


X-ray reverberation in AGN: towards an extended corona

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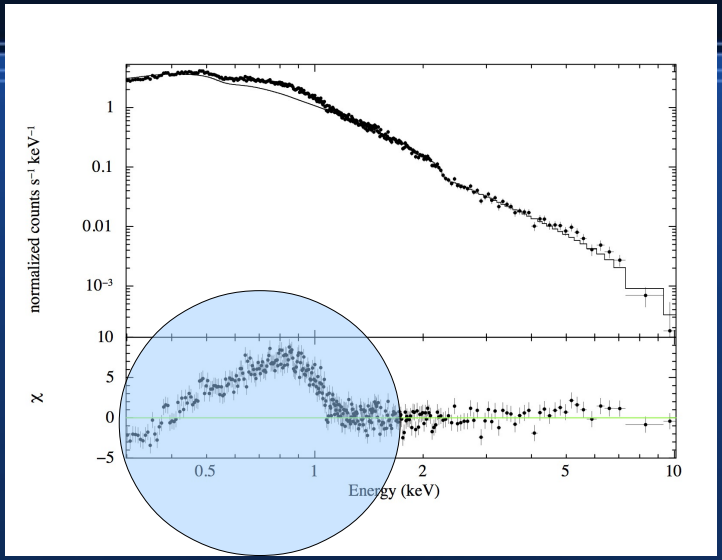
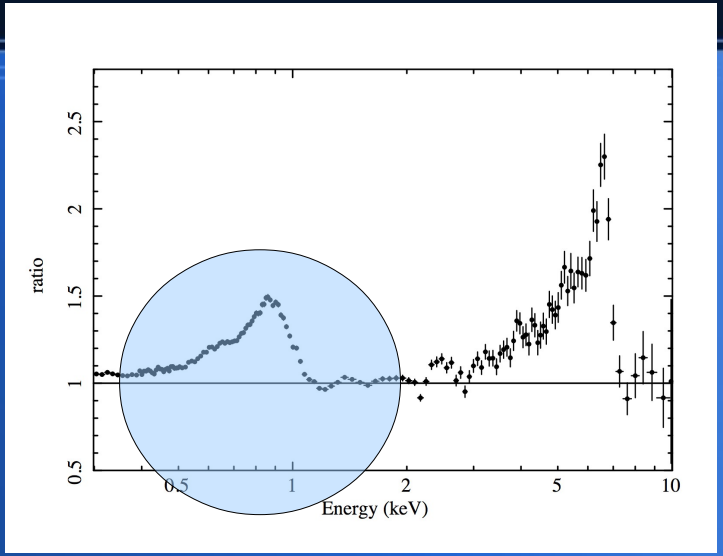
on behalf of a larger collaboration.

