Results from the use of the X-ray reverberation model KYNREFREV in XSPEC

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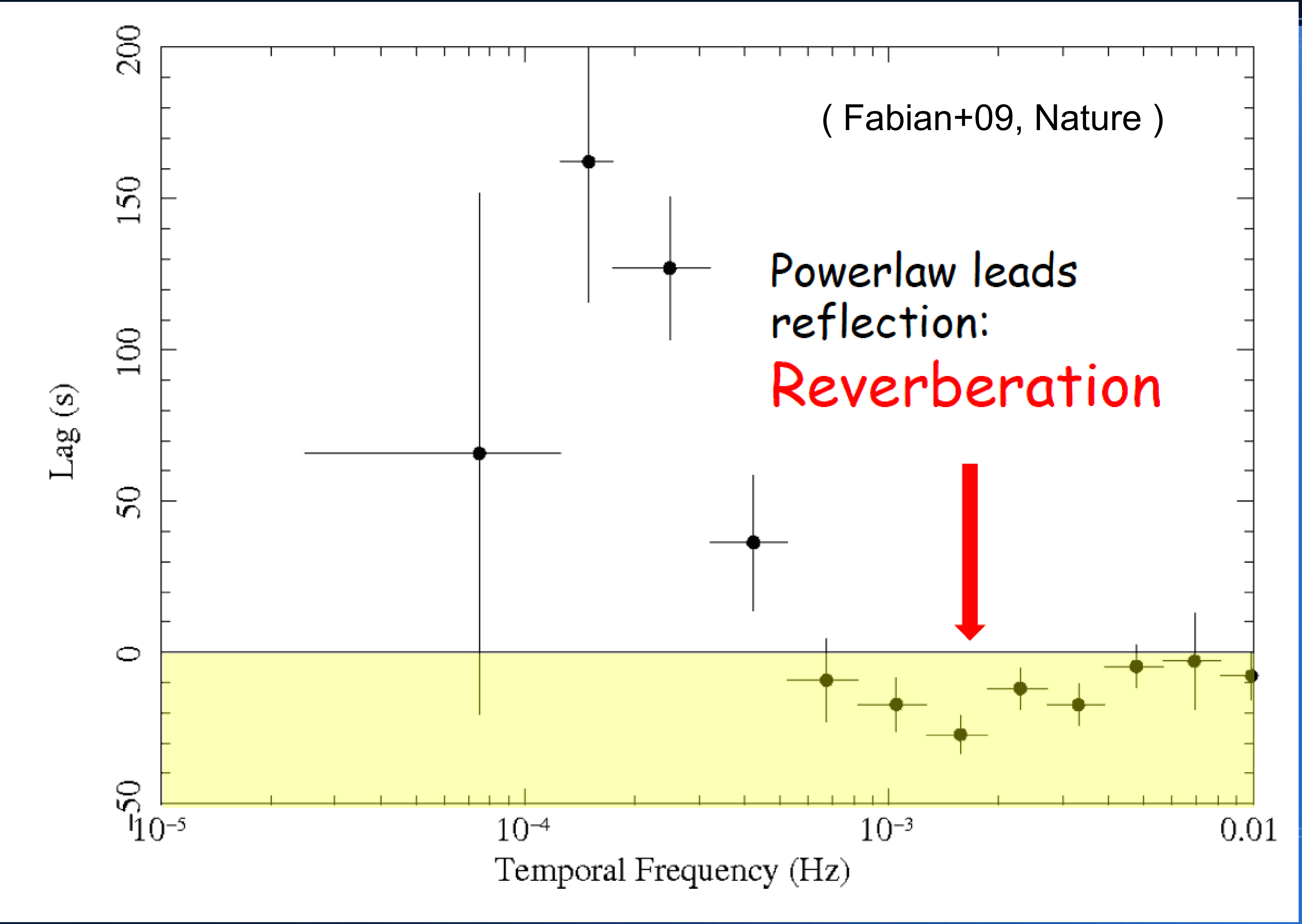
on behalf of a larger collaboration.

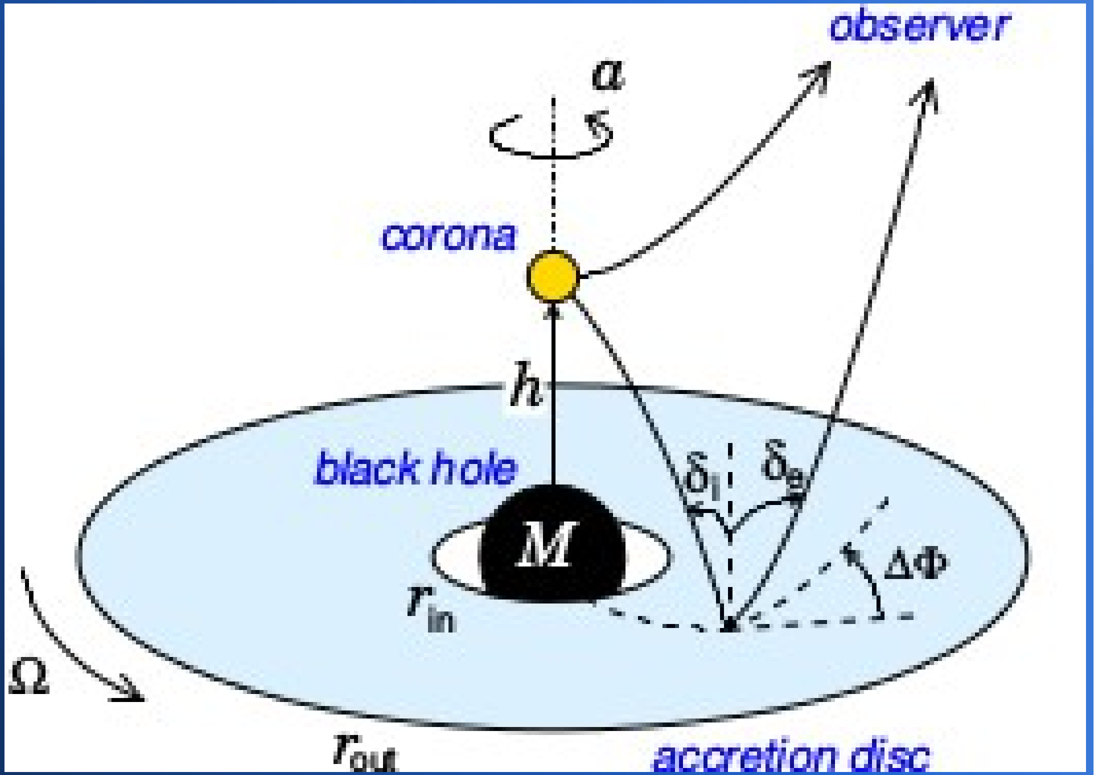
X-ray Soft/negative=reverberation lags



Reverberation in X-rays

Overview

- X-ray reverberation mapping of the inner parts of the accretion disc → clues to the geometry of the corona.
- Reverberation mapping in the lamp-post geometry of the compact corona → *ionisation of the disc (Chainakun+16,* Dovčiak+17, in prep.).
- **Goal**: understanding the lags versus frequency/energy → model parameters: **height** of the corona, **inclination** of the observer, disc **ionization** profile and black hole **spin**.



