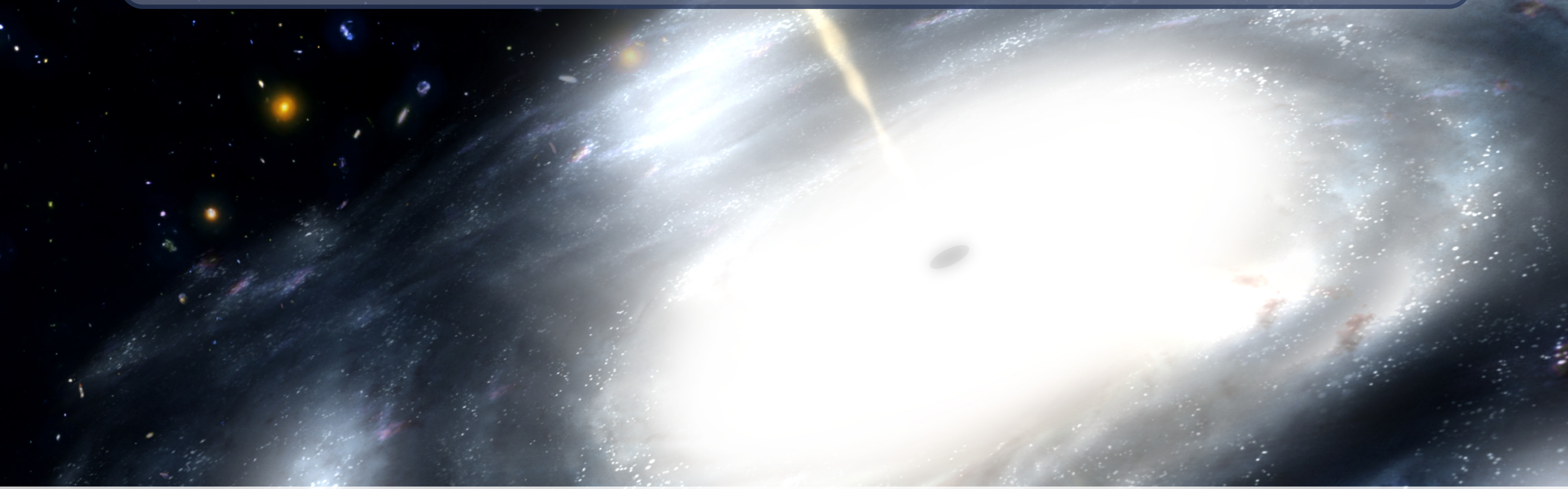
Accretion on Black Holes:

Testing the Lamp Post Geometry



Thomas Dauser – Remeis Observatory Bamberg & ECAP

in collaboration with J. García, J. Wilms, M. Fink, T. Beuchert, and many others

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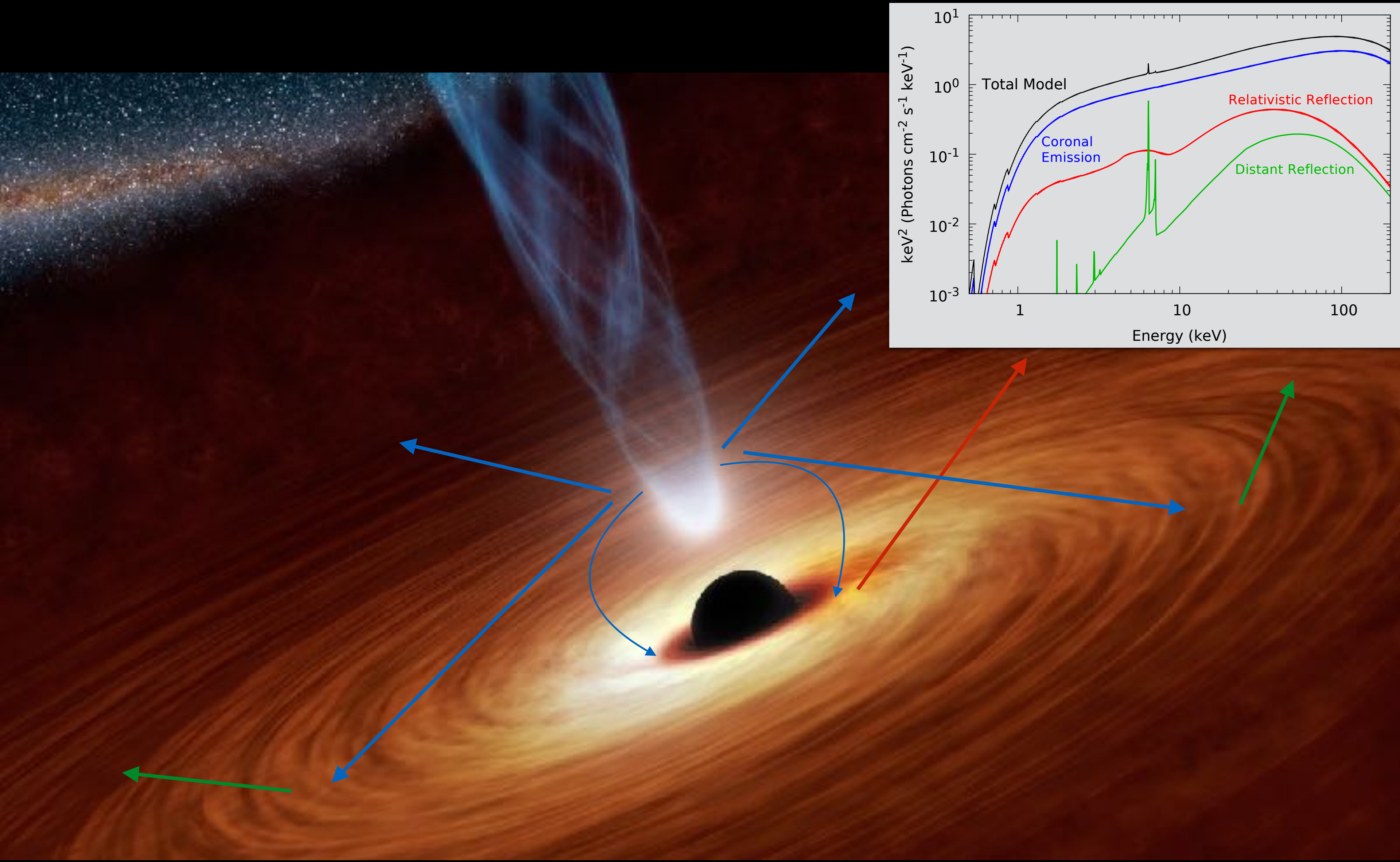
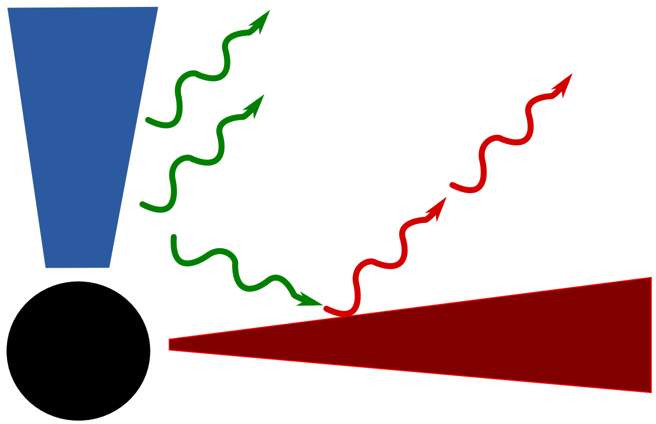


X-ray Reflection from Accretion Disks

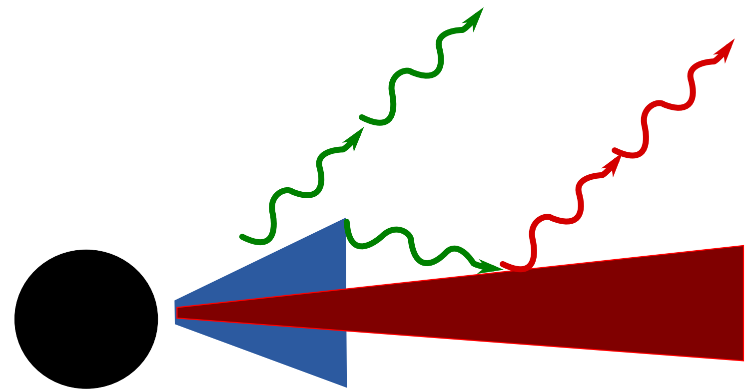
Accretion Geometry: The Primary Source of Radiation