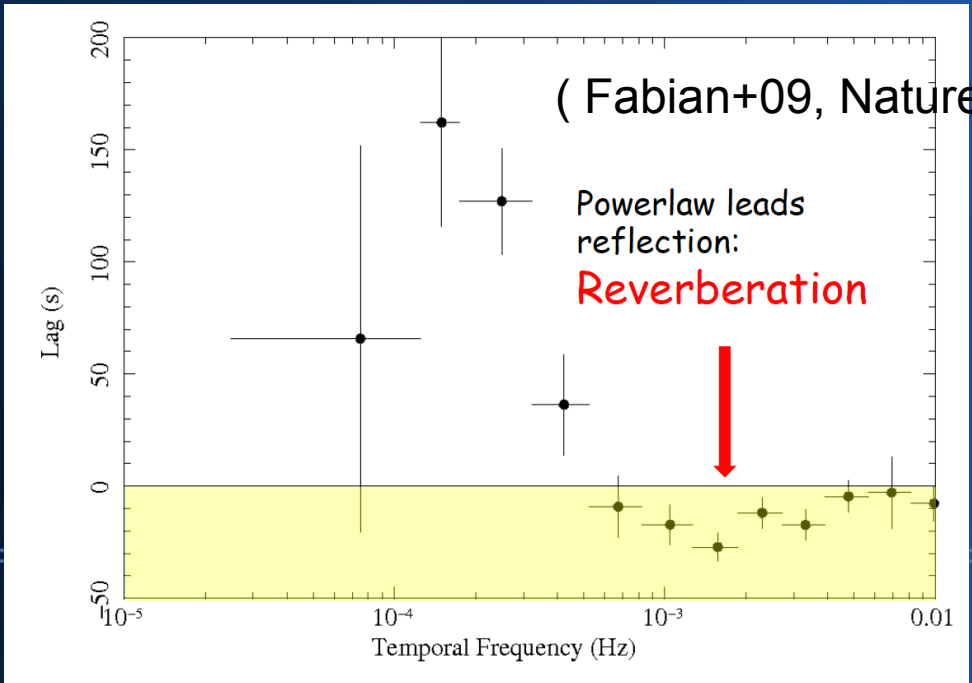
X-ray reverberation in AGN



NLSy1

1H0707-495

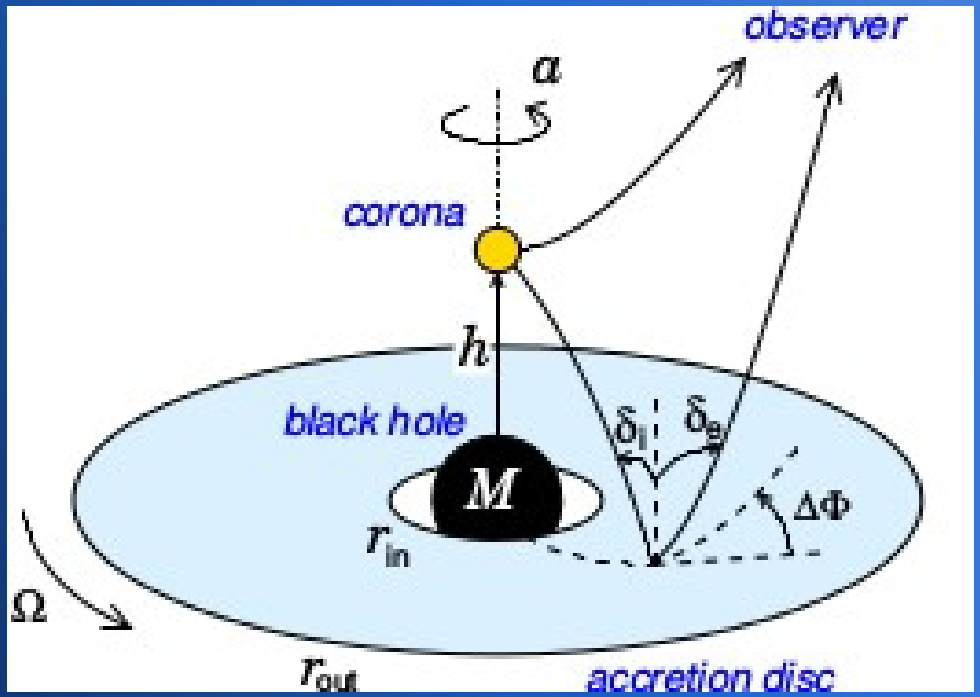




X-ray reverberation in AGN

KYNXILREV model

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



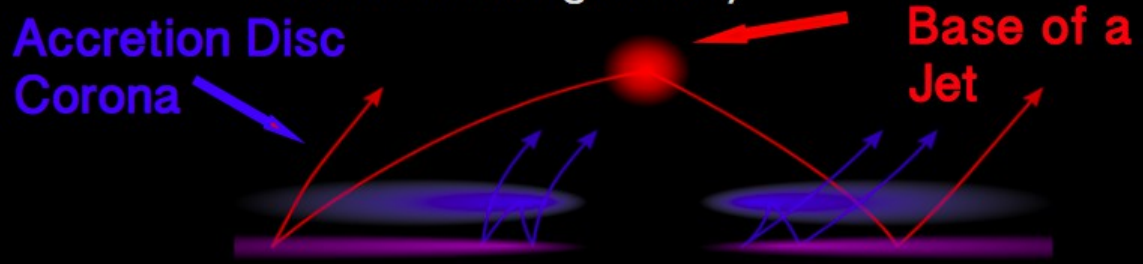
The sketch of the lamp-post geometry. (Credits: Dovčiak+14)

