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

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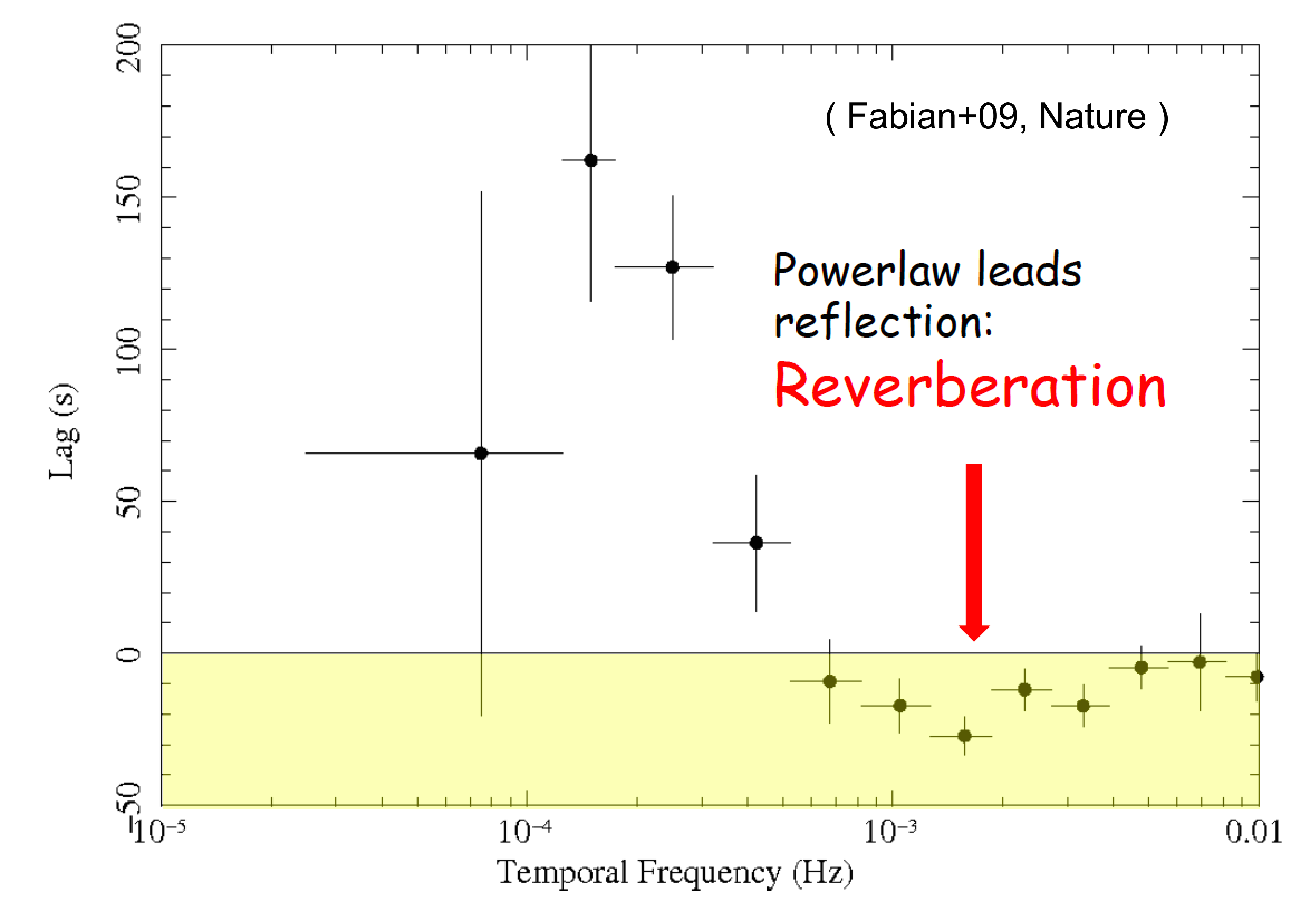
on behalf of a larger collaboration.