Lamp Post



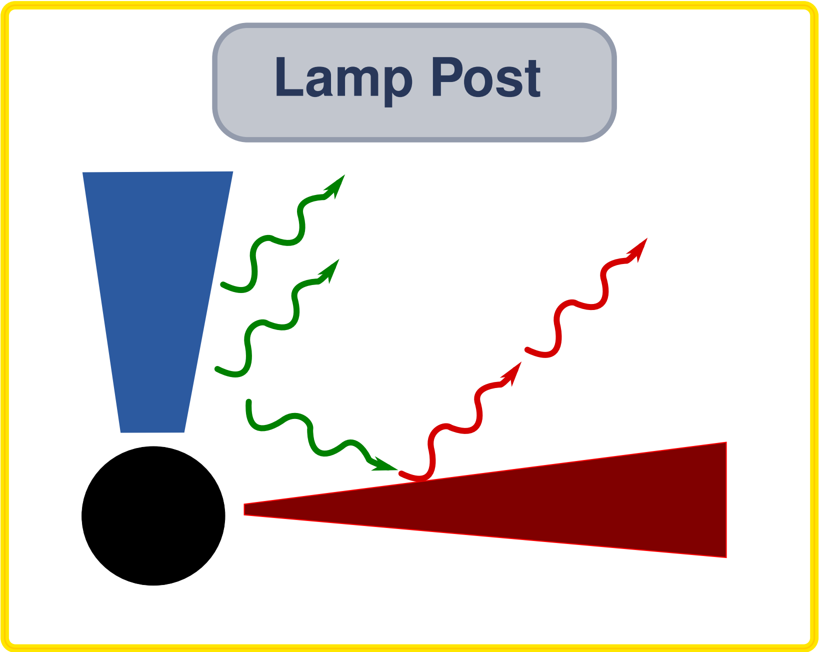
steep emissivity

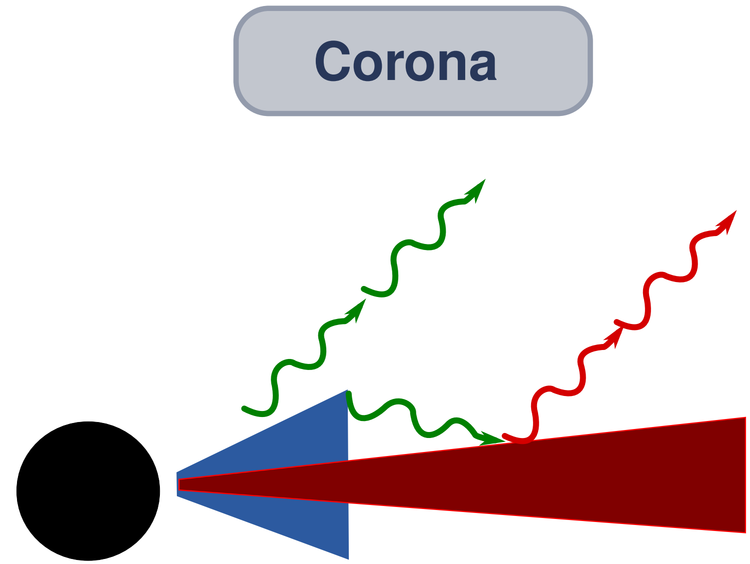
Corona



emissivity $\propto r^{-3}$

Accretion Geometry: The Primary Source of Radiation





steep emissivity

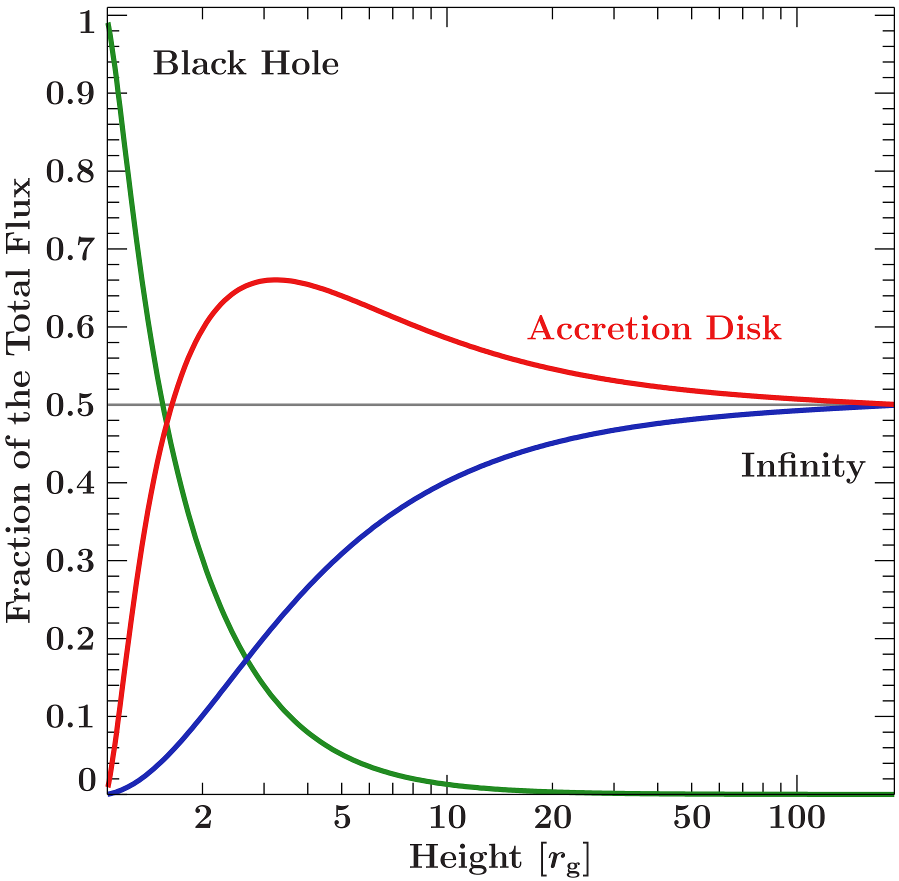
emissivity $\propto r^{-3}$

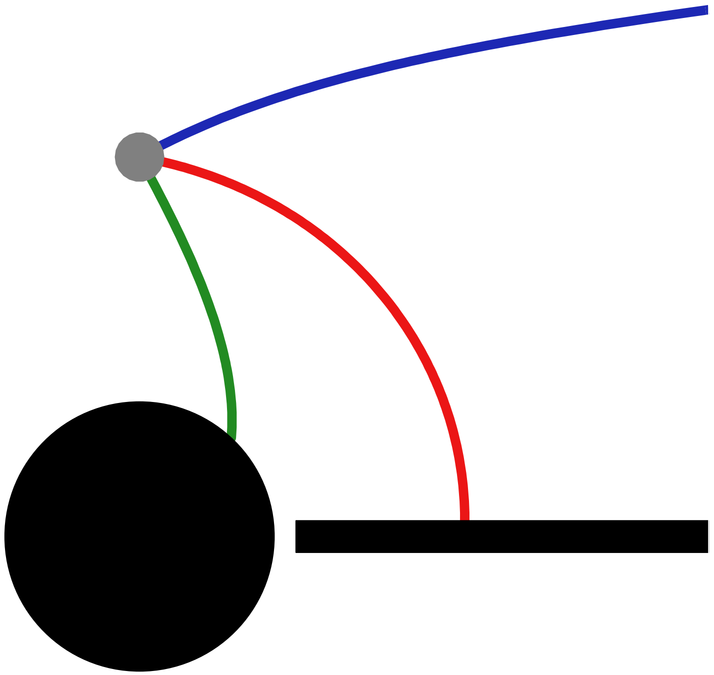
Usually emissivities steeper than r^{-3} are observed (described by a **broken power law emissivity**) (see, e.g., Fabian et al., 2004; Miller et al., 2013)
$\Rightarrow$ naturally explained in the lamp post geometry
$\Rightarrow$ agrees with measurements of the emissivity (see, e.g., Wilkins & Fabian, 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)

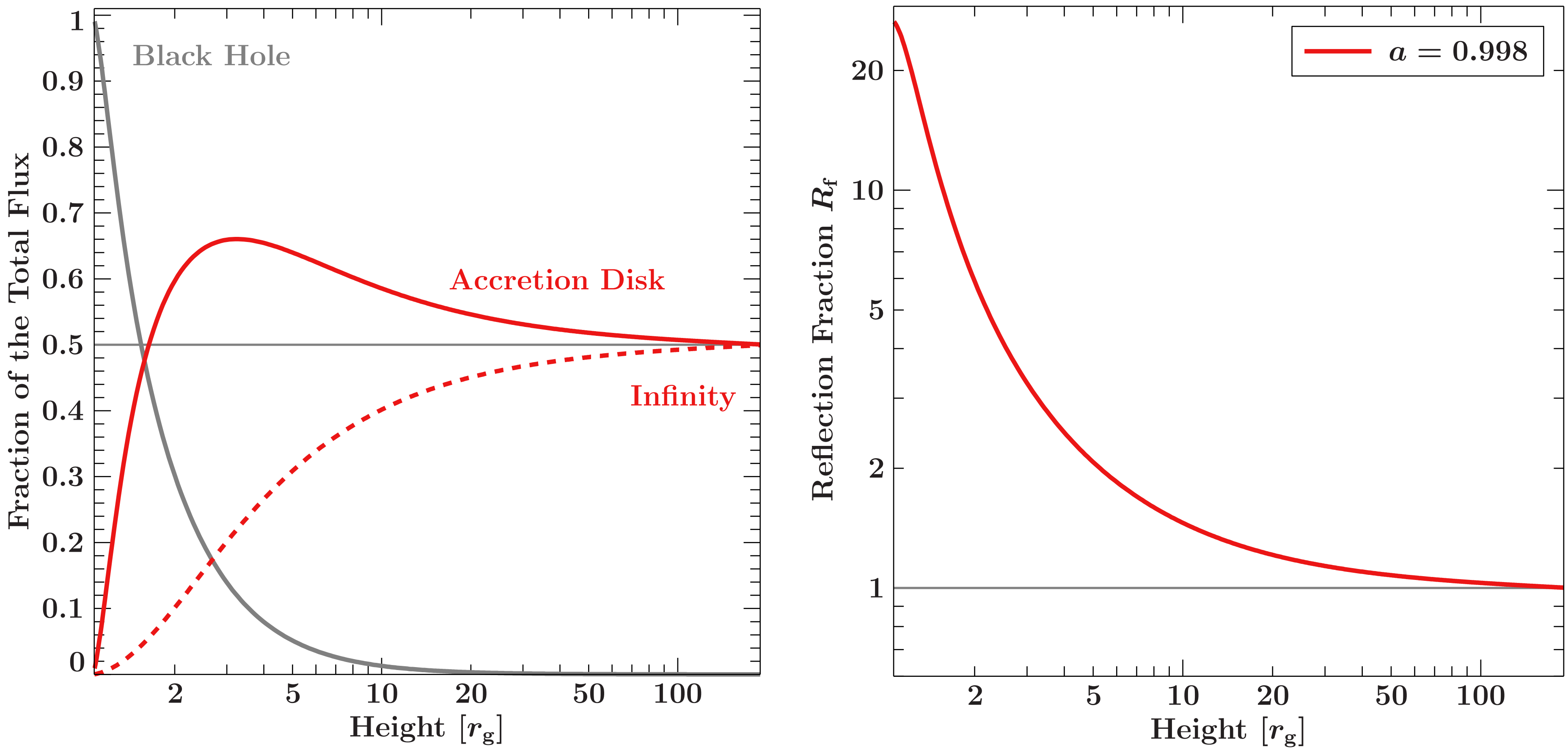
Reflection Fraction in the Lamp Post Geometry