The sketch of the lamp-post geometry. (Credits: Dovčiak+14)

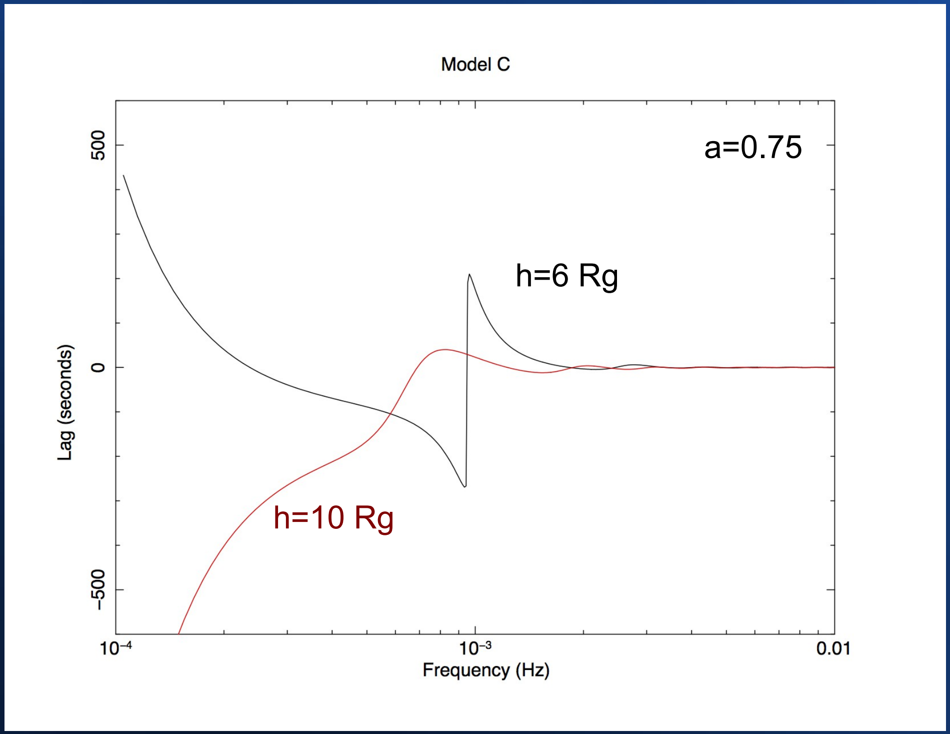
The model: *"The relativistic reflection model in the lamp-post geometry"*

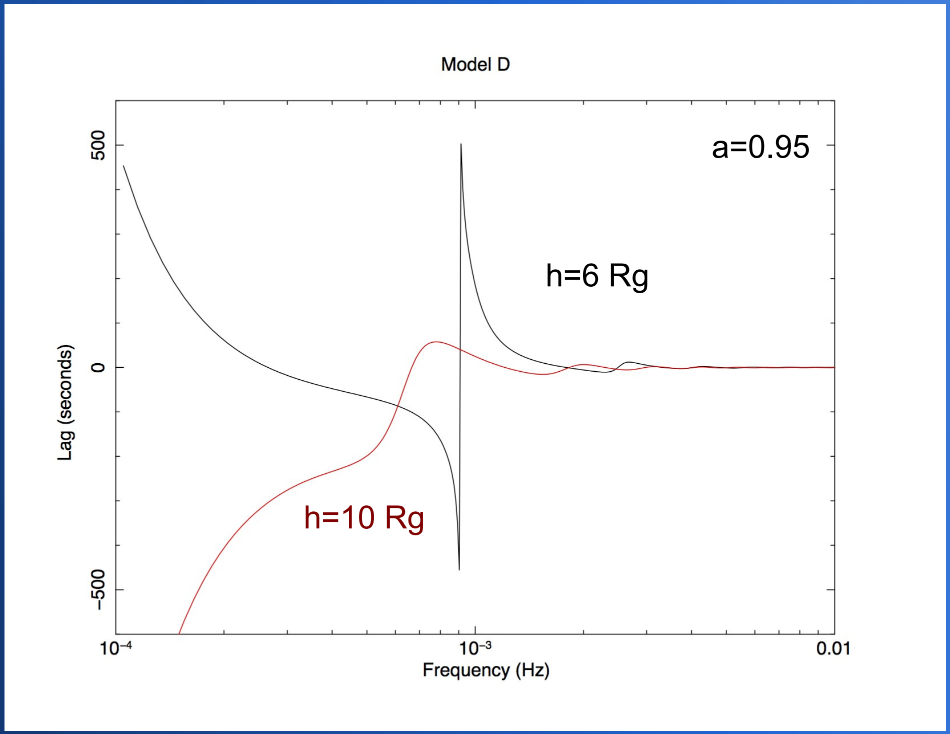
Approximations in KYNREFREV

- Black hole: Spinning BH, with mass M and dimensionless spin parameter a = 0 -1
- Accretion disc: co-rotating, Keplerian, geometrically thin, optically thick, *ionised* disc extending from r_{in} up to r_{out} (GM/c^2).
- Corona: **hot point-like plasma** on the rotation axis at height ***h*** and emitting power-law radiation, $F_p \sim E^{-\Gamma} e^{-E/Ec}$.
- Observer: with an inclination angle Θ_o with respect to the symmetry axis of the disc.
- Light rays: *Fully relativistic ray-tracing code in vacuum* for photon paths from the corona to the disc and to the observer & from the disc to the observer.
- Reflection: REFLIONX (Ross & Fabian, 2005), tables for constant density slab illuminated by the power-law incident radiation used to compute the re-processing in the ionised accretion disc.
- The ionisation of the disc, $\xi \rightarrow$ amount of the incident primary flux (dependent on the luminosity of the primary source, height of the corona and mass of the black hole) $\rightarrow$ density of the accretion disc (different *density radial profiles* are used).
- Several limb brightening/darkening prescriptions for directionality of the re-processed emission.

The model: *“The relativistic reflection model in the lamp-post geometry”*

Phase wrapping





Extrapolated to higher frequencies fitted models for IRAS 13224-3809 with the obtained value for spin given the data (0. 74± 0. 02; model C) and for a highly spinning BH (0. 95, model D) at left and right, respectively. See Caballero-Garcia et al. (2017)