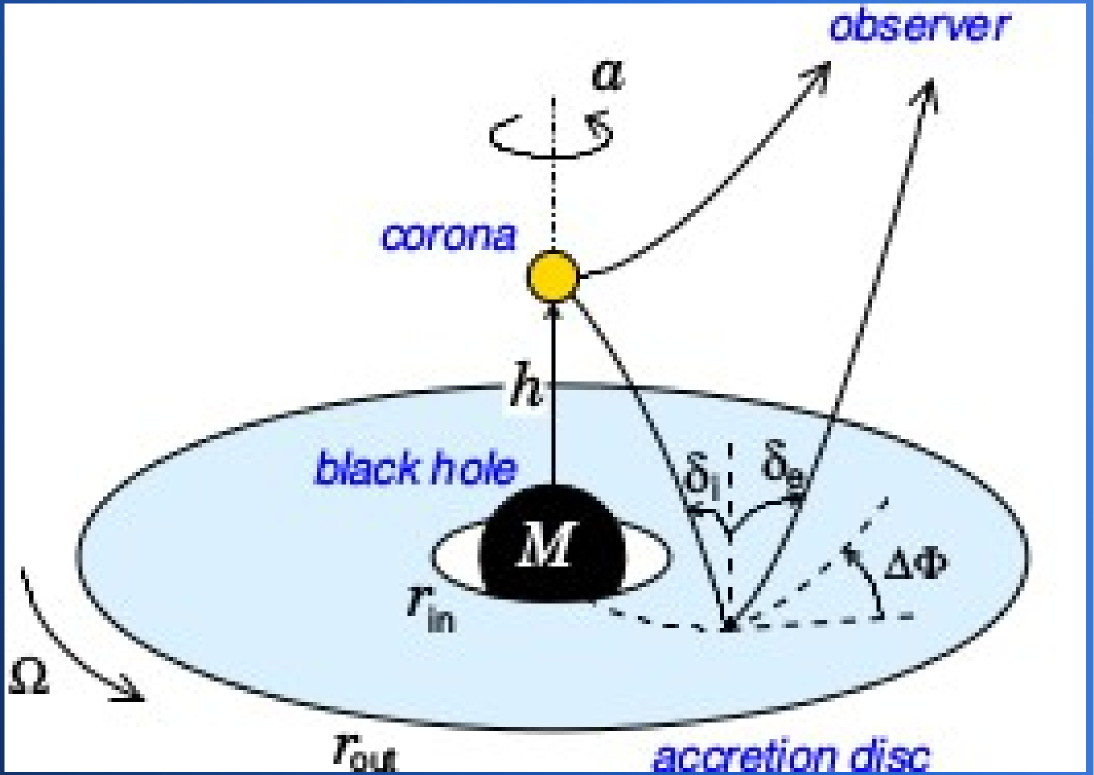
X-ray Soft/negative=reverberation lags



Reverberation in X-rays

Overview

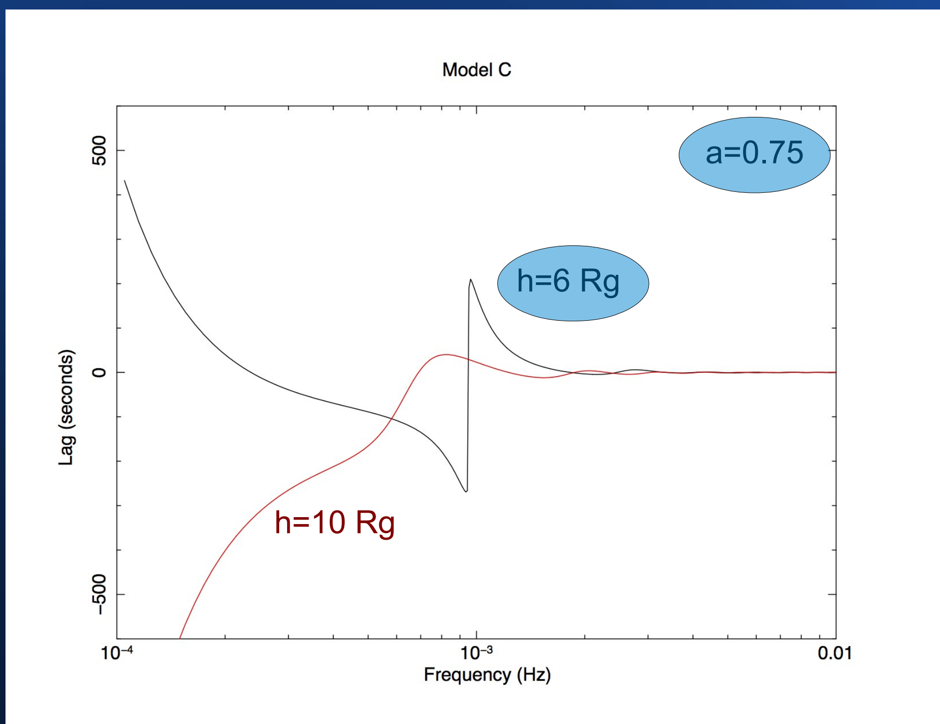
- X-ray reverberation mapping of the inner parts of the accretion disc → clues to the geometry of the corona.
- Reverberation mapping in the lamp-post geometry of the compact corona → *ionisation profile of the disc (Chainakun+16,* Dovčiak+17, in prep.).
- <u>Light rays</u>: *Fully relativistic ray-tracing code in vacuum* for photon paths from the corona to the disc and to the observer & from the disc to the observer.
- **Goal**: *understanding the lags versus frequency/energy* → model parameters: **height** of the corona, **inclination** of the observer, disc **ionization profile** and black hole **spin**.