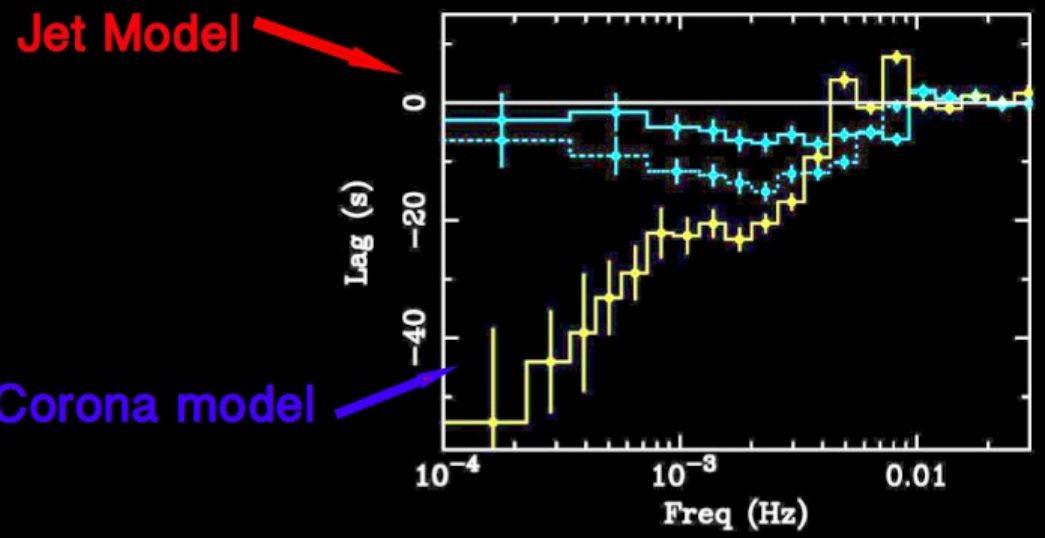
X-ray reverberation in AGN

ATHENA → ***Huge effective area @1keV !!!!!***

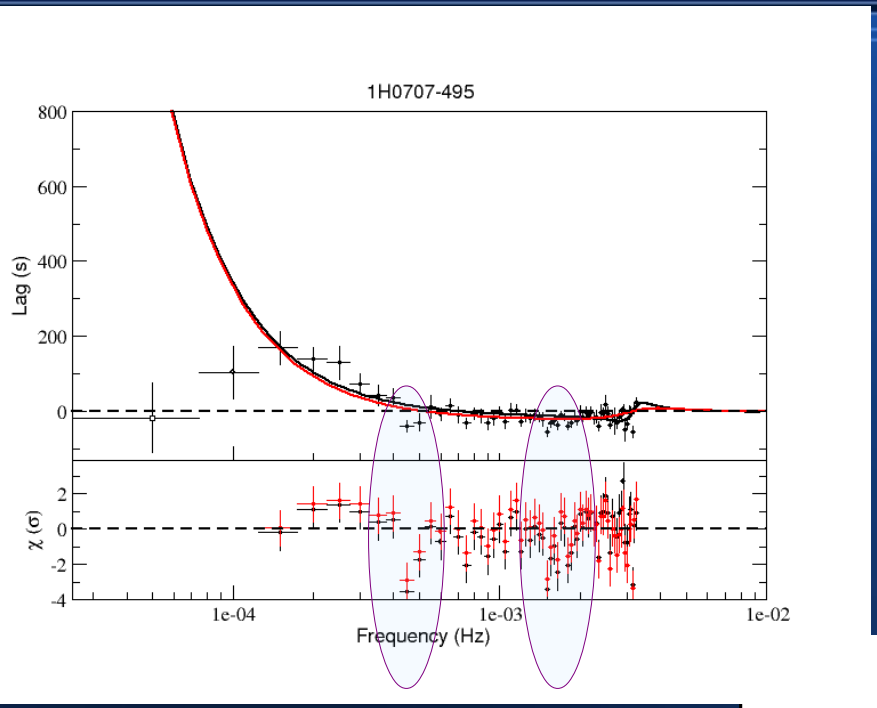
Mapping black holes near the event horizon