The model: *"The relativistic reflection model in the lamp-post geometry"*

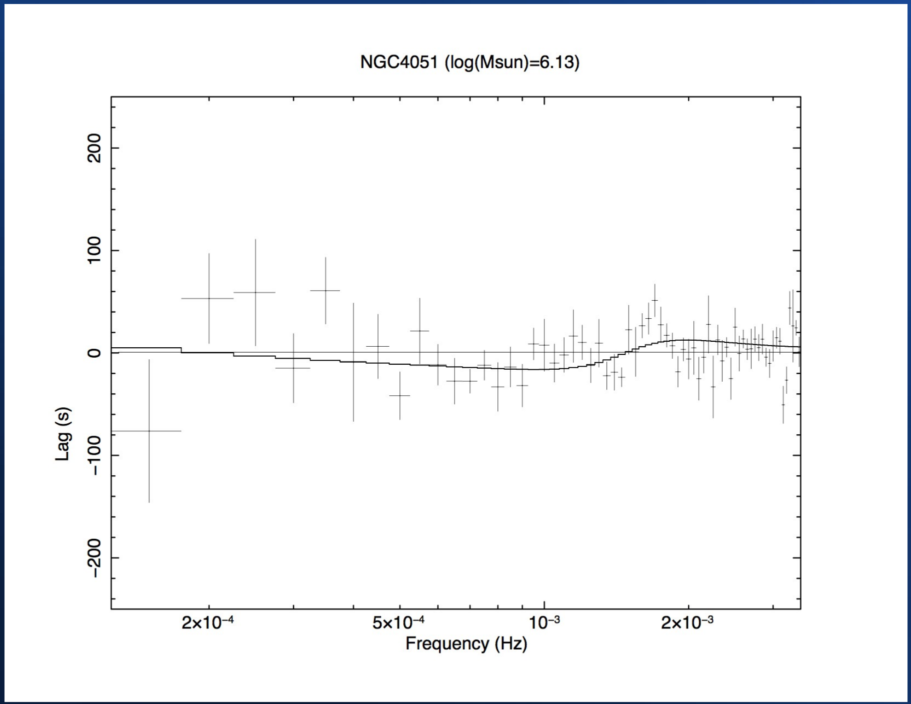
Fits with XSPEC using KYNREFREV

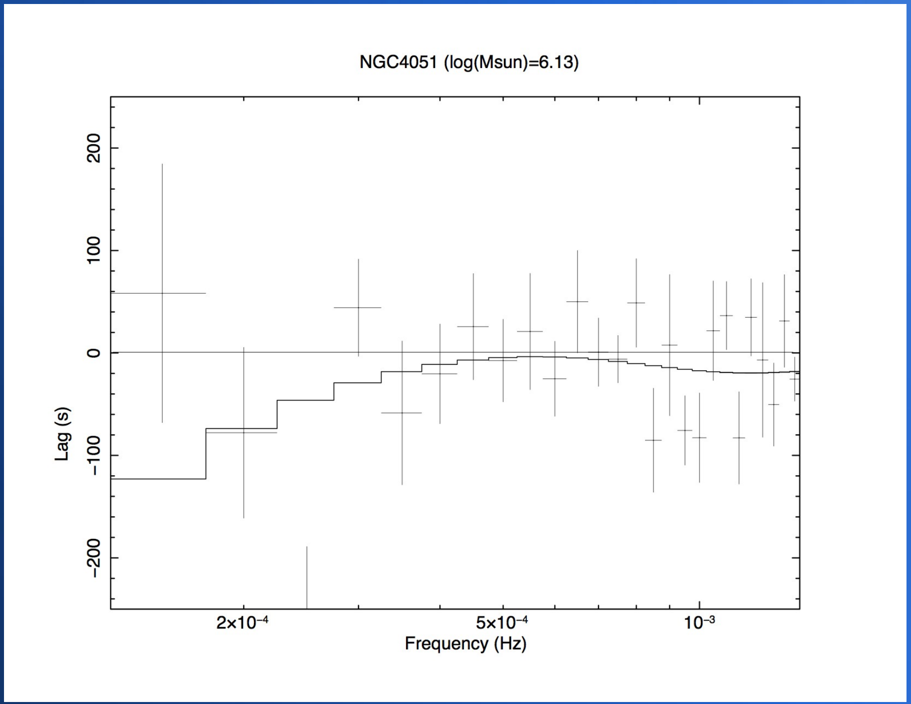
- We have produced time-lags from a sample of 10 AGN (in the mass range 10^6-10^8 $M_\odot$).
- Applying statistical procedures (Epitropakis & Papadakis+16) the light curve was divided in 20 ks segments in different energy bands taking the (2-4, 0.3-10, 1-10) keV reference energy bands.
- We used also the prescription of Epitropakis & Papadakis+17 for the continuum (hard) time-lags.
- We fitted the (0.3-1 vs. 2-4, 0.3-1 vs. 1-10, 5-7 vs. 2-4, 5-7 vs. 0.3-10 keV) time-lags versus frequency **global spectrum** with the KYNREFREV model.
- We obtain very good fits in gral. ($\chi^2_\upsilon \sim 1$) with a run-time of the order of seconds (i.e. alike normal X-ray energy-spectral fitting) → <u>Novel in XSPEC (and very efficient) method</u> !

The model: *“The relativistic reflection model in the lamp-post geometry”*

Fitting the data (using XSPEC):

NGC 4051

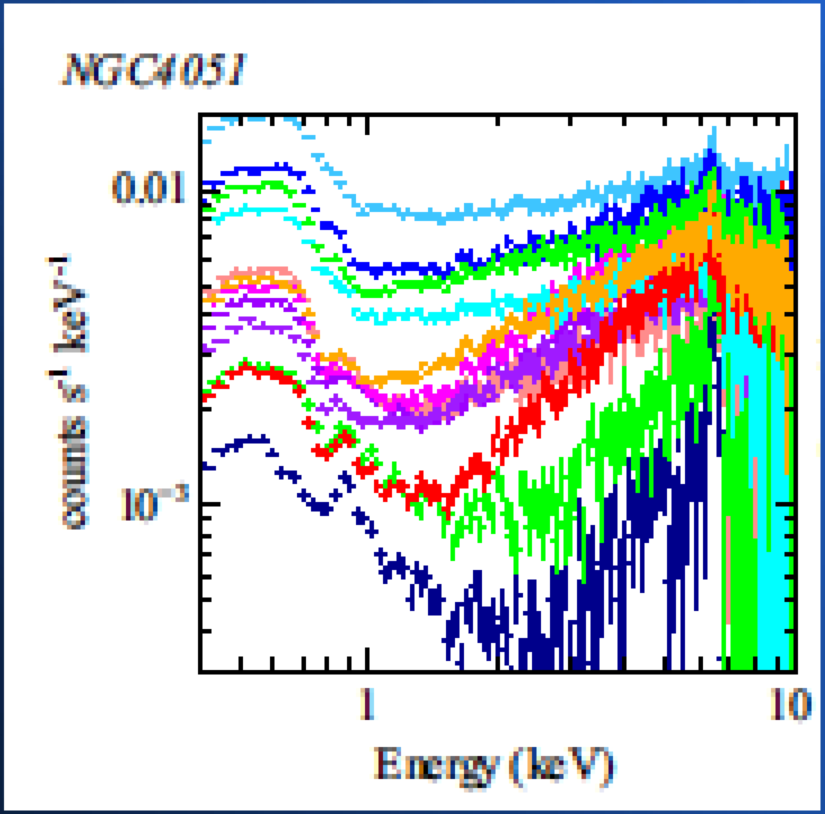




The soft lag-frequency fitted global spectra of NGC 4051 (0.3-1 vs. 2-4 keV and 5-7 vs. 0.3-10 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra (Kara+17)