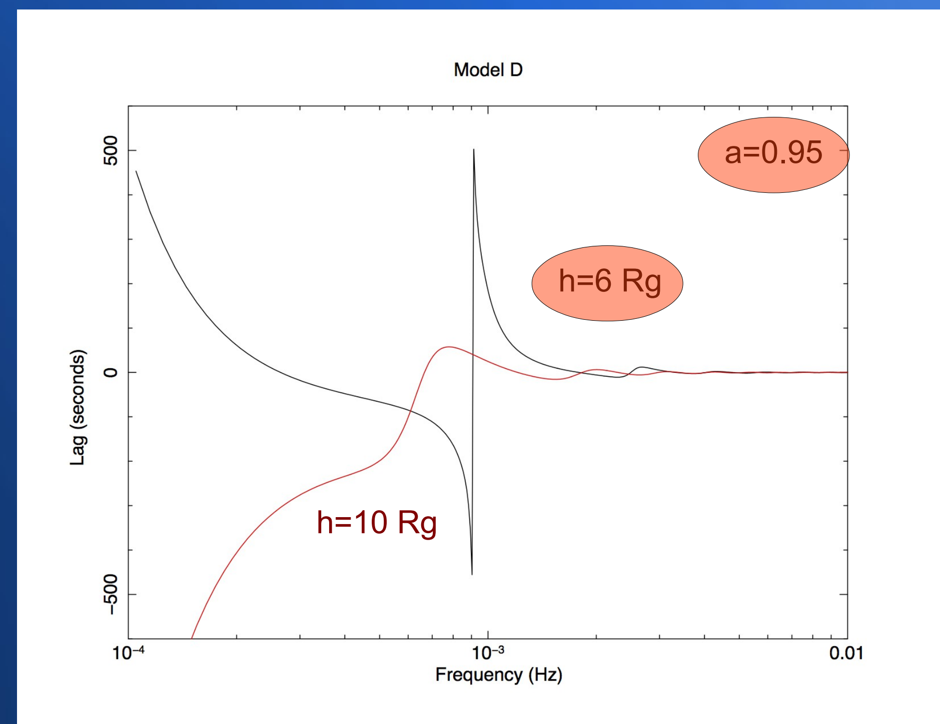


The sketch of the lamp-post geometry. (Credits: Dovčiak+14)

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

Phase wrapping (effect from GR)





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

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

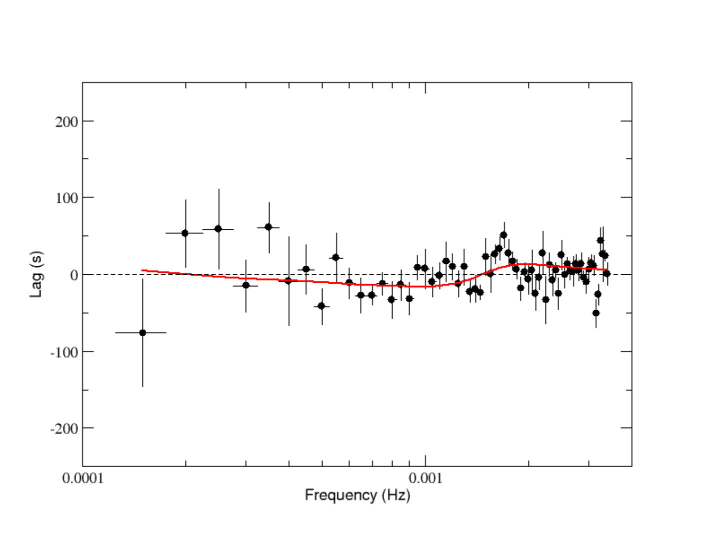
***Fits with XSPEC using KYNREFREV*: Observational data**

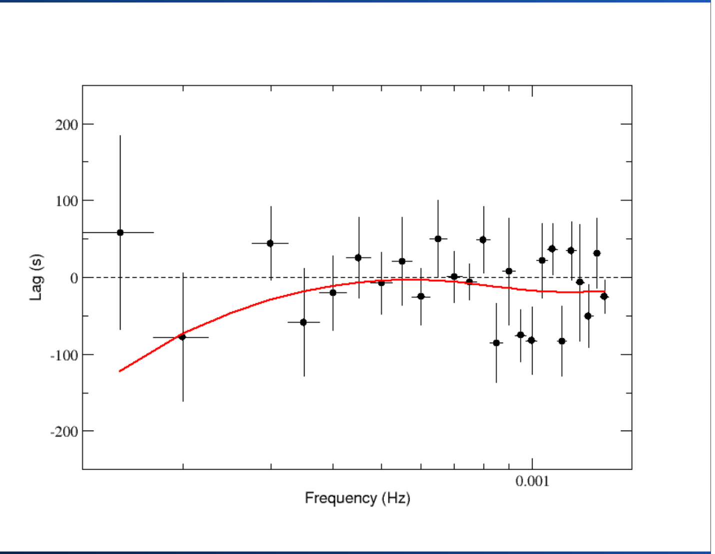
- We have produced time-lags from a sample of 7 AGN (in the mass range 10^6-10^8 $M_\odot$).
- Applying statistical procedures (Epitropakis & Papadakis+16) the light curve was divided in 20 ks segments in different energy bands taking the (2-4, 0.3-10, 1-10) keV reference energy bands.
- We used also the *phenomenological* 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. (χ^2_υ ~ 1) with a run-time of the order of seconds (i.e. alike normal X-ray energy-spectral fitting) → Novel in XSPEC (and very efficient) method !

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

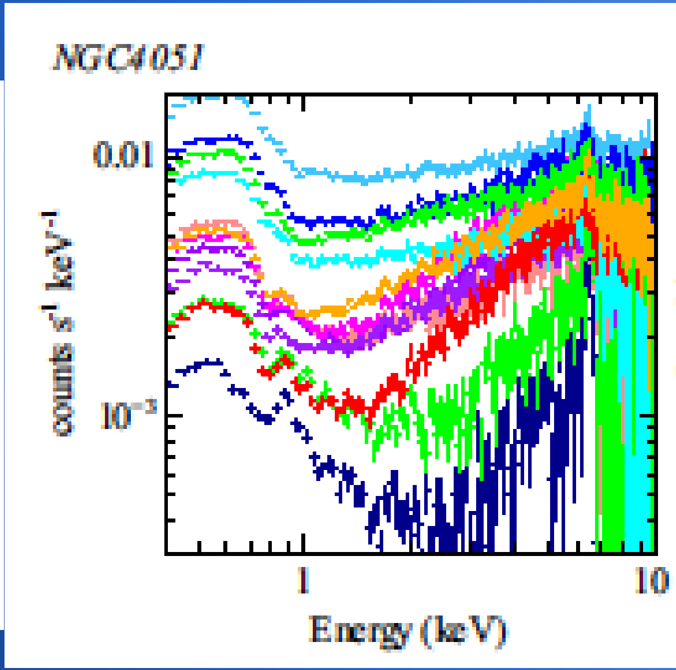
Fitting the data (using XSPEC):

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.