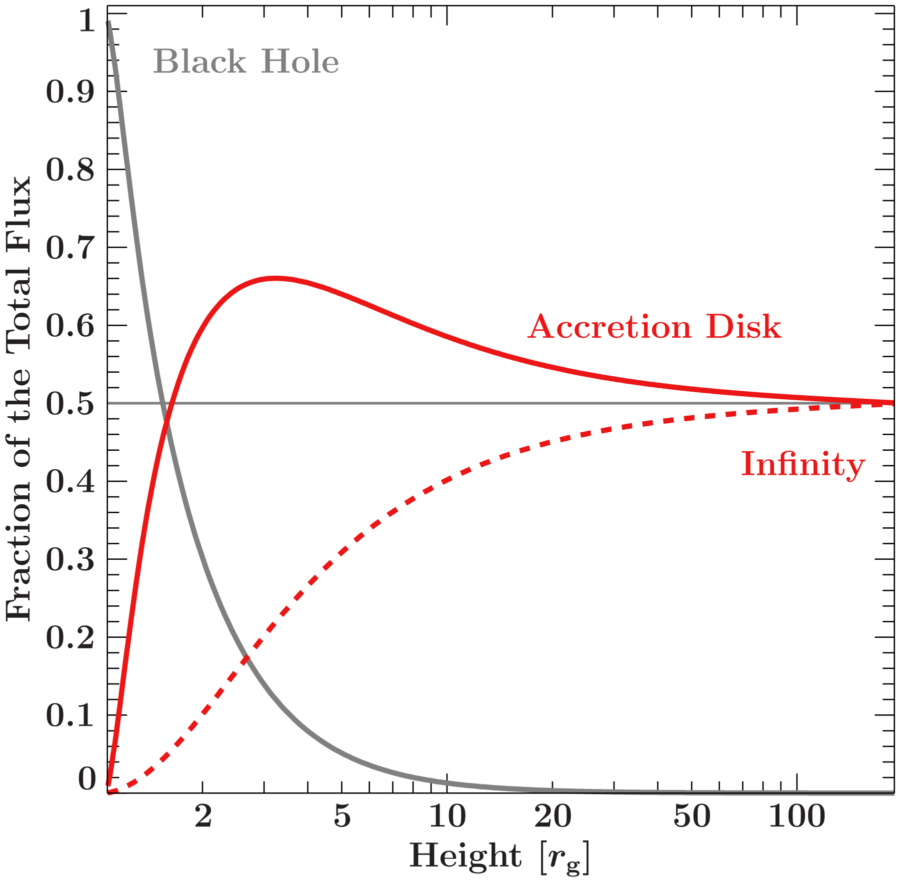
lamp post geometry: fraction of photons / flux hitting the disk compared to infinity depends on the height source

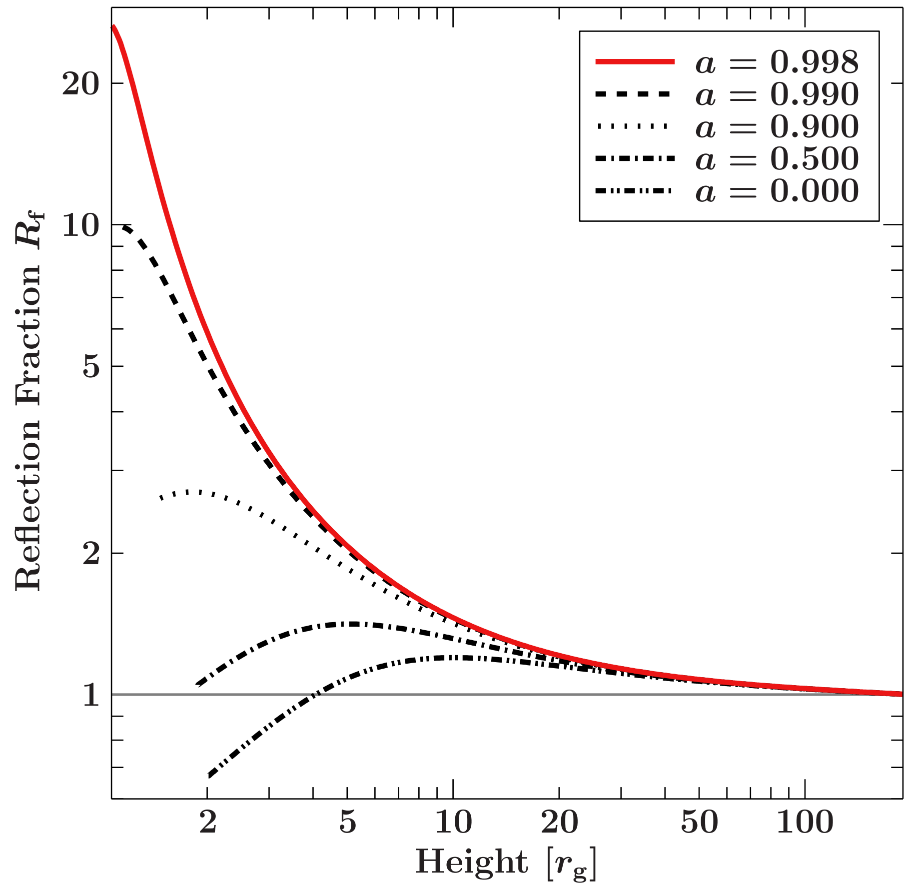
Reflection Fraction in the Lamp Post Geometry



$$\textbf{reflection fraction } (R_\mathrm{f}) = \frac{Flux(\text{Accretion Disk})}{Flux(\text{Infinity})}$$

Reflection Fraction in the Lamp Post Geometry





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

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

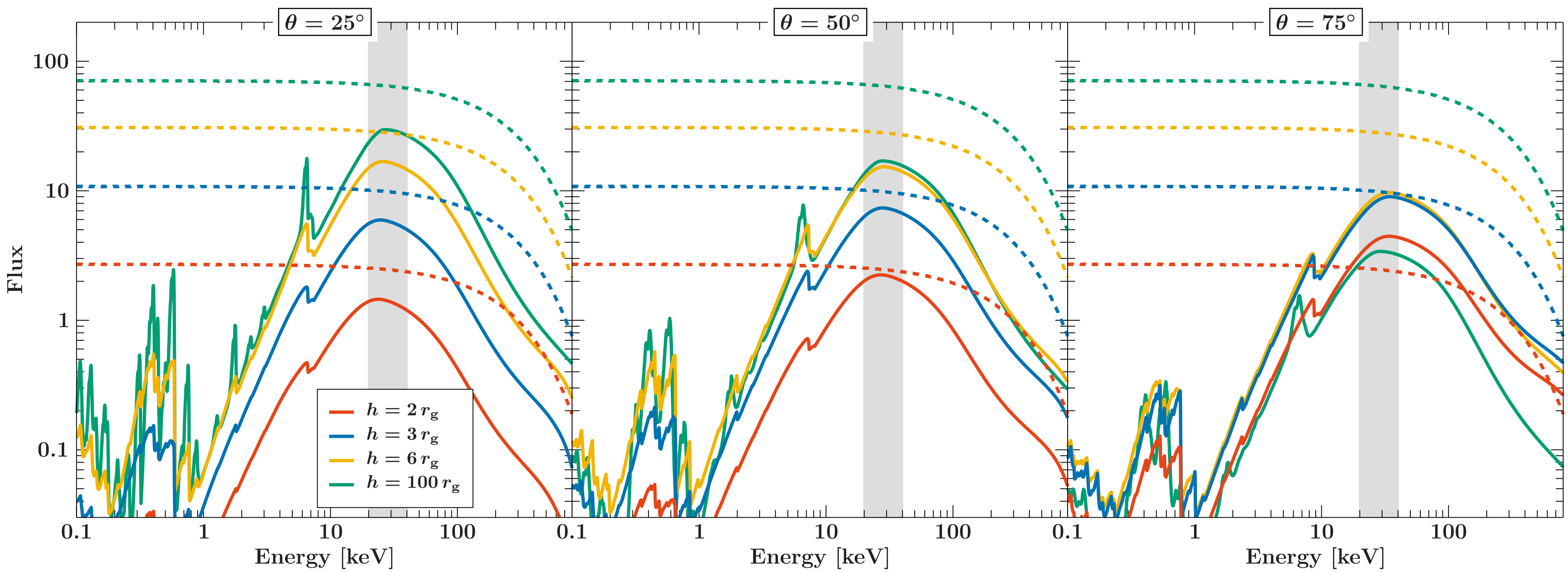
Ratio between reflected and direct flux at the Compton hump (20–40 keV)