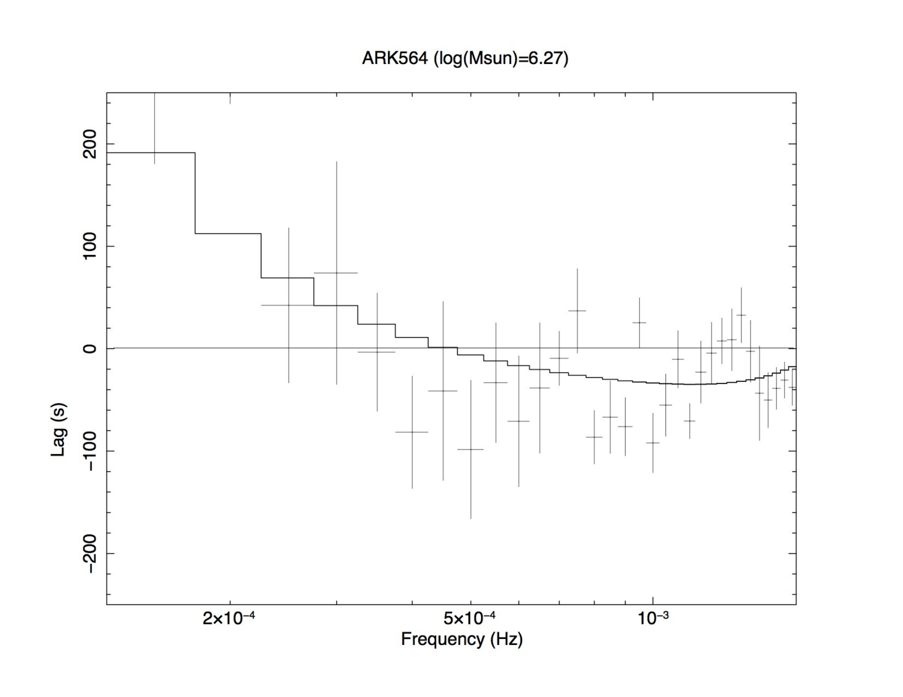


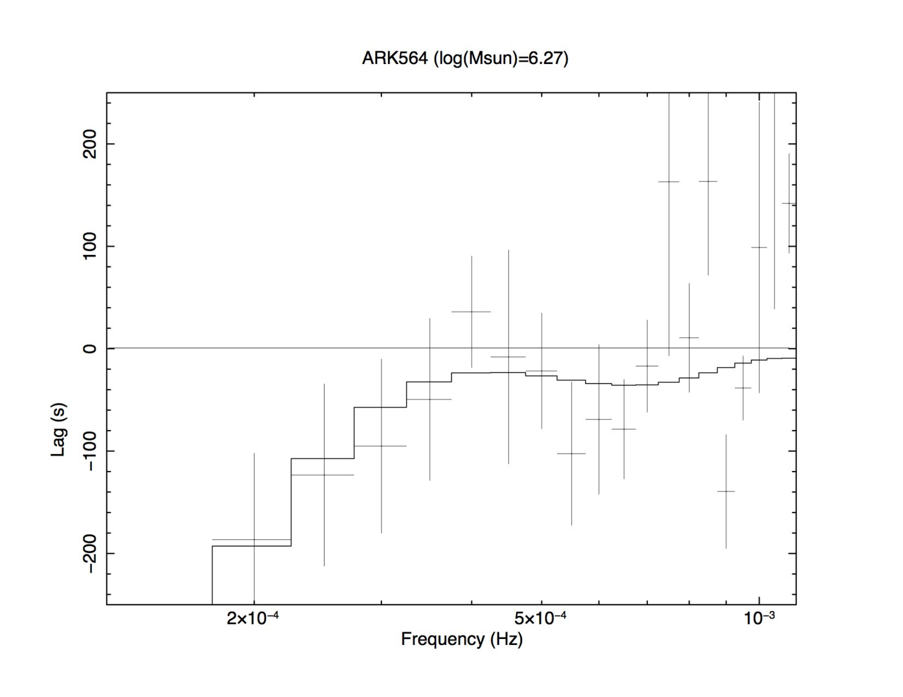
Spectral evolution of NGC 4051

The model: *“The relativistic reflection model in the lamp-post geometry”*

Fitting the data (using XSPEC):

ARK 564

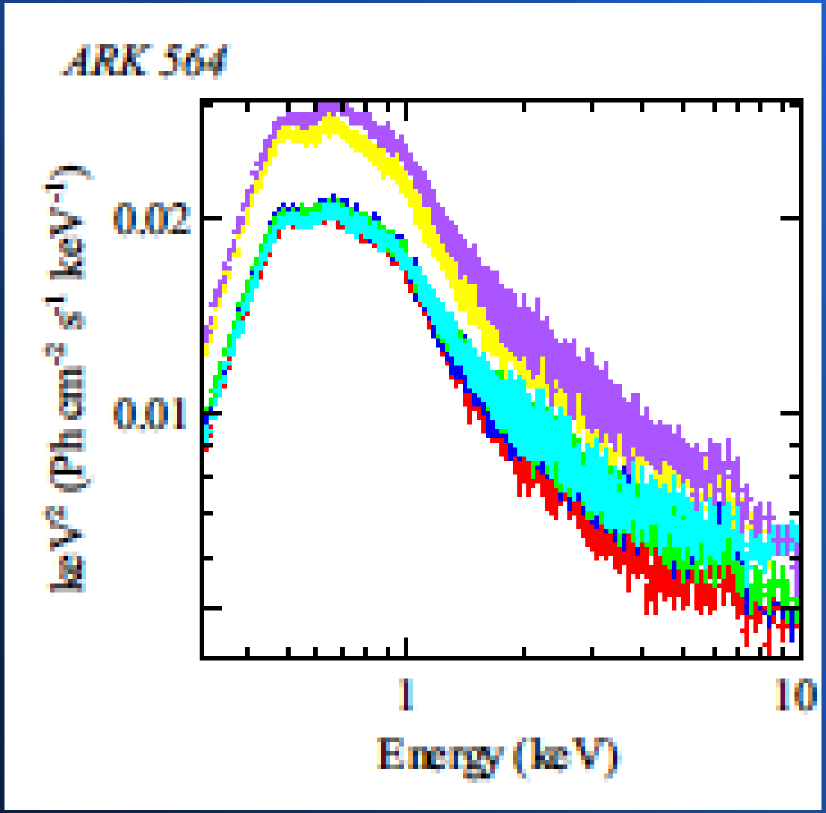




The soft lag-frequency fitted global spectra of ARK 564 (0.3-1 vs. 2-4 keV and 5-7 vs. 2-4 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra (Kara+17)