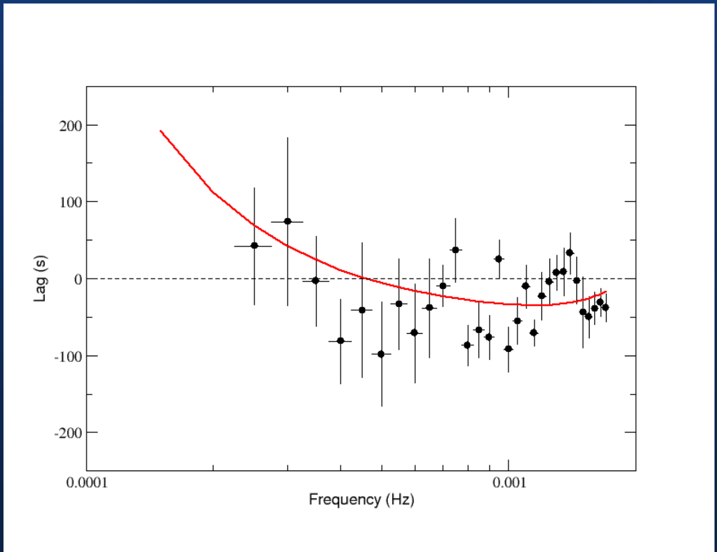


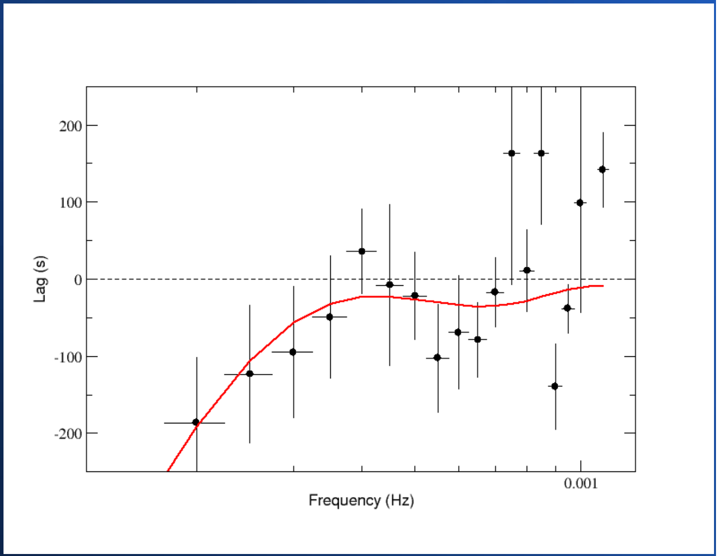
Spectral evolution of NGC 4051 (Kara+17)

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

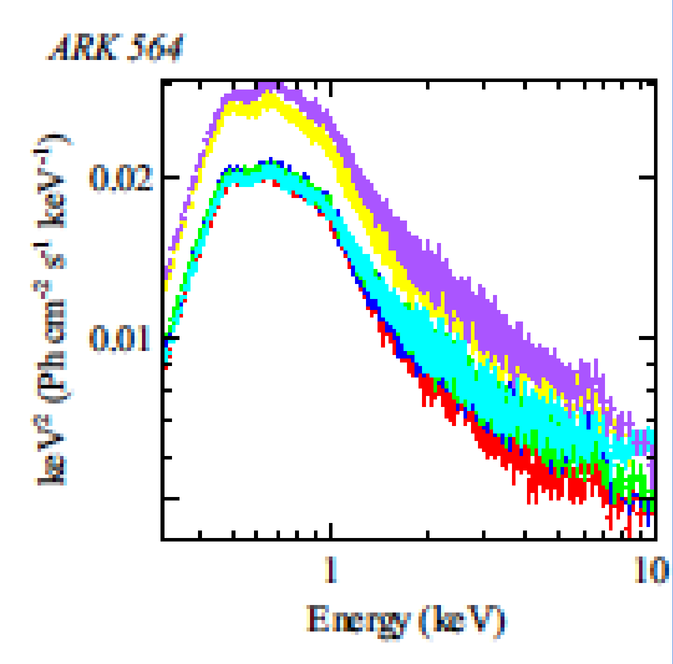
Fitting the data (using XSPEC):

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.

