td>$A_{\text{Fe}}$</td>
<td>$1.79^{+0.10}_{-0.29}$</td>
<td>$1.73^{+0.19}_{-0.12}$</td>
<td>$4.00^{+0.00}_{-0.10}$</td>
</tr>
<tr>
<td>$E_{\text{Fe}}$</td>
<td>$6.53^{+0.06}_{-0.09}$</td>
<td>$6.52 \pm 0.03$</td>
<td>$6.38^{+0.01}_{-0.02}$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$35.0^{+0.6}_{-35.0}$°</td>
<td>$37.7^{+3.4}_{-2.2}$°</td>
<td>44.0°</td>
</tr>
<tr>
<td>$\chi^2/d.o.f.$</td>
<td>2417.7/2139</td>
<td>5059.3/3809</td>
<td>1684.7/1576</td>
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## Comparison

<table>
<thead>
<tr>
<th>work</th>
<th>Holczer et al.</th>
<th>Miller et al.</th>
<th>present work</th>
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<tbody>
<tr>
<td>full covering zones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fast</td>
<td>$N_H$</td>
<td>81 ± 7</td>
<td>(80.0)</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>3.82 ± 0.03</td>
<td>(3.95)</td>
</tr>
<tr>
<td>slow(1)</td>
<td>$N_H$</td>
<td>2.3 ± 0.3</td>
<td>0.27 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>-1.5-0.5</td>
<td>0.88 ± 0.16</td>
</tr>
<tr>
<td>slow(2)</td>
<td>$N_H$</td>
<td>3.0 ± 0.4</td>
<td>11.8 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>1.5-3.5</td>
<td>2.39 ± 0.01</td>
</tr>
<tr>
<td>local</td>
<td>$N_H$</td>
<td>0.40</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>-</td>
<td>-</td>
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<tr>
<td>partial covering zones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>zone 1</td>
<td>$N_H$</td>
<td>-</td>
<td>1910 ± 300</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>zone 2</td>
<td>$N_H$</td>
<td>-</td>
<td>29 ± 1</td>
</tr>
<tr>
<td></td>
<td>log $\xi$</td>
<td>-</td>
<td>1.38 ± 0.03</td>
</tr>
</tbody>
</table>
The relativistic reflection model has no trouble modelling both the hard excess and the soft excess.

The reflection model can robustly explain the broadband X-ray spectra of AGNs without any partial-covering absorbers.

Most energy is generated within a few gravitational radii; signatures from inner radius are expected.