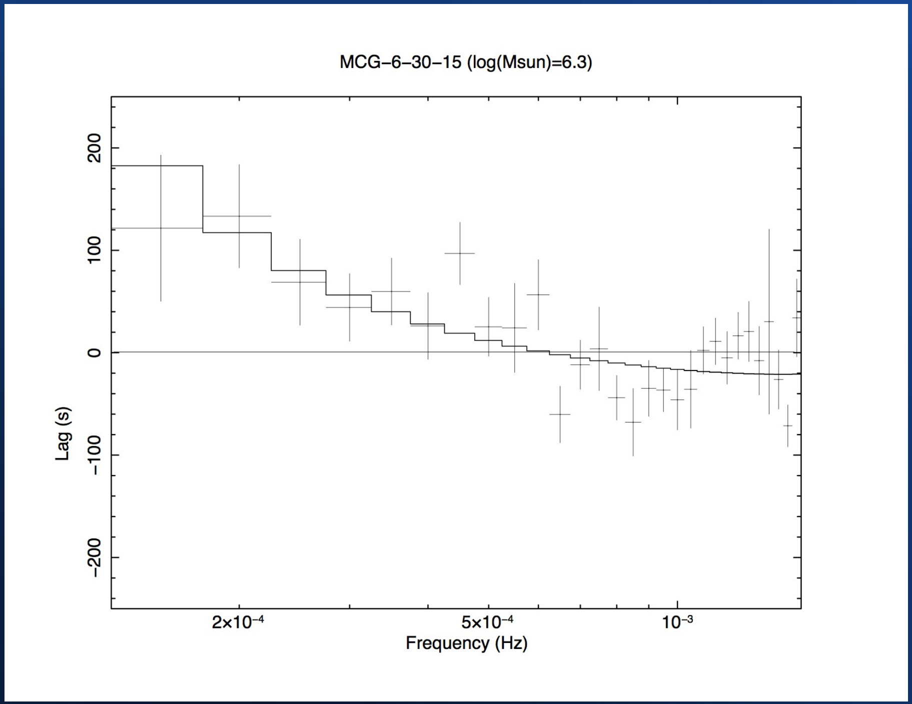


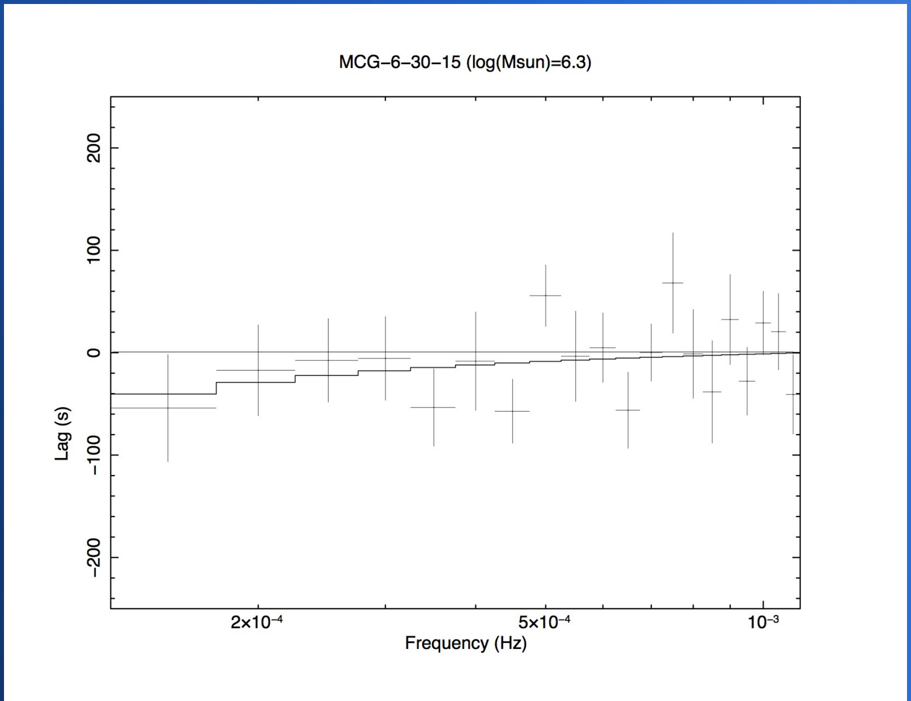
Spectral evolution of ARK 564

The model: *“The relativistic reflection model in the lamp-post geometry”*

Fitting the data (using XSPEC):

MCG-6-30-15

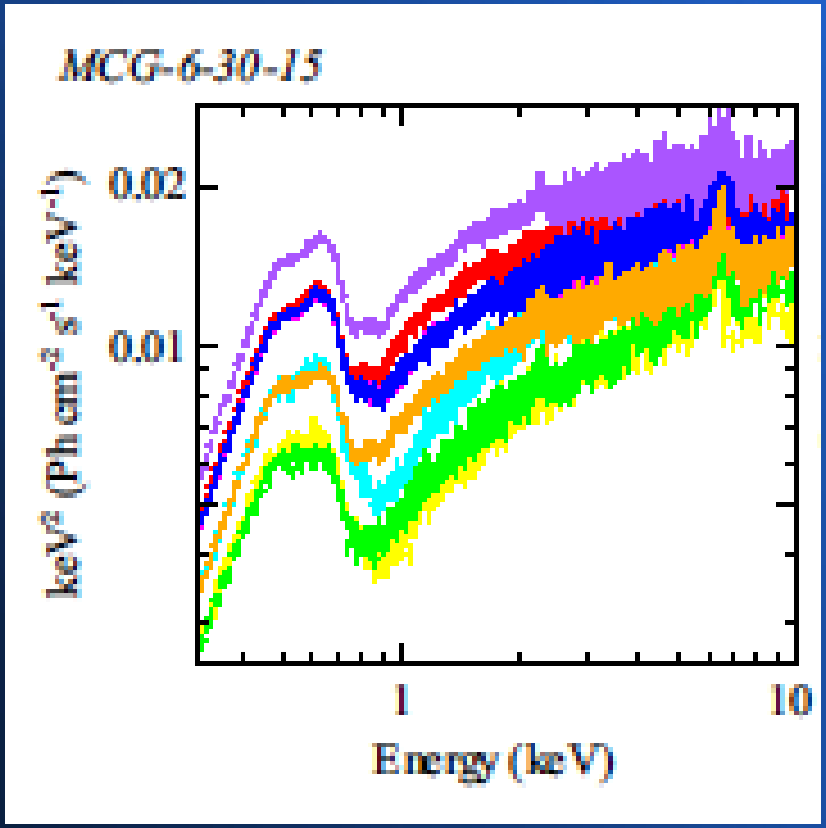




The soft lag-frequency fitted global spectrum of MCG-6-30-15 (0.3-1 vs. 2-4 keV and 5-7 vs. 2-4 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra (Kara+17)