Observed Strength

Motivation: in order to investigate the accretion geometry, need to understand **how much primary radiation is incident** on the **accretion disk**

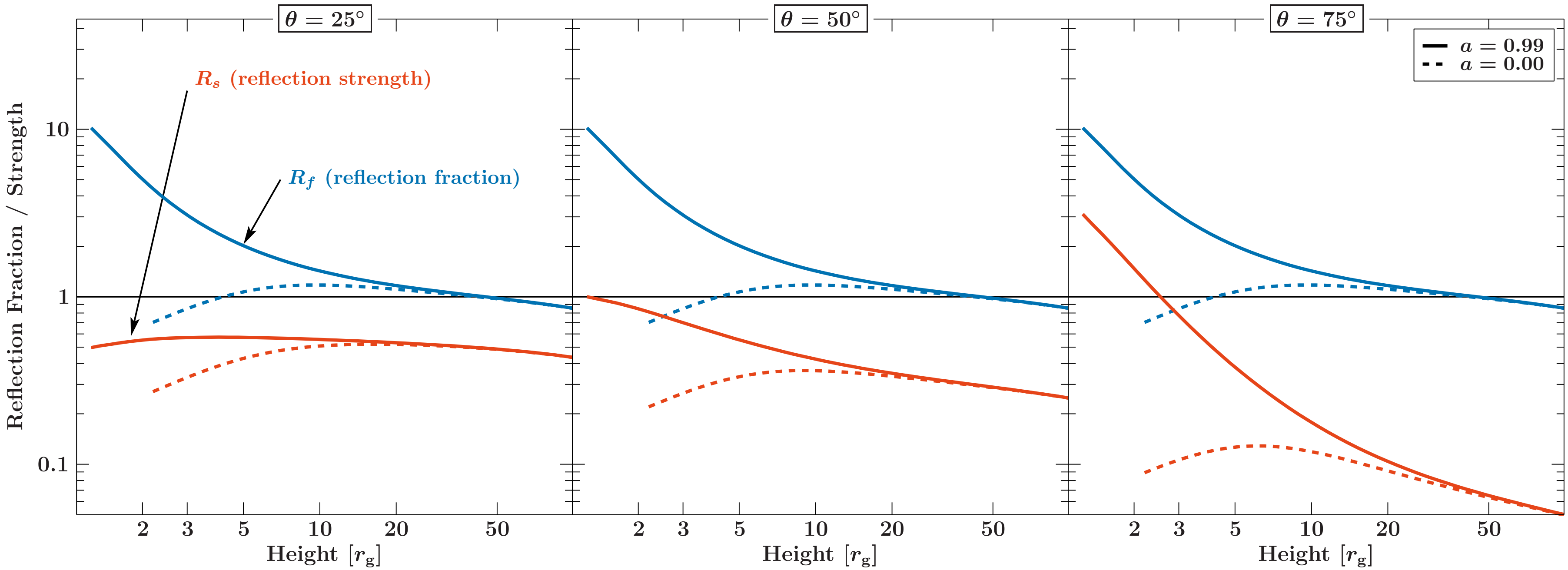
Relativistic Reflection: Predicted Reflection Fraction

reflection spectra: source at height *h* seen under inclination θ



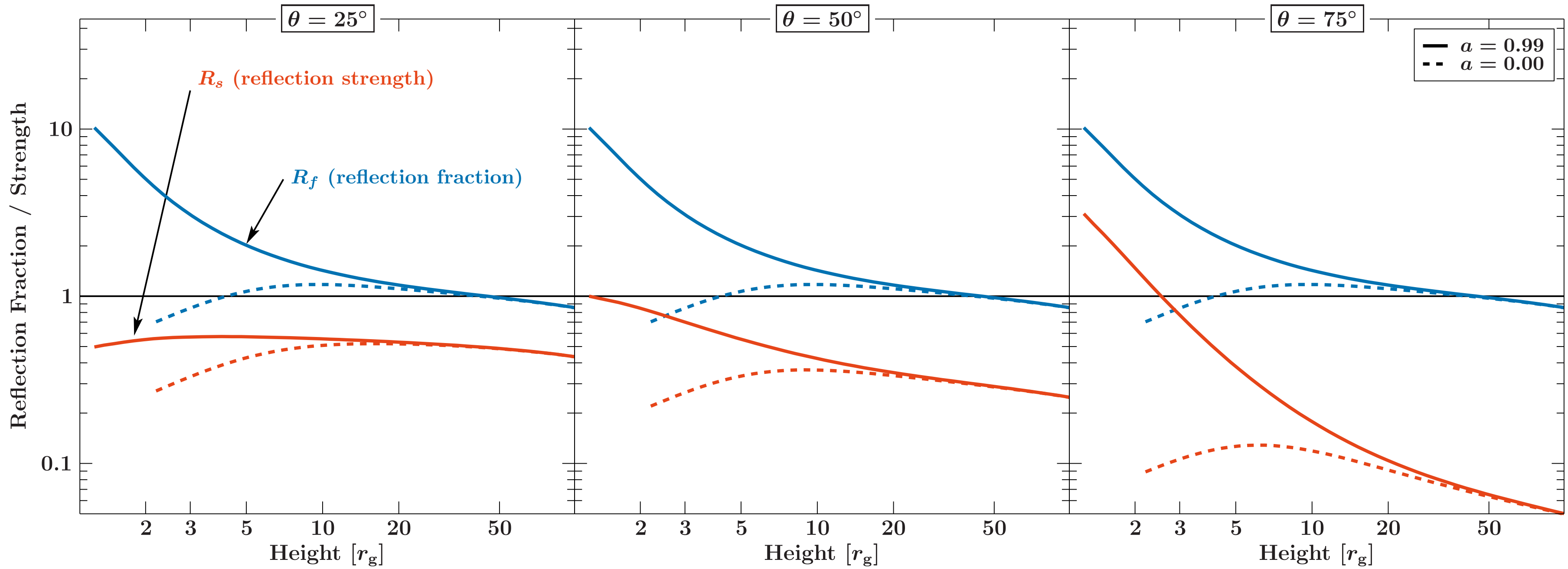
- strong dependency of reflection on inclination angle
- large boost in reflection fraction possible for low heights
- largest boost for large angle and low height source

Observed Spectrum: Reflection Strength



- strength (R_S) strongly depends on the inclination
- greatest strength for large inclination angles

Observed Spectrum: Reflection Strength



- strength (R_S) strongly depends on the inclination
- greatest strength for large inclination angles

$\rightarrow$ only **high reflection** fraction for **low height** and **large spin**
$\rightarrow$ prediction: some sources should show **strong reflection**

Sample Study: Testing the Lamp Post Geometry

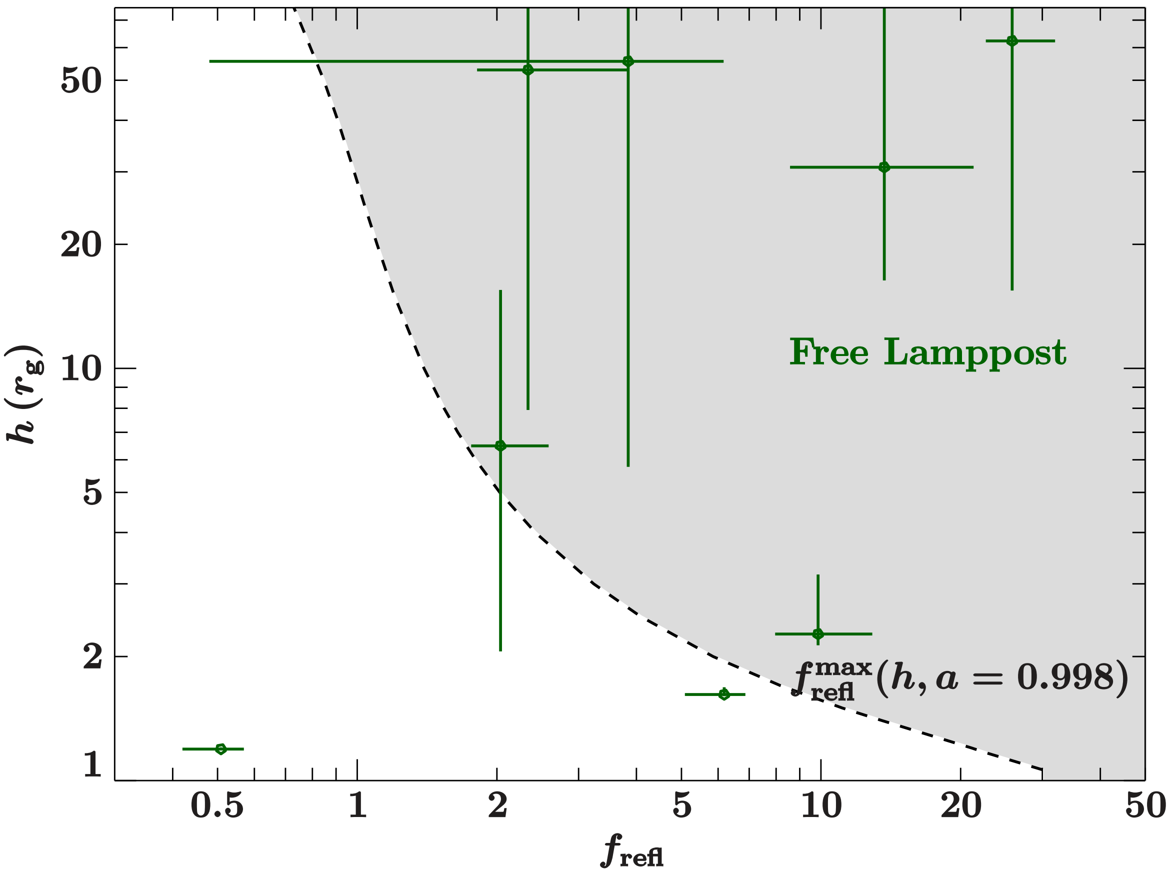
*Fink at al., in prep (**Poster J10**)*

Aim: Constraining the height of the primary source for a sample of sources $\Rightarrow$ **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**)*