Reverberation mapping: disk-jet connection
& accretion flow geometry

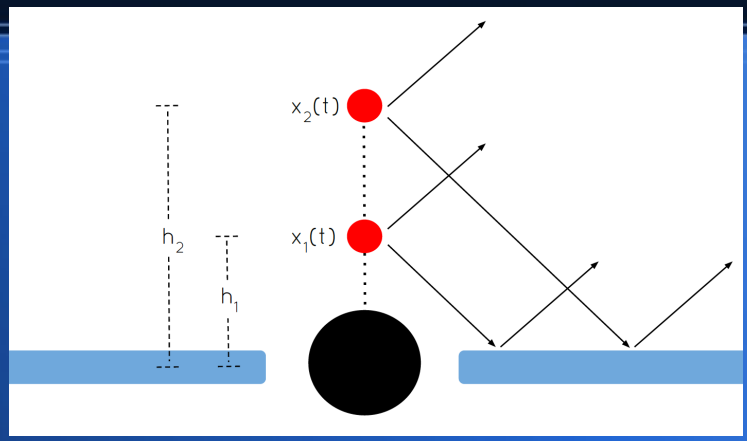




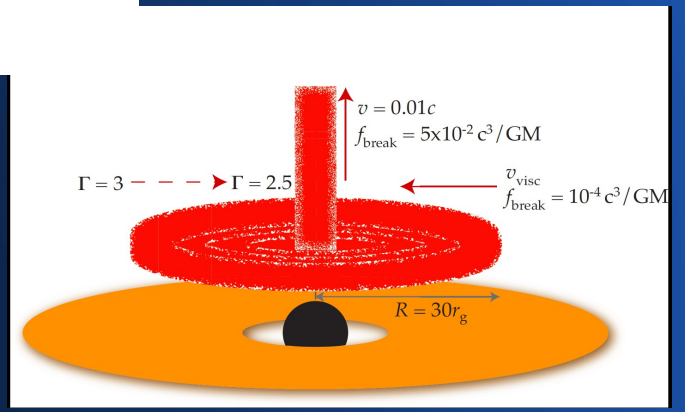
X-ray reverberation in AGN



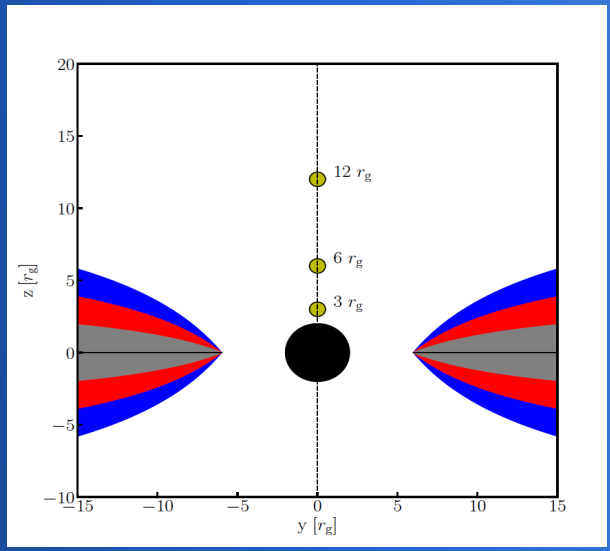
Caballero-Garcia et al. (2018), Caballero-Garcia et al. (2019)



Chainakun & Young (2017)

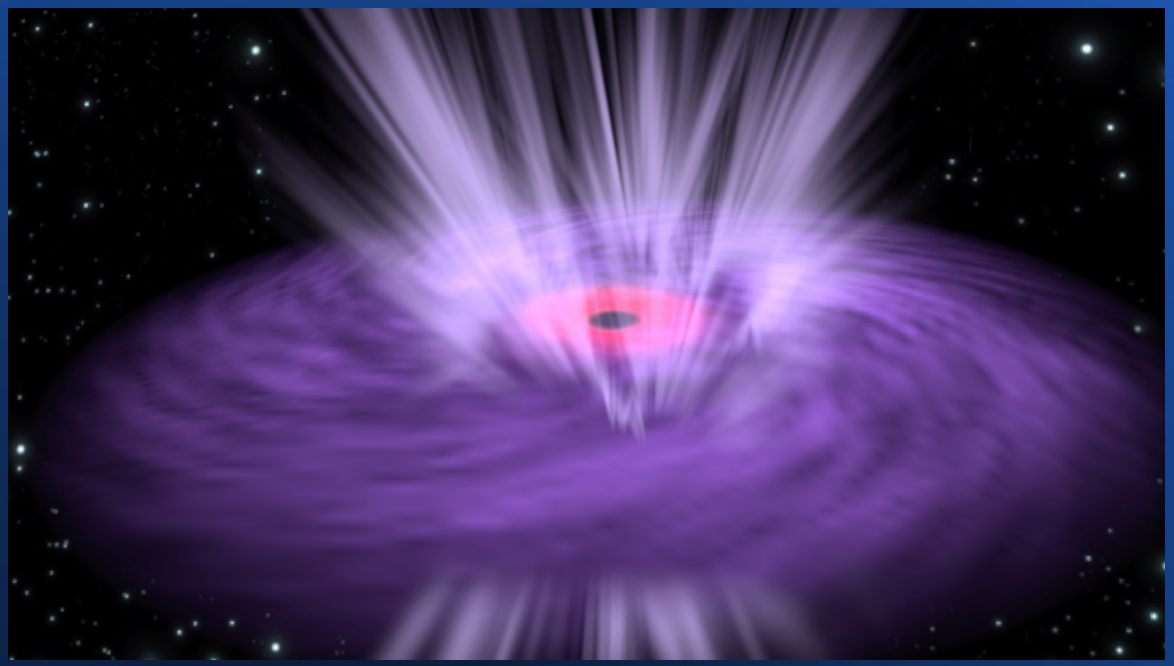


Wilkins et al. (2016)



Taylor & Reynolds (2018)