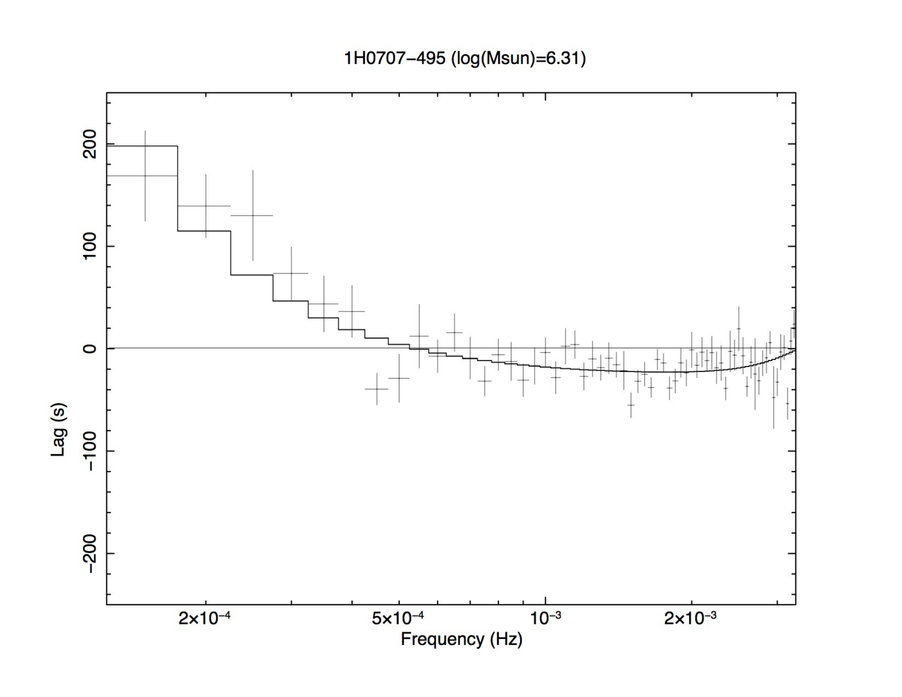


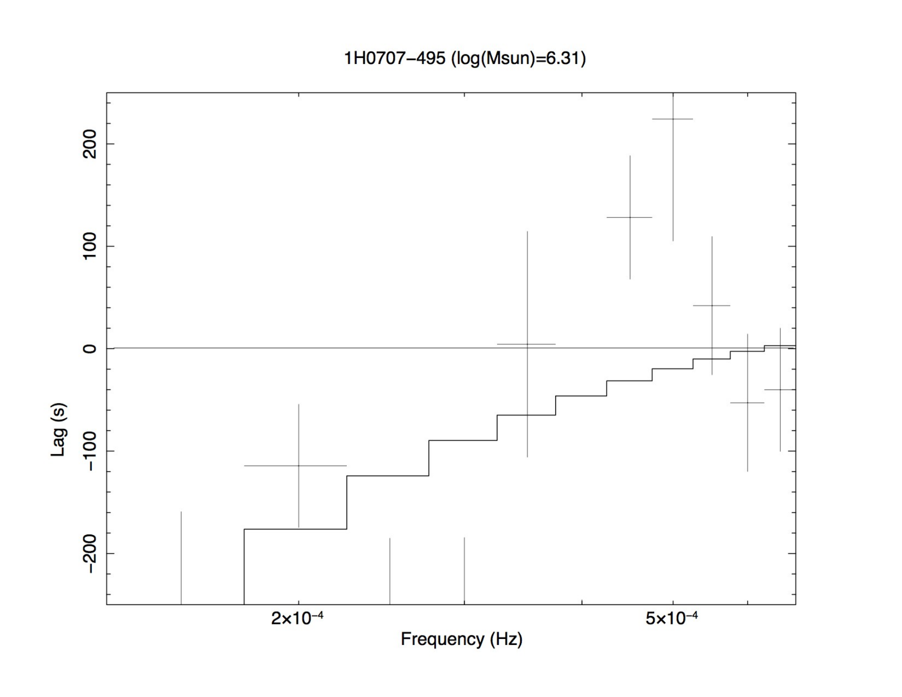
Spectral evolution of MCG-6-30-15

The model: *“The relativistic reflection model in the lamp-post geometry”*

Fitting the data (using XSPEC):

1H 0707-495

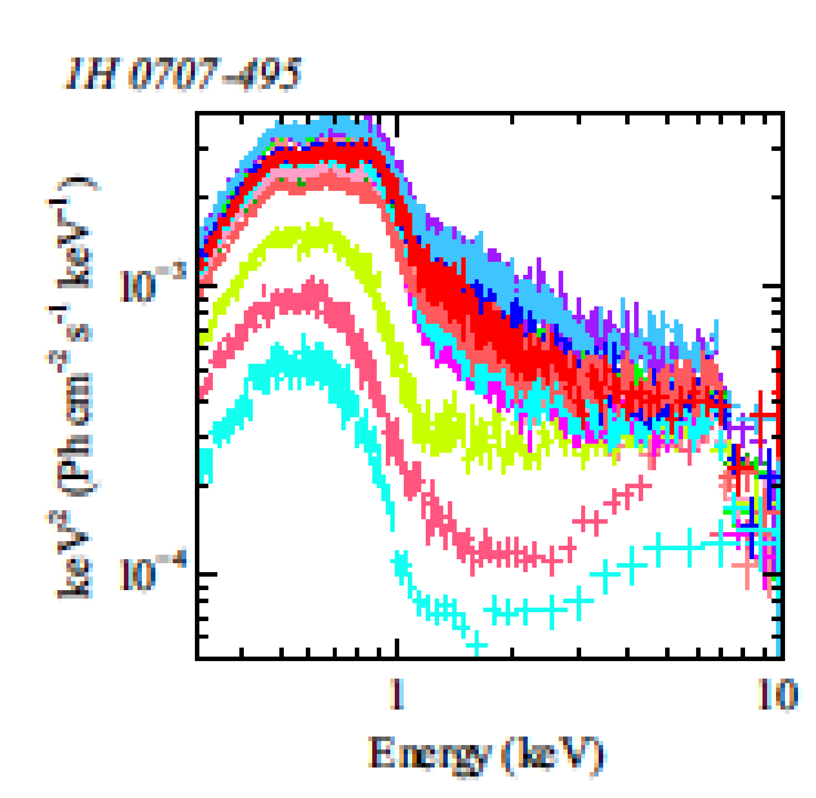




The soft lag-frequency fitted global spectra of 1H 0707-495 (0.3-1 vs. 1-10 keV and 5-7 vs. 0.3-10 keV) as obtained using XSPEC.

The model: *“The relativistic reflection model in the lamp-post geometry”*

X-ray energy spectra (Kara+17)