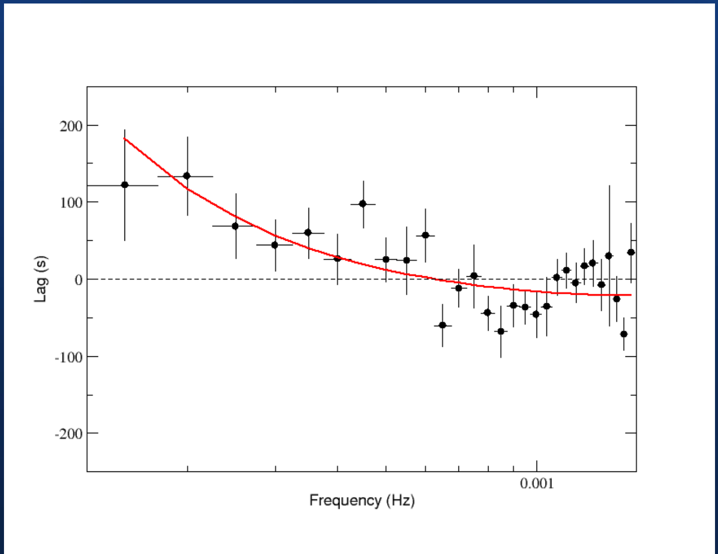


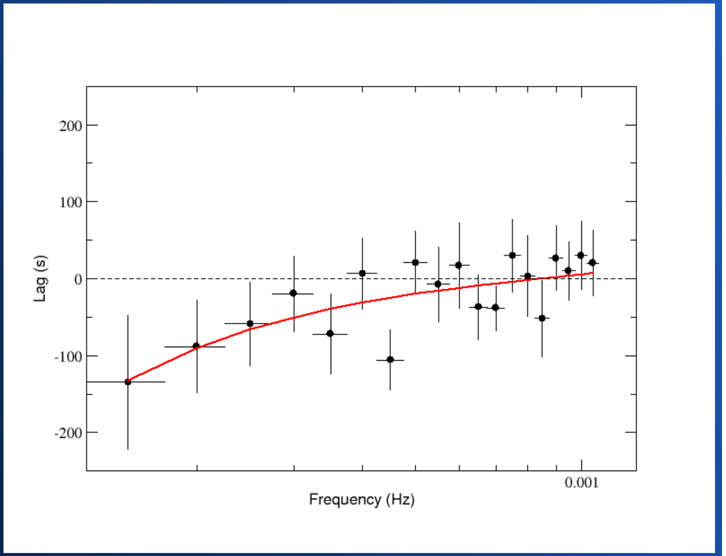
Spectral evolution of ARK 564 (Kara+17)

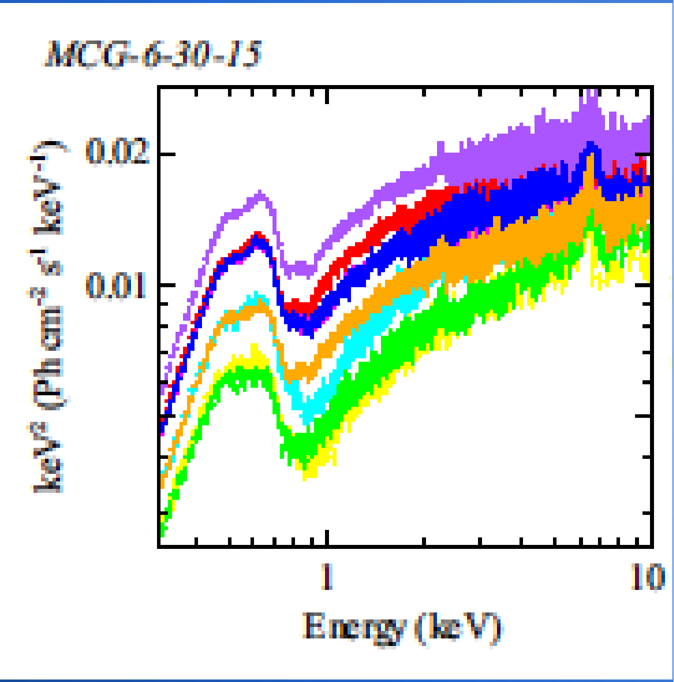
The model: *“The relativistic reflection model in the lamp-post geometry”*

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

MCG 6-30-15







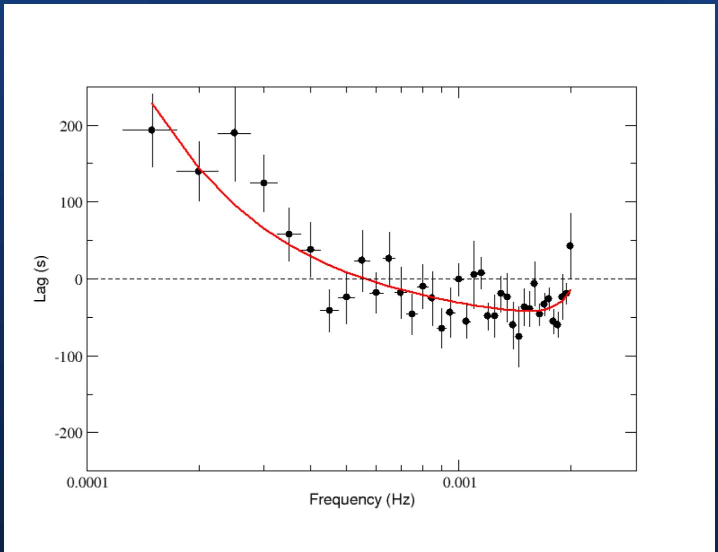
The soft lag-frequency fitted global spectrum of MCG-6-30-15 (0.3-1 vs. 2-4 keV and 5-7 vs. 2-4 keV) as obtained using XSPEC.