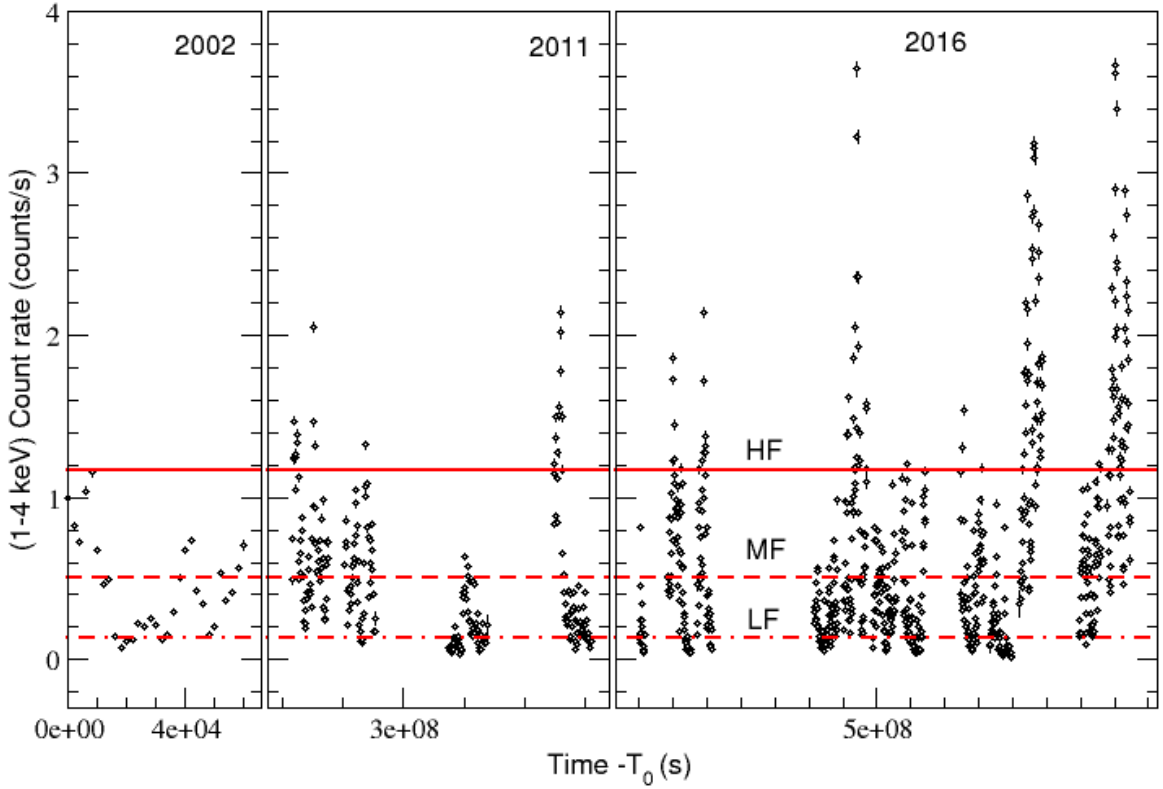
IRAS 13224-3809



Artist's impression illustrating a supermassive black hole with X-ray emission emanating from its inner region (pink) and ultra-fast winds streaming from the surrounding disk (purple). Credit: ESA

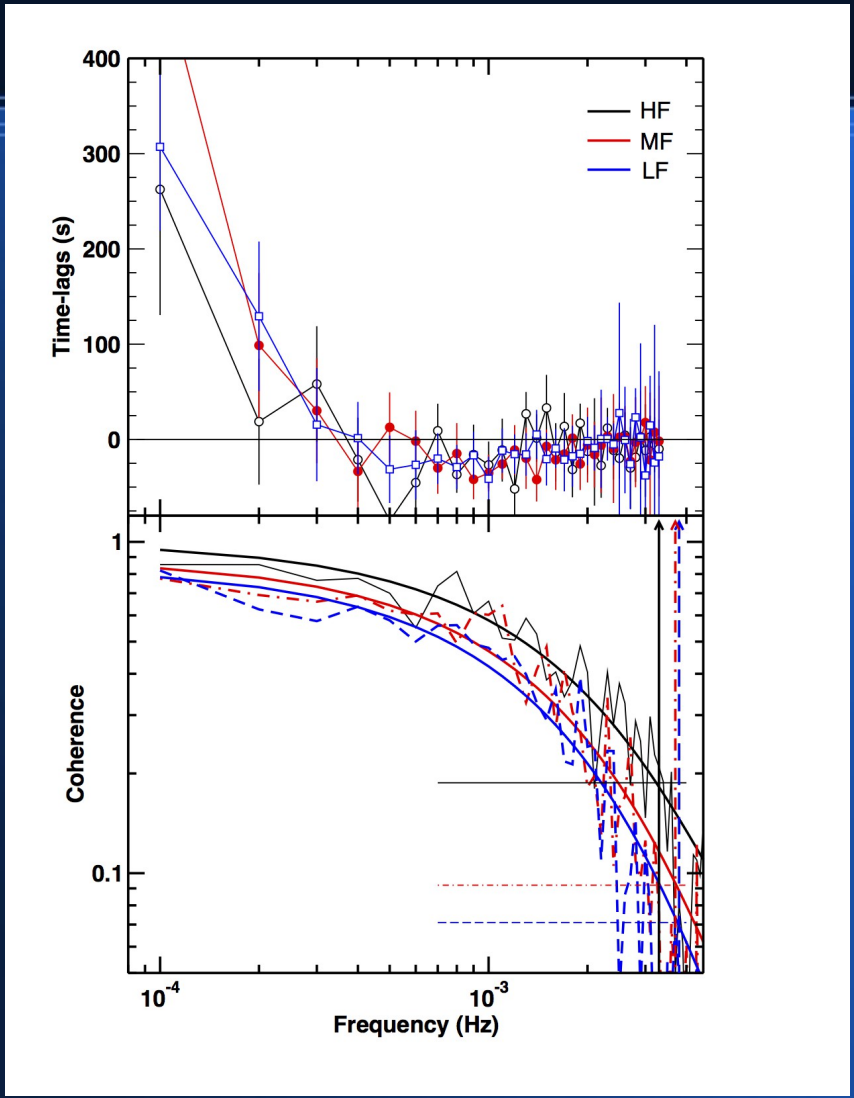
- IRAS 13224-3809 is a **radio-quiet** and X-ray bright ($4x10^{-12}$ ergs $s^{-1}cm^{-2}$ in the 0.3 − 10.0 keV band) NLSy1.
- Distance of D = 295 Mpc.
- Probably the most variable source (known so far) both in UV and X-ray wavebands.
- **It has been observed with *XMM-Newton* during $2x10^6$ s** (PI: Fabian).
- We have analyzed (time-lag and energy spectra) all the *XMM-Newton* data but separating it in low-flux (LF), medium-flux (MF) and high-flux (HF) levels.