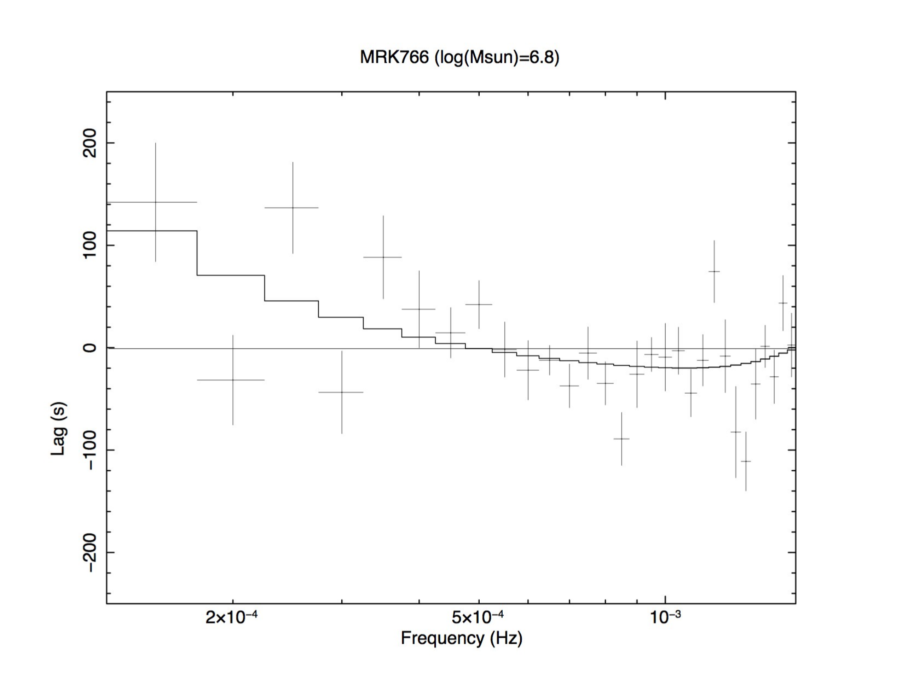


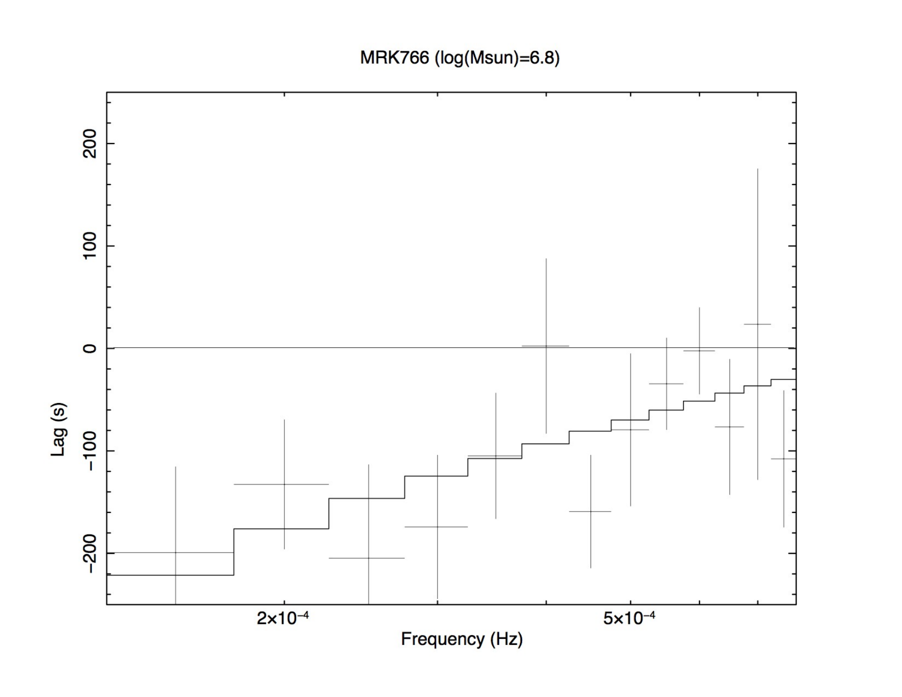
Spectral evolution of 1H0707-495

The model: *"The relativistic reflection model in the lamp-post geometry"*

Fitting the data (using XSPEC):

MRK 766

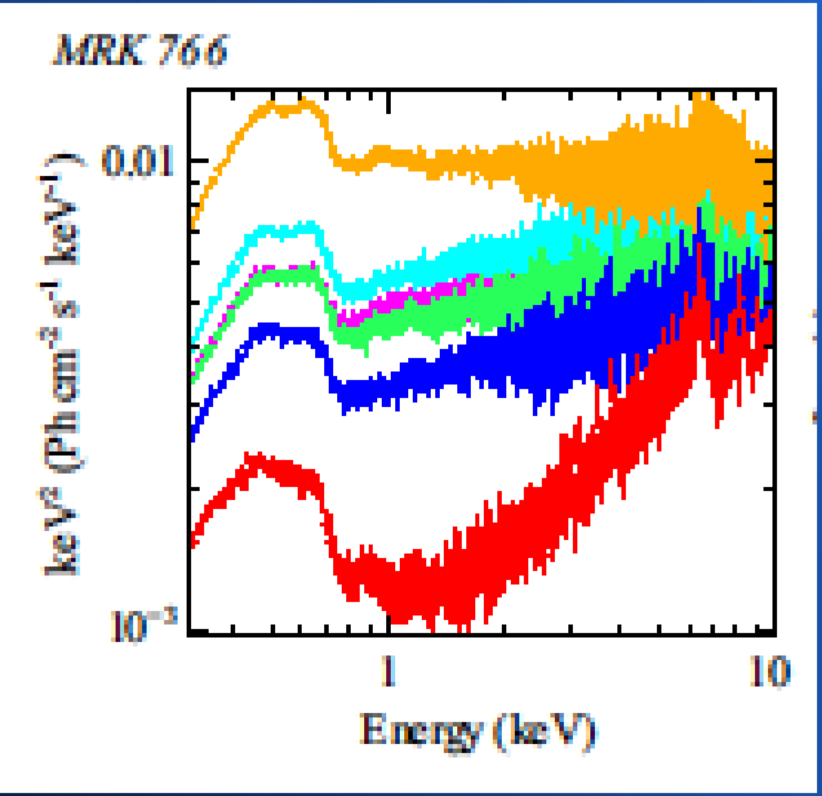




The soft lag-frequency fitted global spectra of MRK 766 (0.3-1 vs. 1-10 keV and 5-7 vs. 2-4 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra (Kara+17)

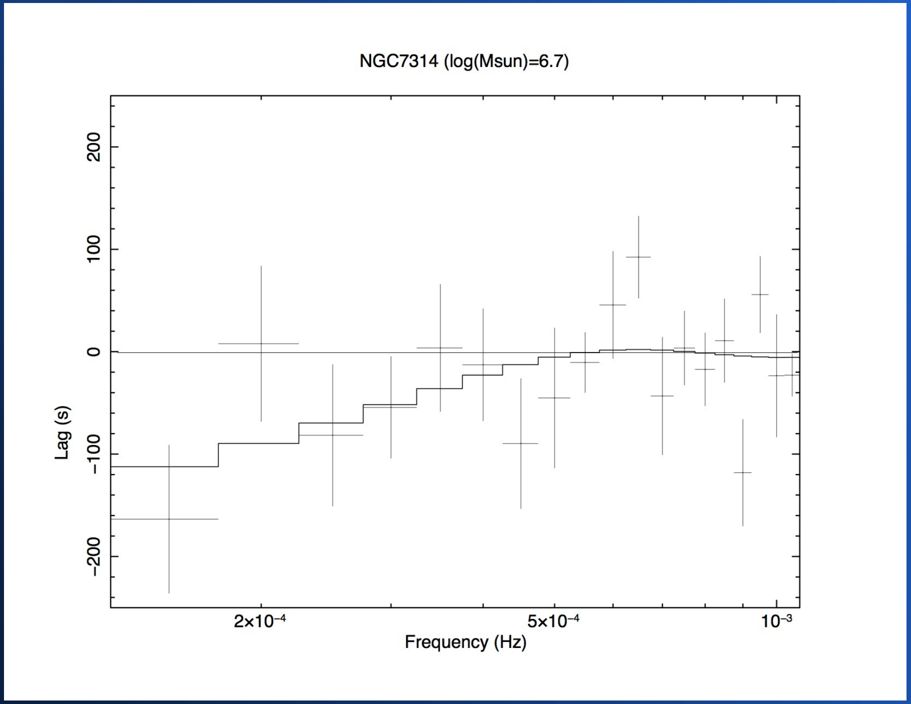


Spectral evolution of MRK 766

The model: *“The relativistic reflection model in the lamp-post geometry”*

Fitting the data (using XSPEC):