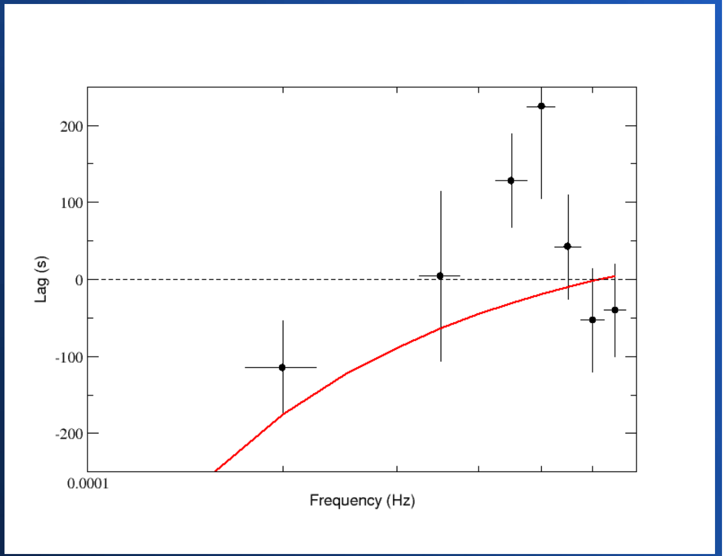
Spectral evolution of MCG-6-30-15 (Kara+17)

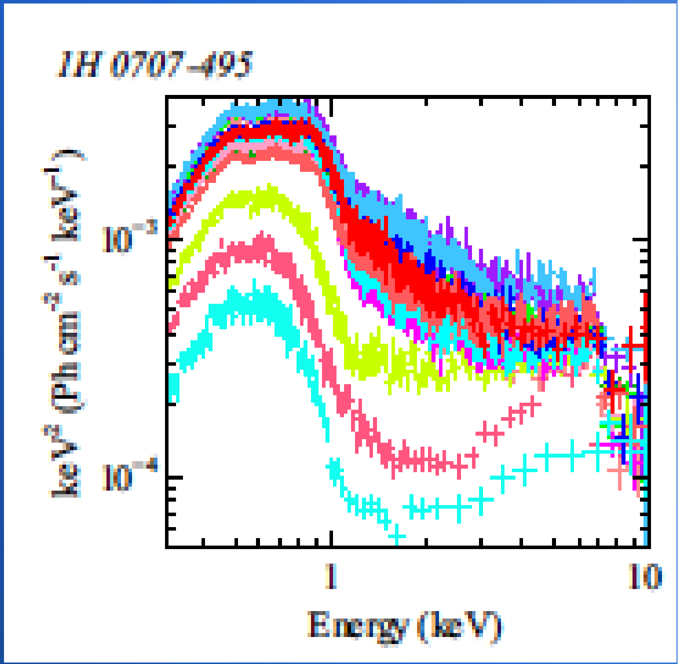
The model: *"The relativistic reflection model in the lamp-post geometry"*

Fitting the data (using XSPEC):

1H 0707-495







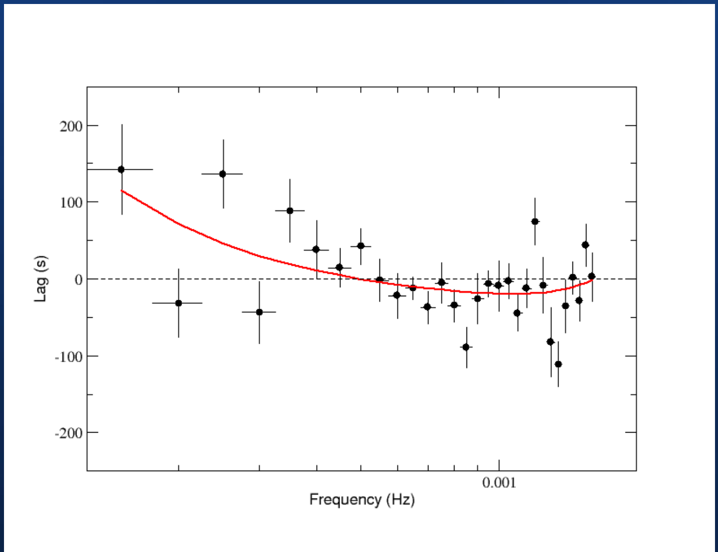
The soft lag-frequency fitted global spectra of 1H 0707-495 (0.3-1 vs. 1-10 keV and 5-7 vs. 0.3-10 keV) as obtained using XSPEC.

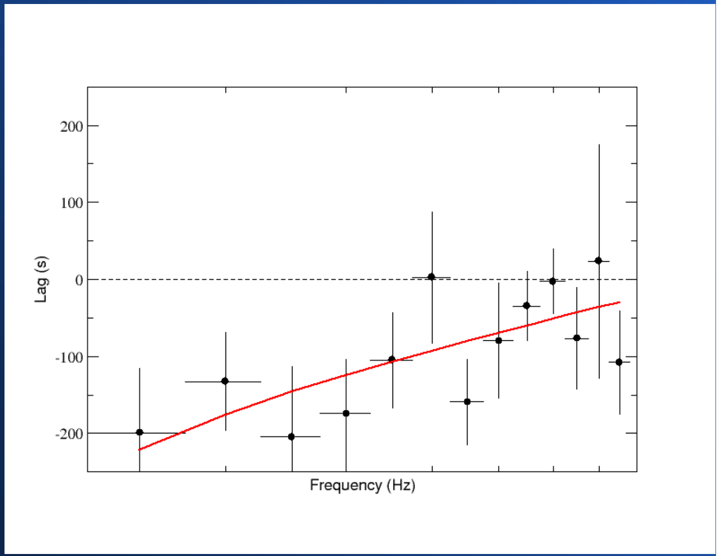
Spectral evolution of 1H0707-495 (Kara+17)