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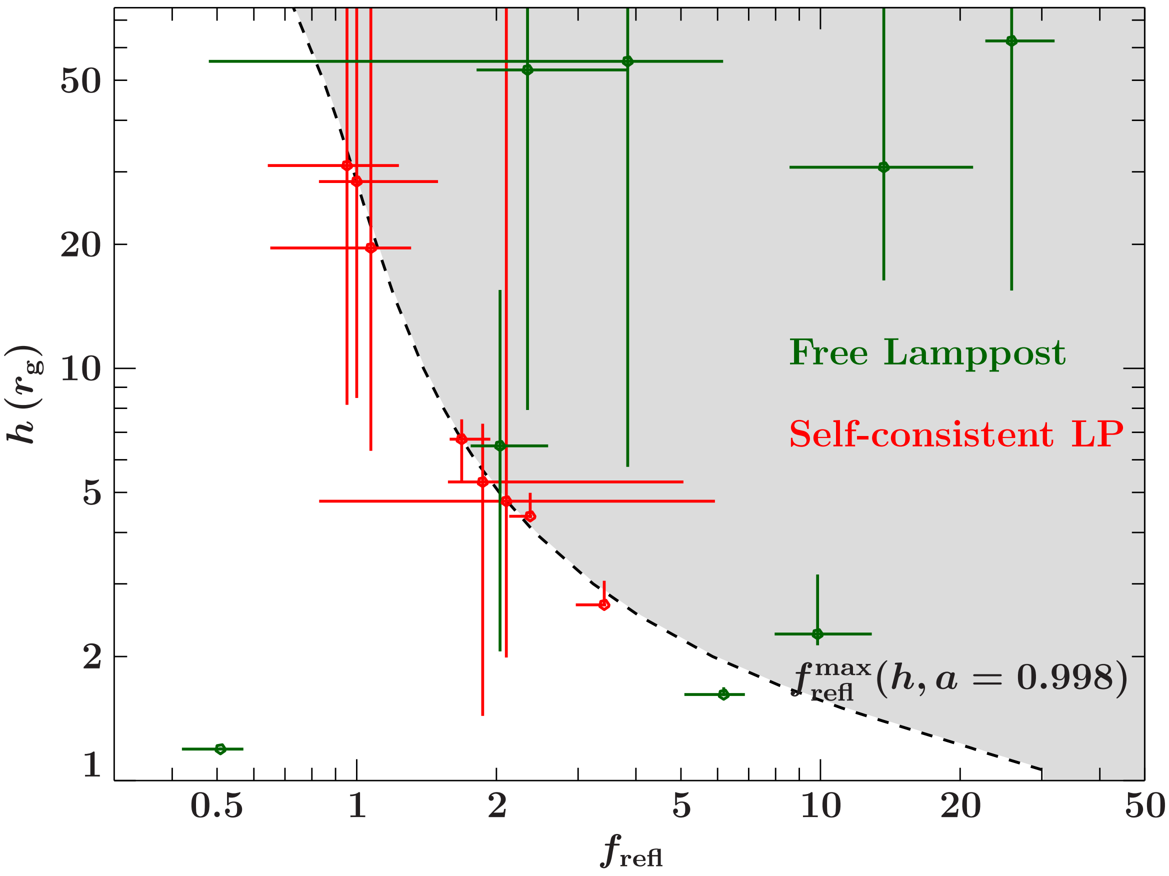
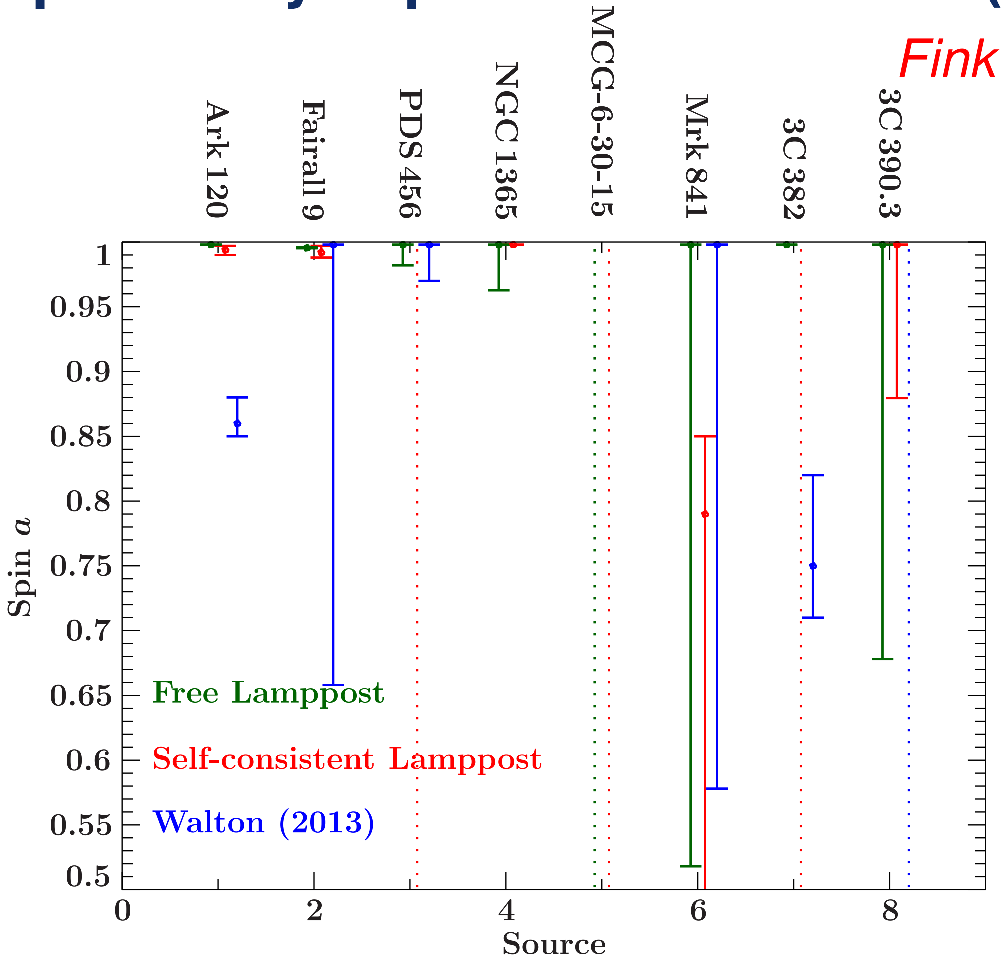