IRAS 13224-3809



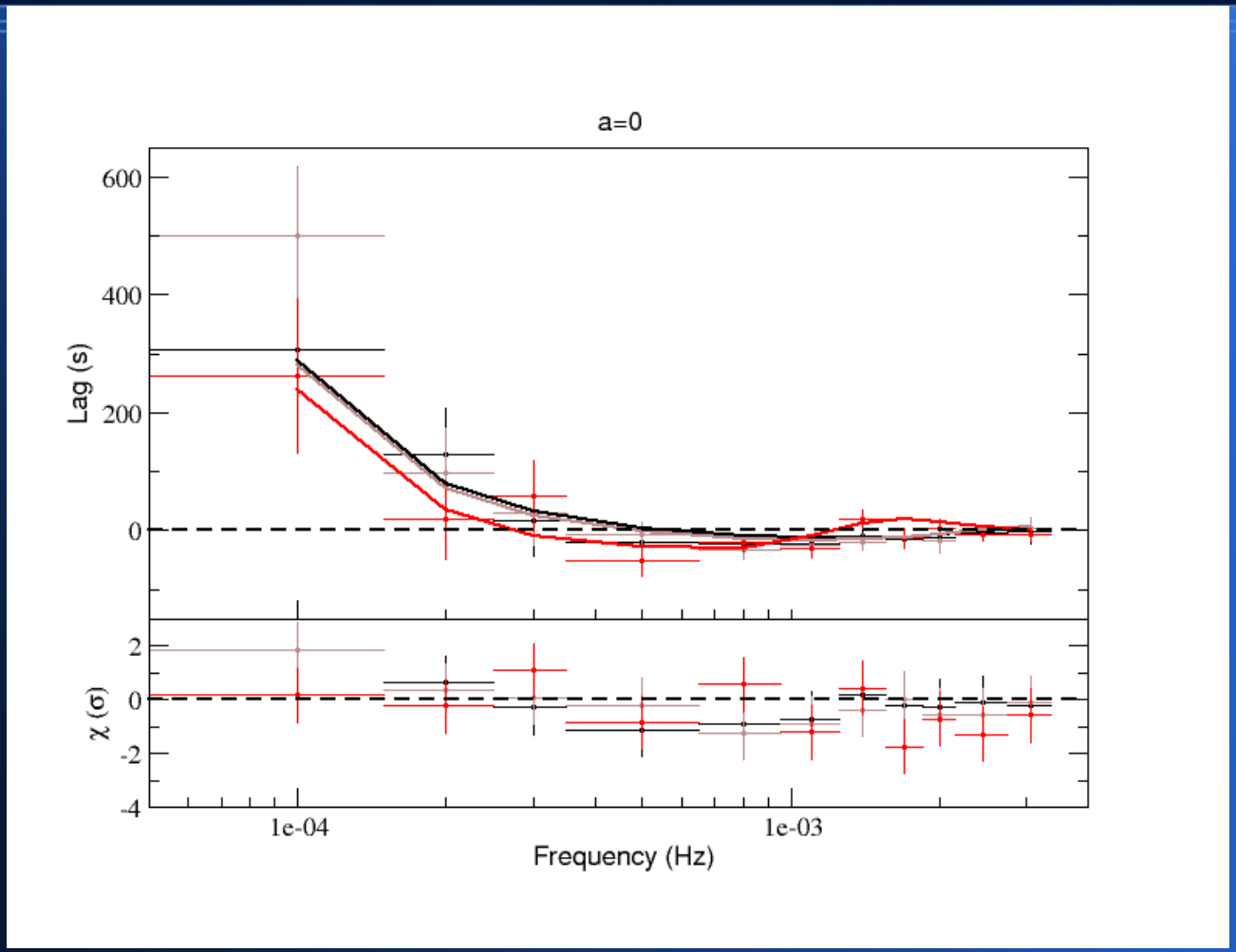
The EPIC pn+MOS, 1-4 keV band light curve, binned in 2 ks. Time is measured in seconds since the start of the 2002 observations. The solid, dashed and dot-dashed horizontal lines indicate the count rate limits of the "HF", "MF" and "LF" intervals (Caballero-Garcia et al. 2019b).