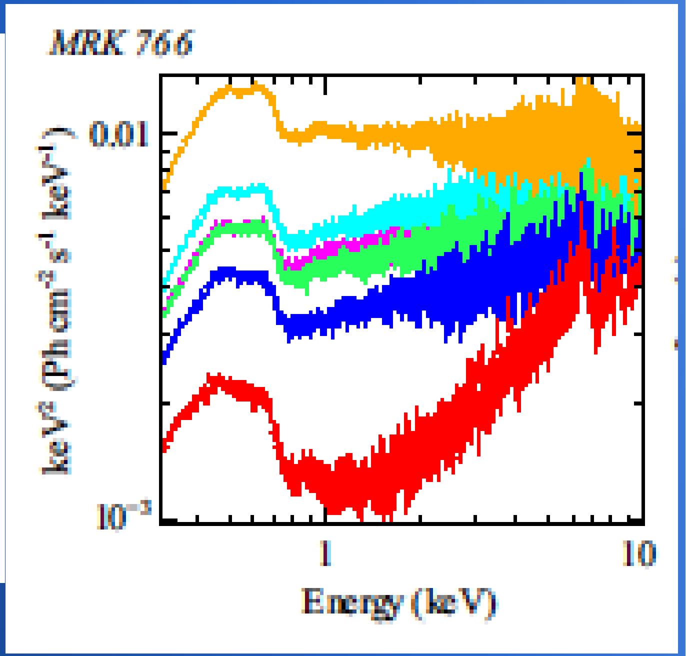
The model: *"The relativistic reflection model in the lamp-post geometry"*

Fitting the data (using XSPEC):

MRK 766







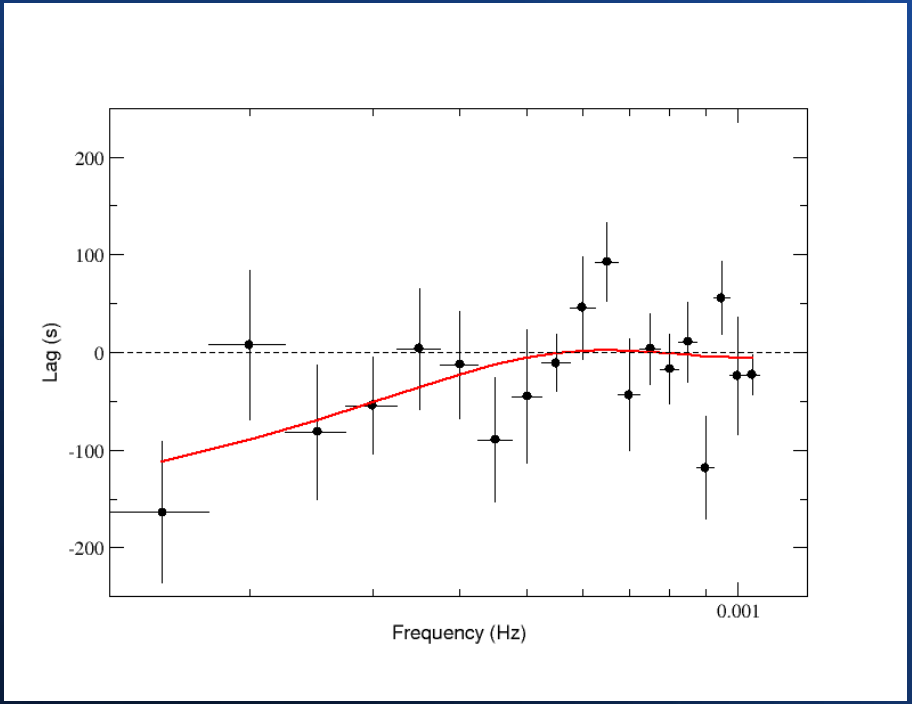
The soft lag-frequency fitted global spectra of MRK 766 (0.3-1 vs. 1-10 keV and 5-7 vs. 2-4 keV) as obtained using XSPEC.

Spectral evolution of 1H0707-495 (Kara+17)

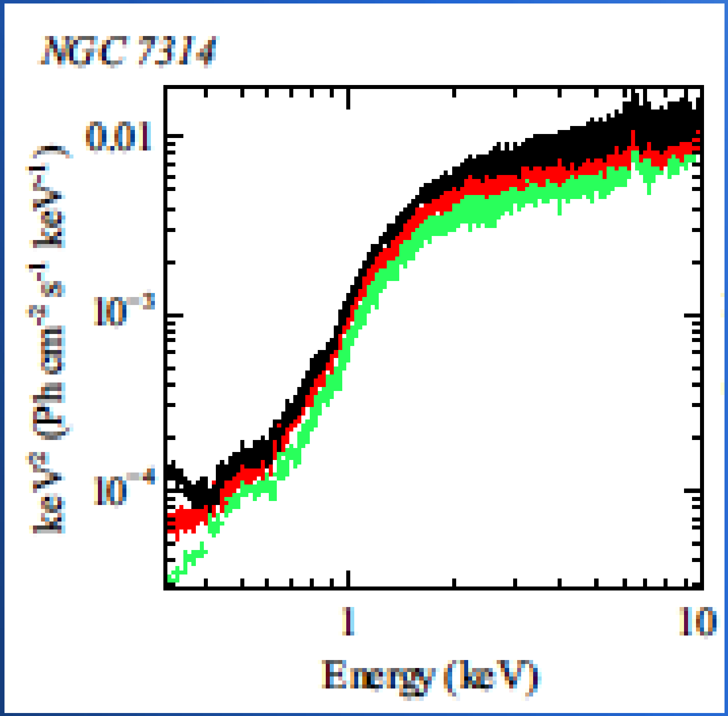
The model: *“The relativistic reflection model in the lamp-post geometry”*

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.