self-consistent normalization results in equally good fits

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**)*

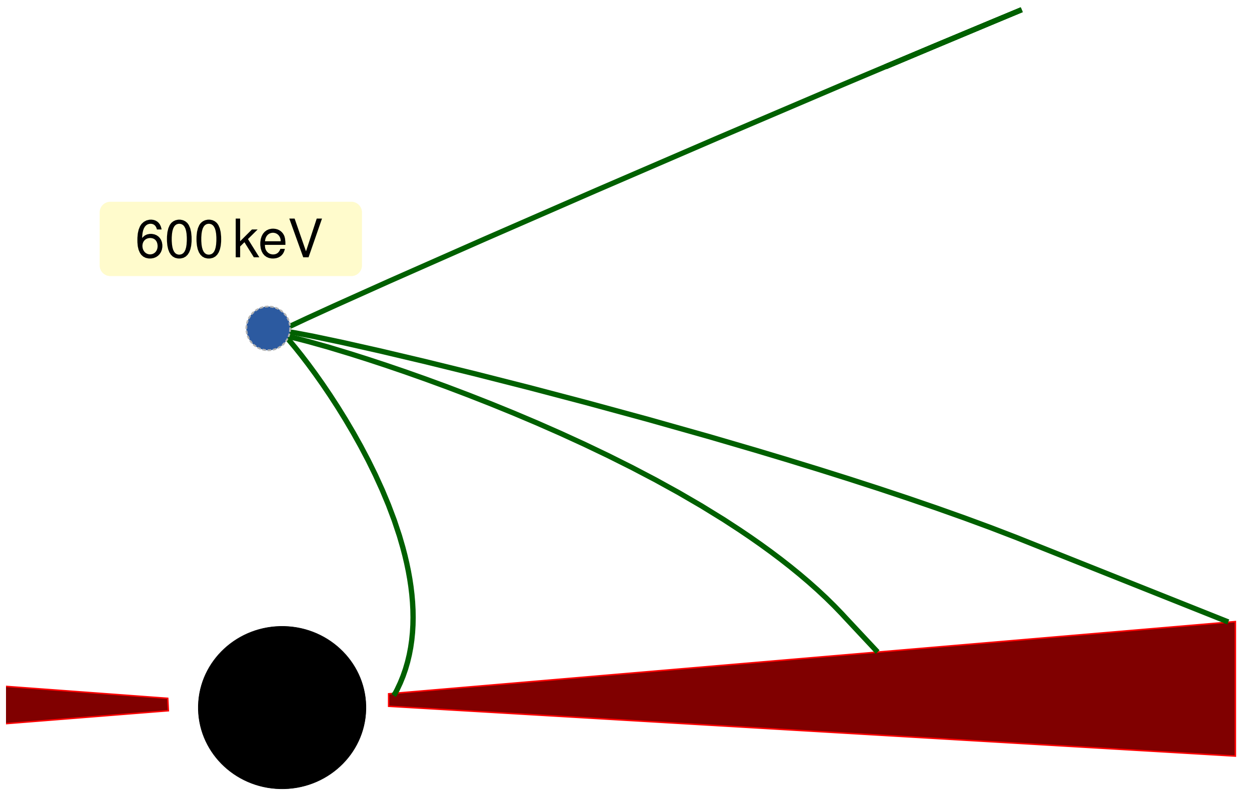


preliminary!

⇒ 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



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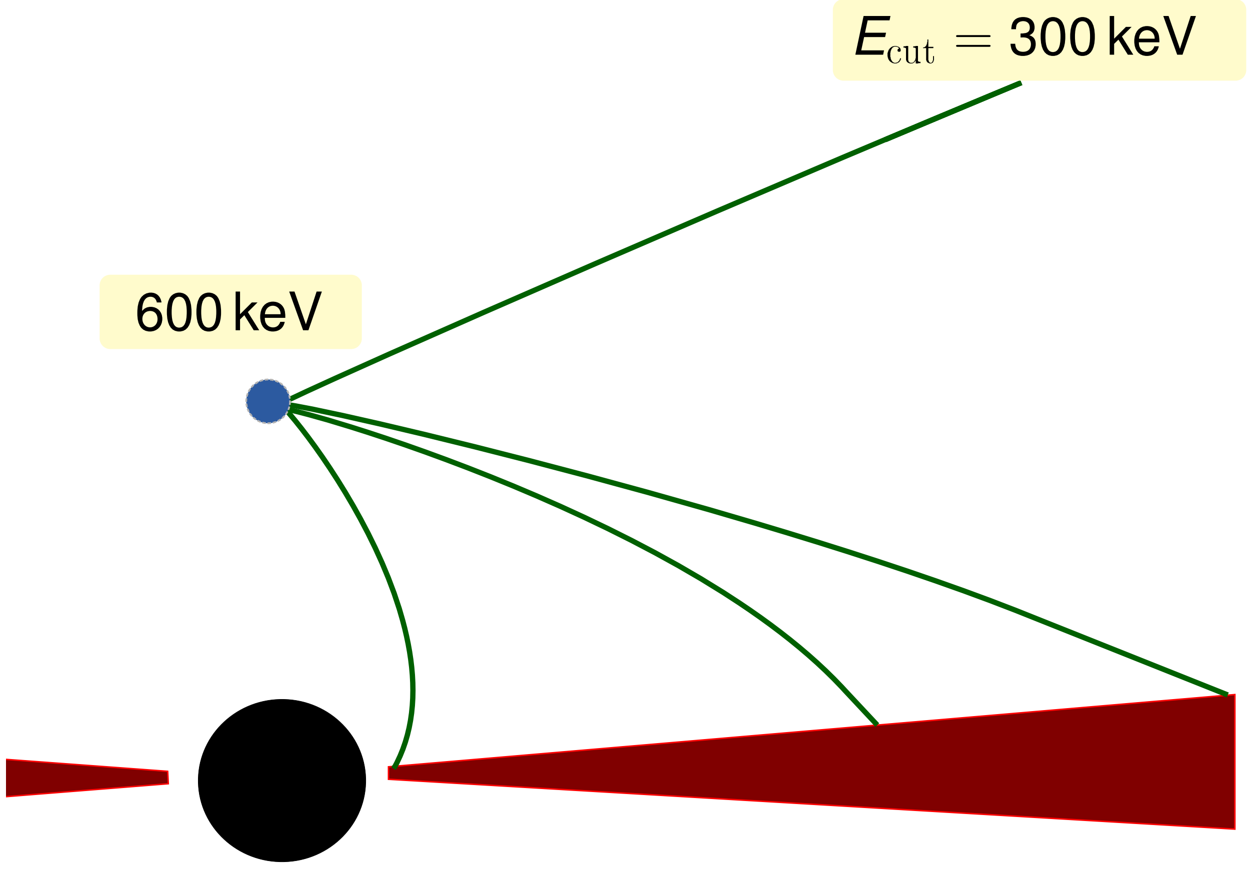

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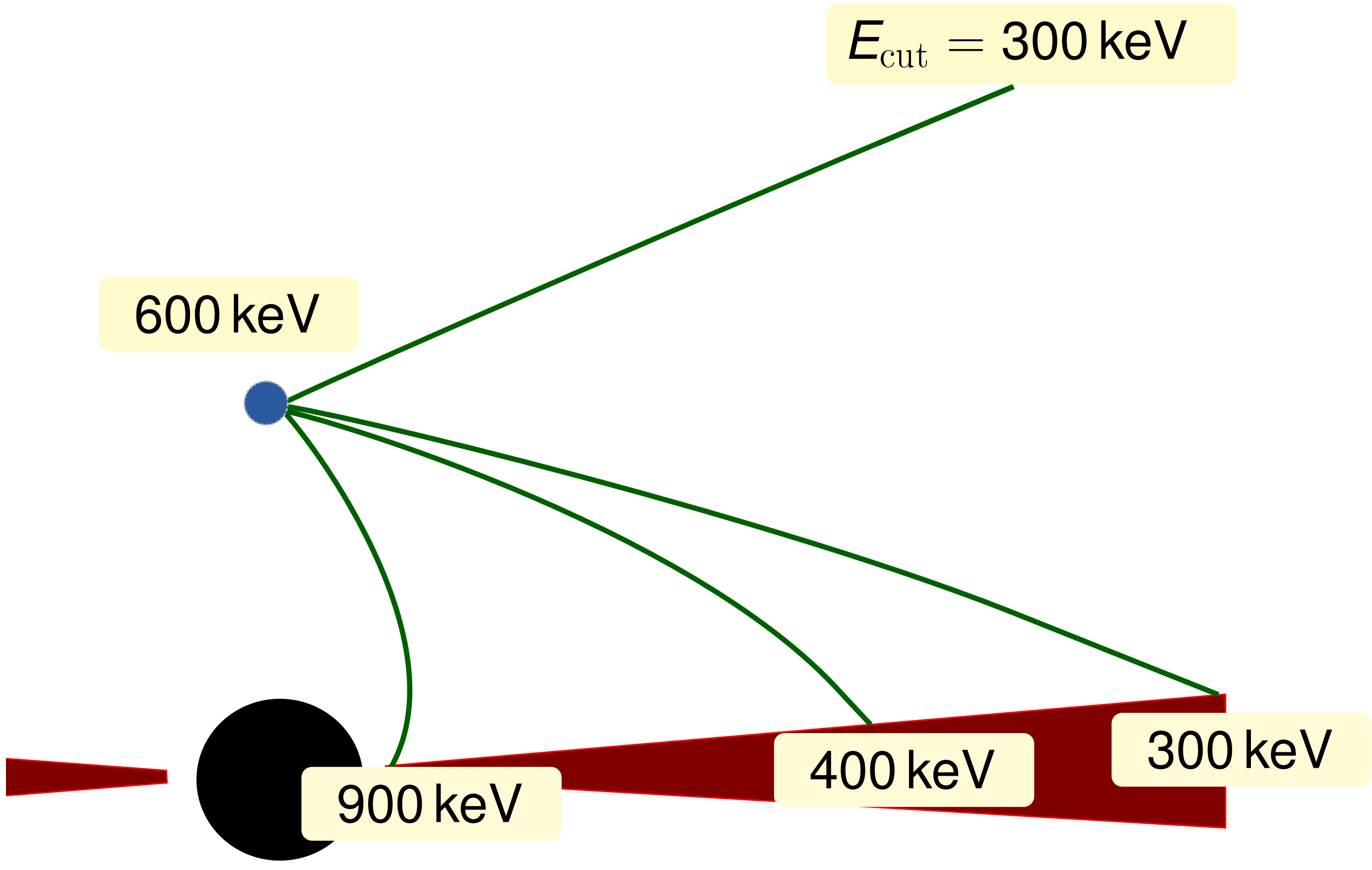