IRAS 13224-3809



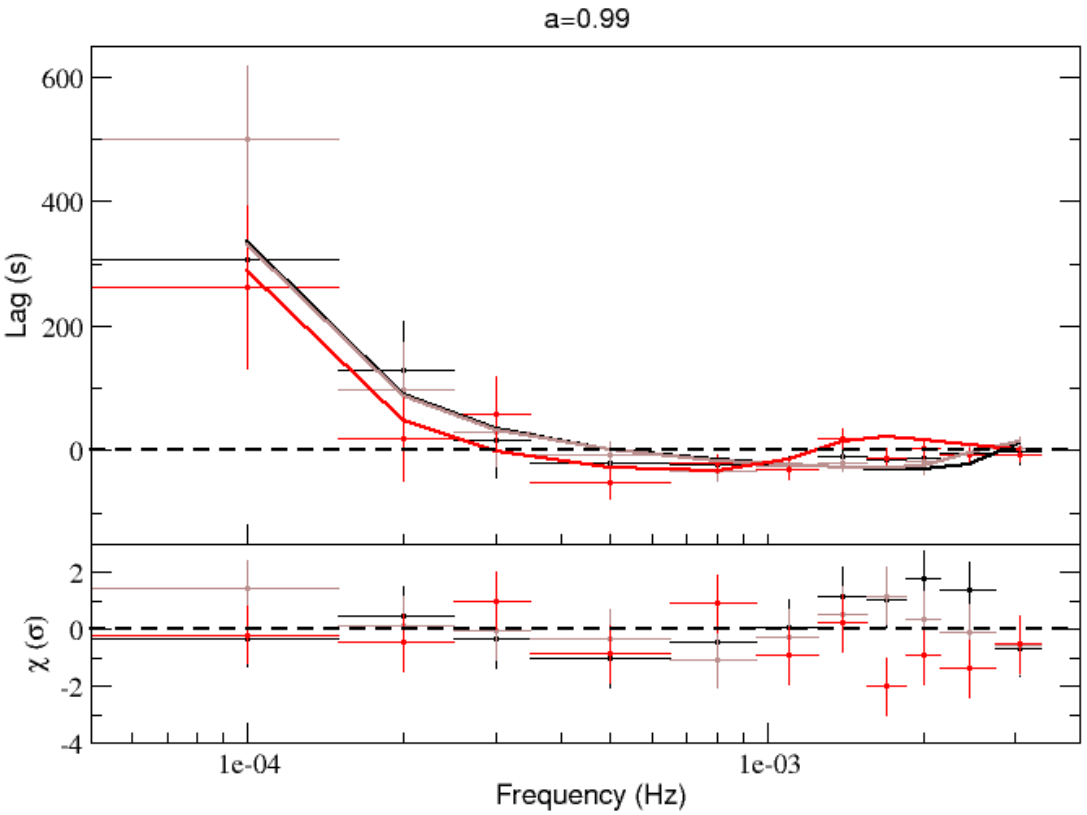
The HF, MF, and LF time-lags spectra (top panel) and the respective coherence functions (bottom panel). The solid black, dashed blue and dot-dashed red vertical lines in the bottom panel indicate the highest frequency up to which we can estimate the HF, MF and LF time-lags, respectively. From Caballero-Garcia et al. (2019b).

IRAS 13224-3809



The (0.3-1 versus 1-4 keV) X-ray soft time-lag versus frequency spectra of IRAS 13224-3809 in the LF, MF and HF states (black, brown and red, respectively). From Caballero-Garcia et al. (2019b).