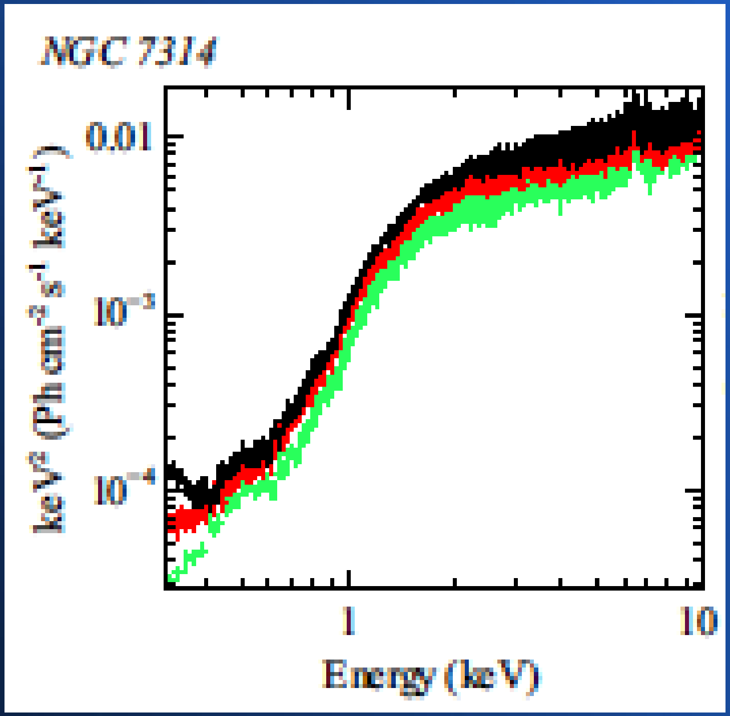
NGC 7314



The soft lag-frequency fitted global spectrum of NGC 7314 (5-7 vs. 2-4 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra (Kara+17)

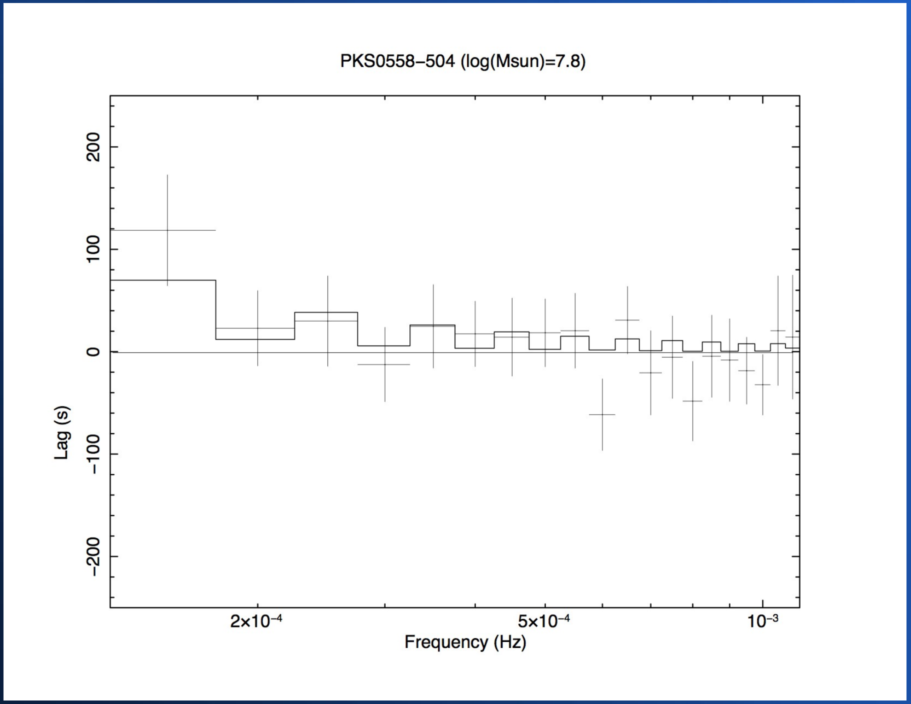


Spectral evolution of NGC 7314

The model: *"The relativistic reflection model in the lamp-post geometry"*

Fitting the data (<u>using XSPEC</u>):

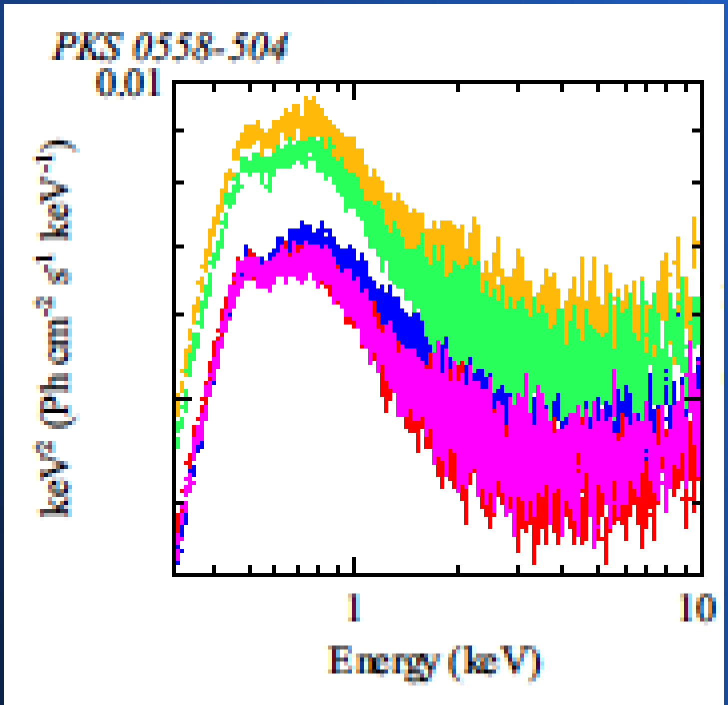
PKS 0558-504



The soft lag-frequency fitted global spectrum of PKS 0558-504 (0.3-1 vs. 1-10 keV) as obtained using XSPEC.

The model: *"The relativistic reflection model in the lamp-post geometry"*

X-ray energy spectra ([Kara+17])



Spectral evolution of PKS 0558-504

The model: *“The relativistic reflection model in the lamp-post geometry”*

log(Mass) $log(M_\odot)$	Spin a/M (GM/c)	View. angle θ_o	Height h (GM/c^2)
	NGC 4051		
6.13	0.30±0.15	75±10	25±15
	ARK 564		
6.27	≤0.5	≤60	≤50
	MCG-6-30-15		
6.3	≤0.25	70±20	10±5
	1H 0707-495		
6.31	0.64±0.12	≤40	6±2
	MRK 766		
6.8	≤1	60±8	20±5
	PKS 0558-504		
7.8	≤1	≤8	≤11

Parameters: 1) a/M; 2) Theta_o; 8) M/M8 and 9) ***height***

The model: *"The relativistic reflection model in the lamp-post geometry"*

Results

- The values for the parameters obtained ***h and*** Θ_o are well-constrained and *in coarse* agreement with Emmanoulopoulos+14, Epitropakis+16 differences because <u>the ionization of the disc is now included</u> !).
- 1H 0707-495 *has the lowest values for the inclination angle and height* of the lamp post.
- NGC4051 have (averaged) time-lags ≈ 0 because its energy-spectrum is highly variable. [NOTE that we have taken all the data available to produce the lags]
- The <u>values obtained for *the spin are lower than the ones found from spectroscopy*</u> (e.g. Brenneman+13,14; see discussion in Caballero-Garcia+17).

The model: *"The relativistic reflection model in the lamp-post geometry"*

Conclusions

- First lamp-post reverberation model taking into account all known physical aspects is **ready for use into XSPEC** (Dovčiak+17, in prep.).
- KYNREFREV is very **well suited for obtaining the height *h* of the lamp-post corona.**
- **We are working further to solve phase wrapping effects in order to get realistic values for the spin parameter.**
- **The last version of the code includes thermal reverberation from the accretion disc.**
- The lamp-post is the first approximation. More work is needed in the future in order to address *possible **(other) extended coronae geometries***.

Acknowledgements

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STRONGGRAVITY

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