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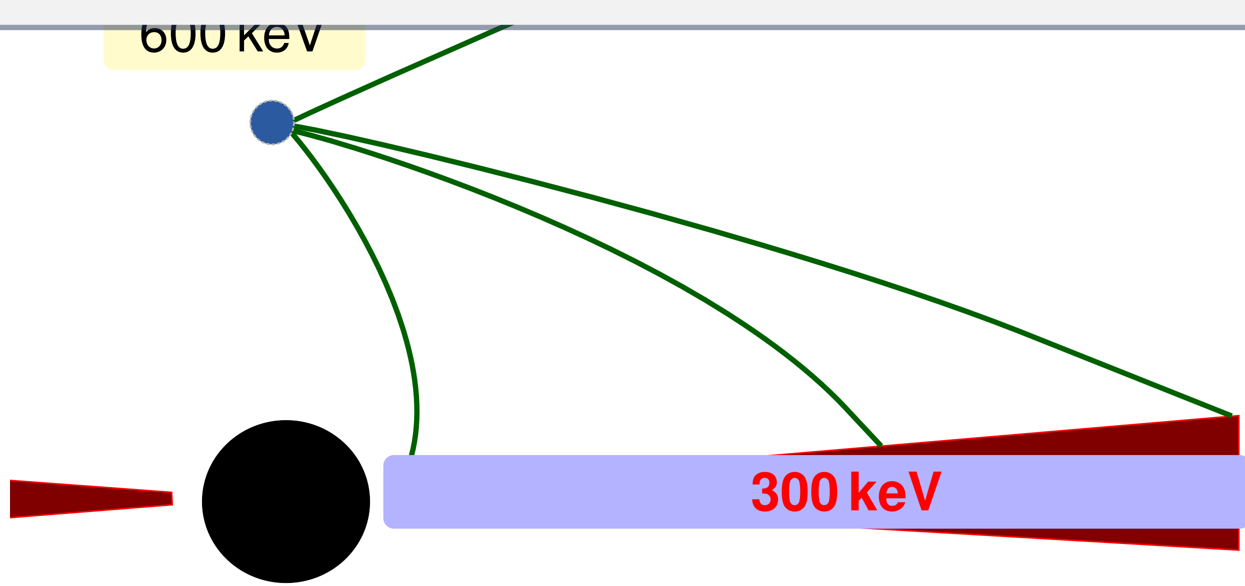
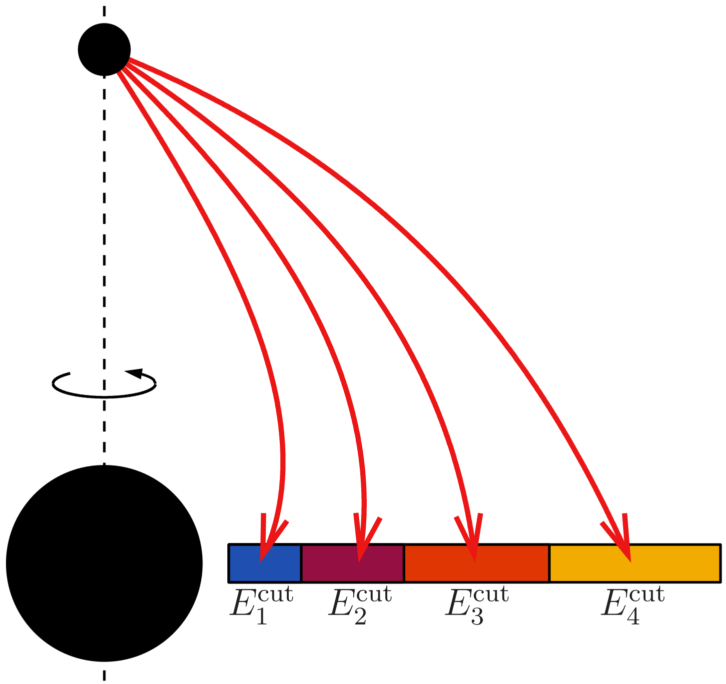
current **limitations of reflection modeling**:
one input spectral shape for the complete disk

problem: convolution of multiple zones of the accretion disk necessary, but **computationally very expensive**



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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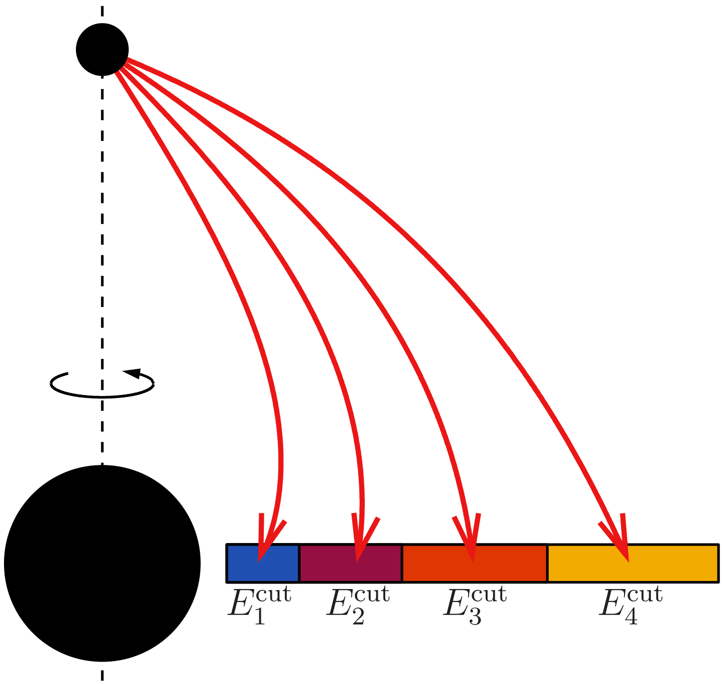


reflection spectrum for each zone relativistically smeared separately

download: `www.sternwarte.uni-erlangen.de/research/relxill/`

(other models unchanged, but faster: including `nthcomp`, coronal geometry, line models...)

relxill

modeling relativistic reflection

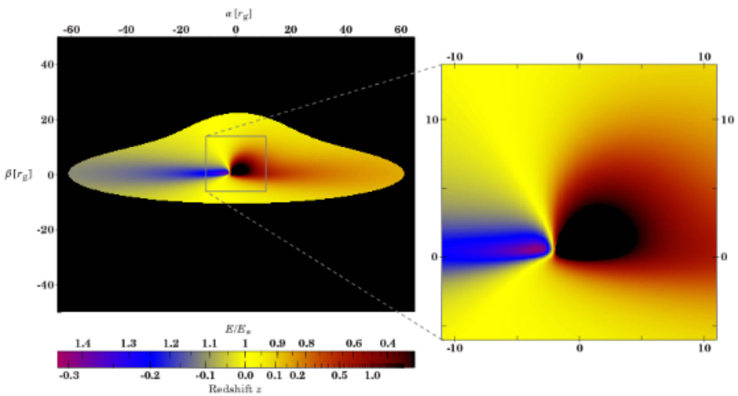
Home About Download Model Parameters Contact

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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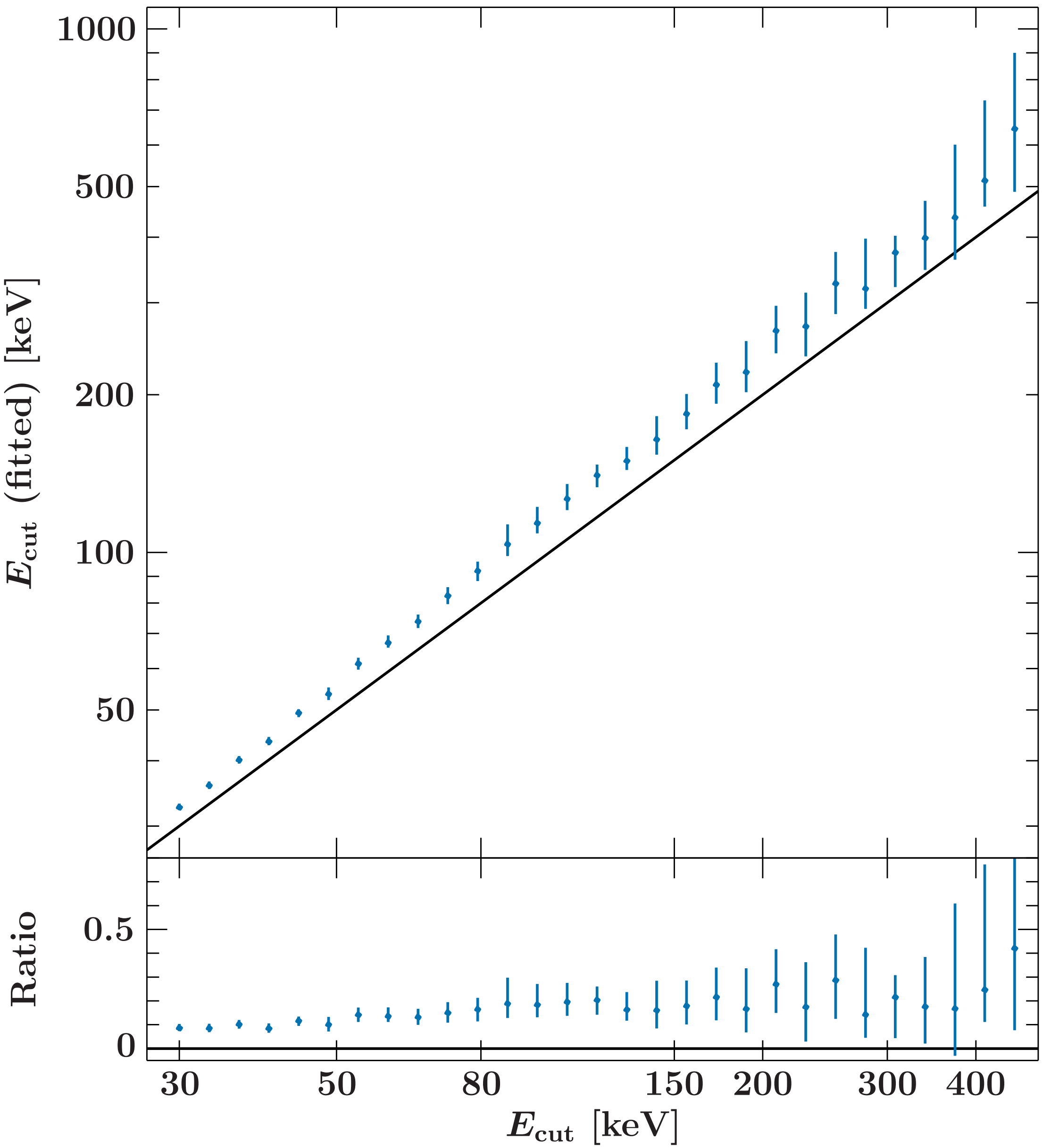
Multi-Zone Model: Change in Cutoff Energy