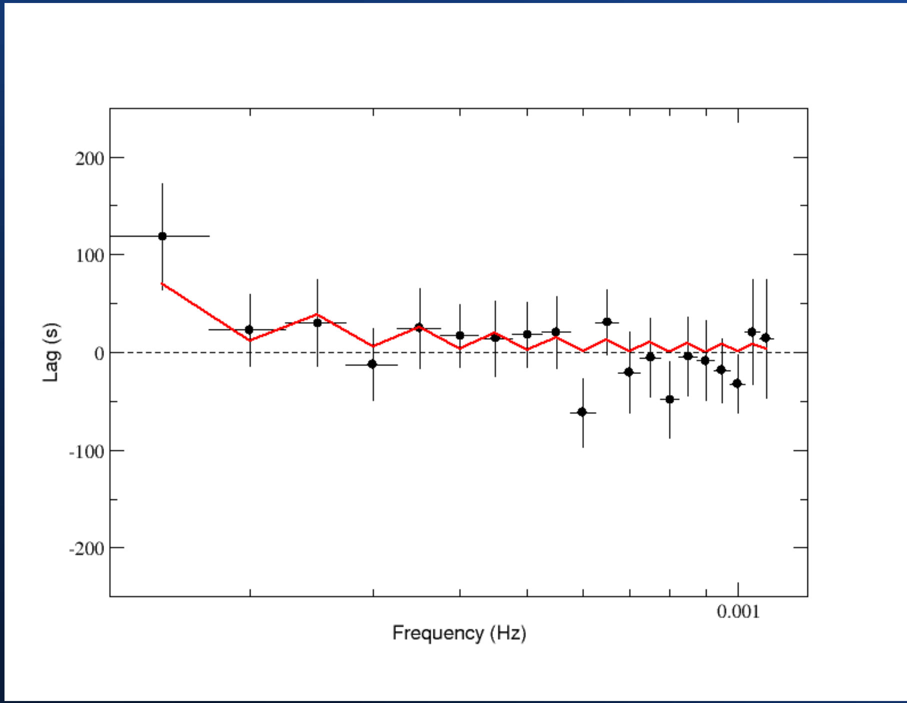


Spectral evolution of NGC 7314 (Kara+17)

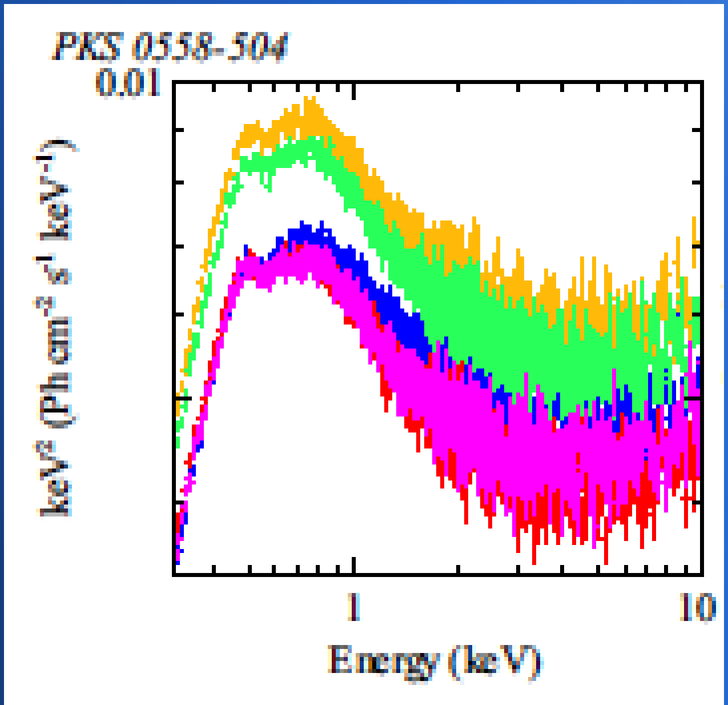
The model: *"The relativistic reflection model in the lamp-post geometry"*

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.



Spectral evolution of PKS 0558-504 (Kara+17)

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	$\leq$0.5	$\leq$60	$\leq$50
	MCG-6-30-15		
6.3	$\leq$0.25	70±20	10±5
	1H 0707-495		
6.31	0.64±0.12	$\leq$40	6±2
	MRK 766		
6.8	$\leq$1	60±8	20±5
	PKS 0558-504		
7.8	$\leq$1	$\leq$8	$\leq$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 the ionization of the disc is now included !).
- 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 values obtained for *the spin are lower than the ones found from spectroscopy* (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 (not used in this presentation).**
- The lamp-post is the first approximation !!! More work is needed in the future in order to address *possible* ***(other) extended coronae geometries***.

Acknowledgements

Financial support provided by the European "Seventh Frame-work Programme (FP7/2007-2013) under grant agreement # 312789”.

Period of the project's realization 1.1.2013 – 31.12.2017

STRONGGRAVITY

EU FP7-SPACE research project 312789

2013 - 2017