Accretion on Black Holes: Testing the Lamp Post Geometry

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X-ray Reflection from Accretion Disks
Accretion Geometry: The Primary Source of Radiation

Lamp Post

steep emissivity

Corona

emissivity $\propto r^{-3}$
Usually emissivities steeper than $r^{-3}$ are observed (described by a broken power law emissivity) (see, e.g., Fabian et al., 2004; Miller et al., 2013)
⇒ naturally explained in the lamp post geometry
⇒ agrees with measurements of the emissivity (see, e.g., Wilkins & Fabian, 2012; Wilkins & Gallo, 2015)
How can we test the nature of the primary source?

- analyze the continuum: usually continuum produced by a corona or a jet fits equally well to data (see, e.g., Nowak et al., 2011)
- measure the emissivity profile (see, e.g., Wilkins & Fabian, 2012)
- timing / reverberation lags ... (see, e.g., Kara et al., 2016)
- compare a full model of primary and reflected radiation to data (including normalization)
Reflection Fraction in the Lamp Post Geometry

lamp post geometry: fraction of photons / flux hitting the disk compared to infinity depends on the height source
Reflection Fraction in the Lamp Post Geometry

The reflection fraction \( R_f \) is defined as:

\[
R_f = \frac{\text{Flux}(\text{Accretion Disk})}{\text{Flux}(\text{Infinity})}
\]

This fraction depends on the height source. The graph shows how the fraction of photons hitting the disk compared to infinity varies with height. The solid line represents \( a = 0.998 \).
Reflection Fraction in the Lamp Post Geometry

The reflection fraction $(R_f)$ is given by:

$$R_f = \frac{\text{Flux(Accretion Disk)}}{\text{Flux(Infinity)}}$$

This diagram illustrates the fraction of photons reflected as a function of the height in the lamp post geometry, comparing the accretion disk, black hole, and infinity.
Different ways to define the reflected normalization

**Reflection Fraction** $R_f$

Ratio between intensity illuminating the disk to intensity reaching the observer

**System Intrinsic**

**Reflection Strength** $R_s$

Ratio between reflected and direct flux at the Compton hump (20–40 keV)

**Observed Strength**

**Motivation:** In order to investigate the accretion geometry, need to understand how much primary radiation is incident on the accretion disk
Relativistic Reflection: Predicted Reflection Fraction

reflection spectra: source at height $h$ seen under inclination $\theta$

- strong dependency of reflection on inclination angle
- large boost in reflection fraction possible for low heights
- largest boost for large angle and low height source
• strength ($R_s$) strongly depends on the inclination
• greatest strength for large inclination angles
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- greatest strength for large inclination angles

→ only **high reflection** fraction for **low height** and **large spin**
→ **prediction**: some sources should show **strong reflection**
Sample Study: Testing the Lamp Post Geometry

Fink et al., in prep (Poster J10)

Aim: Constraining the height of the primary source for a sample of sources ⇒ does the lamp post geometry describe the data?

- use 16 of the sources with best spectral coverage (XMM-Newton and NuSTAR)
- show that the physical model is able to describe the data
- constrain the height of the primary source
- does the predicted reflection fraction agree with measurements?
- compare with previous measurements
Sample Study: Height vs. Reflection Fraction

Fink at al., in prep (Poster J10)
Sample Study: Height vs. Reflection Fraction

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Self-consistent LP normalization results in equally good fits

more physically sound results and better constraints (reflection fraction strongly depends on inclination and height)
Sample Study: Spin Measurements (preliminary)

Fink at al., in prep (Poster J10)

⇒ spin measurements largely in good agreement
The Primary Source: Cutoff Energy

- determines **energetics of corona** $\rightarrow$ compactness (Fabian et al., 2015, ...)
- García et al. (2015a): cutoff energy important for relativistic reflection
- **energy shifted** due to GR effects

\[ E_{\text{cut}} = 300 \text{ keV} \]

Current limitations of reflection modeling:
- one input spectral shape for the complete disk
- problem: convolution of multiple zones of the accretion disk necessary, but computationally very expensive
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- 600 keV
- 400 keV
- 300 keV
- 900 keV

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600 keV

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relxill 2.0 : overcoming this limitation

fully re-written relxill model with a FFT algorithm for the convolution and additional optimizations faster despite multiple zones

reflection spectrum for each zone relativistically smeared separately
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download: www.sternwarte.uni-erlangen.de/research/relxill/
(other models unchanged, but faster: including nthcomp, coronal geometry, line models...)

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About **relxill**

**general information about on model**

relxill is a new reflection model, which can be readily used in common X-ray data analysis tools such as *isis* or *xspec*. It joins forces of the *xillver* reflection code (Garcia et al., 2010, 2011, 2013) and the *relline* code (Dauser et al., 2010, 2013). The striking new feature is that for each point on the disk the proper *xillver*-reflection spectrum is chosen for each relativistically calculated emission angle. The implications of this improvement and more details regarding the model are provided in Garcia & Dauser et al. (2014, ApJ, 782, 76) and Dauser & Garcia et al. (2014, MNRAS, 444, L100).

The very recent version (since 2.0.0) has been completely re-written, leading to a more stable and faster execution. Moreover for part of the model flavors it is possible to use a multi-zone disk (more information below).

**BASIC FEATURES OF THE RELXILL MODEL PACKAGE**

- simple line models and convolution models
- the *xillver* reflection model
- cutoff power law and nthcomp as primary continuum
- relxill: combining *xillver* reflection with relativistic smearing *relconv*
- Irradiation of the disk by broken power law or lamp post geometry emissivity
- self-consistent normalization of primary and reflected spectrum
- multi-zone disk for the primary spectrum in the lamp post geometry

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Multi-Zone Model: Change in Cutoff Energy

- 10 ksec *NuSTAR* simulations of GX-339 (García et al., 2015b)
- simulate with multi-zone model and fit with the previously used 1-zone model
- model is combination of *xillver* and *relxill*
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Previously cutoff energy $\approx 10\%$ over-predicted
Multi-Zone Model: Are other parameters affected?

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Other parameters (e.g., spin) largely unaffected
Summary

- **reflection fraction** contains information about the primary source
- **reflection strength** (measured normalization) depends on height, inclination, ...

- **sample study**: self-consistent reflection fraction leads to physically consistent results
  → **lamp post geometry describes data well**

- **new relxill model**: multiply radial zones for a proper modeling of the reflection (cutoff energy)
  → only changes around 10% in the cutoff energy
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**Spin measurements**: only reliable with a sound understanding/constraint of the system geometry?
References