- 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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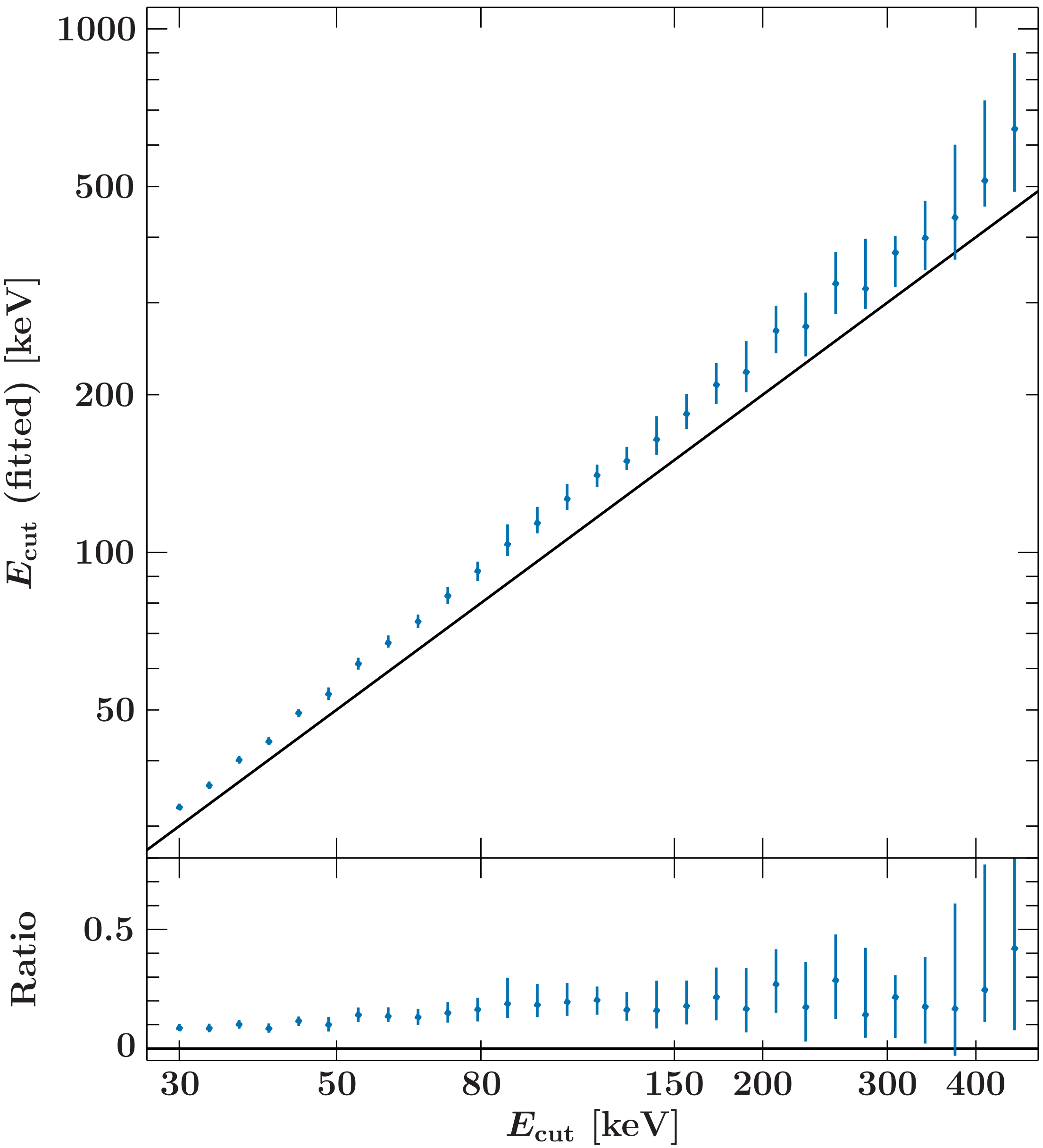

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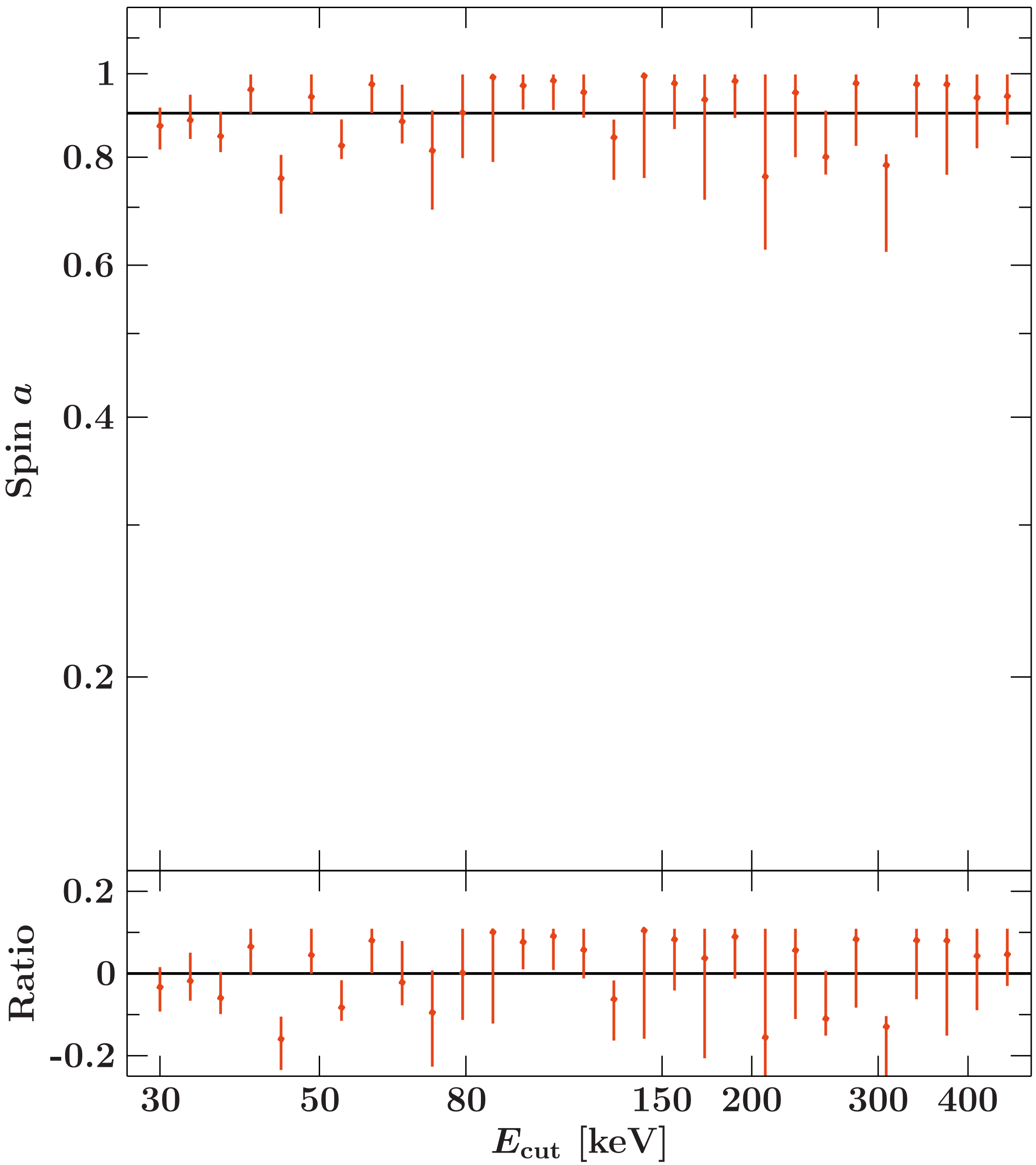
previously cutoff energy ≈10% over-predicted

Multi-Zone Model: Are other parameters affected?



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previously cutoff energy ≈10% over-predicted

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
  $\rightarrow$ **lamp post geometry describes data well**
- **new relxill model**: multiply radial zones for a proper modeling of the reflection (cutoff energy)
  $\rightarrow$ 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

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