IRAS 13224-3809



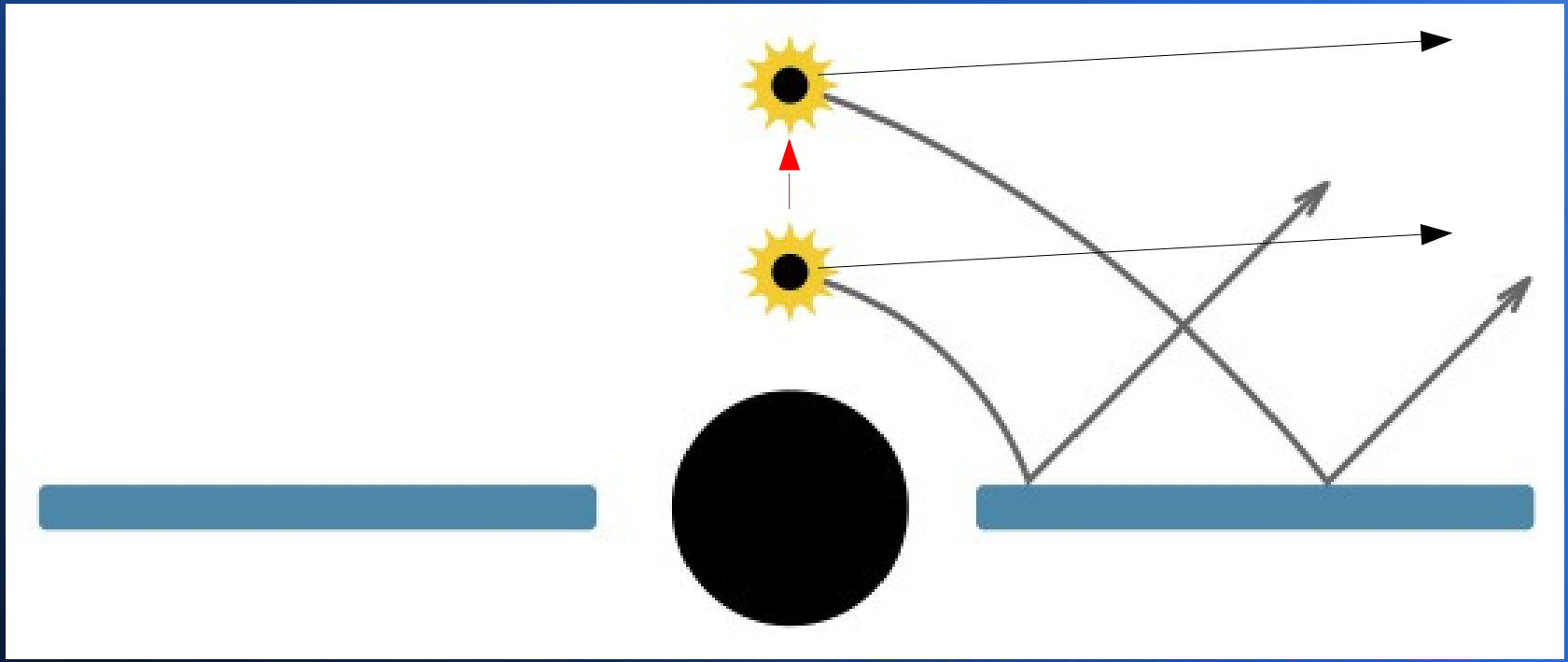
The (0.3-1 versus 1-4 keV) X-ray soft time-lag versus frequency spectra of IRAS 13224-3809 in the LF, MF and HF states (black, brown and red, respectively). From Caballero-Garcia et al. (2019b).

IRAS 13224-3809

a (GM/c)	$0.99^{(f)}$	$0.0^{(f)}$
IRAS 13224-3809 ($M_8 = 0.02^{(f,c)}$, $\Gamma = 2.0^{(f)}$)		
LF state		
θ_0 (deg.)	45 (f)	45 (f)
h (r_g)	9.08±1.0	6.0±2.1
Density (10^{15} cm^{-3})	1.0±0.8	1.1±4.0
A	(7.7±1.7)×10^{-4}	(6.8±1.7)×10^{-4}
s	1.4 (f)	1.4 (f)
χ^2/ν	0.49 (4/8)	0.35 (3/8)
p-value	0.86	0.95
MF state		
θ_0 (deg.)	–	–
h (r_g)	8.6±1.0	7.0±2.0
Density (10^{15} cm^{-3})	1.0±0.3)	1.6±2.4
A	(7.5±1.7)×10^{-4}	(7.2±1.7)×10^{-4}
s	1.4 (f)	1.4 (f)
χ^2/ν	0.49 (4/8)	0.22 (2/8)
p-value	0.87	0.99
HF state		
θ_0 (deg.)	–	–
h (r_g)	18.0±2.2	16.5±2.3
Density (10^{15} cm^{-3})	1.0±0.5	1.0±0.4
A	(6.5±2.3)×10^{-4}	(5.7±2.3)×10^{-4}
s	1.4 (f)	1.4 (f)
χ^2/ν	1.25 (10/8)	1.2 (10/8)
p-value	0.27	0.29

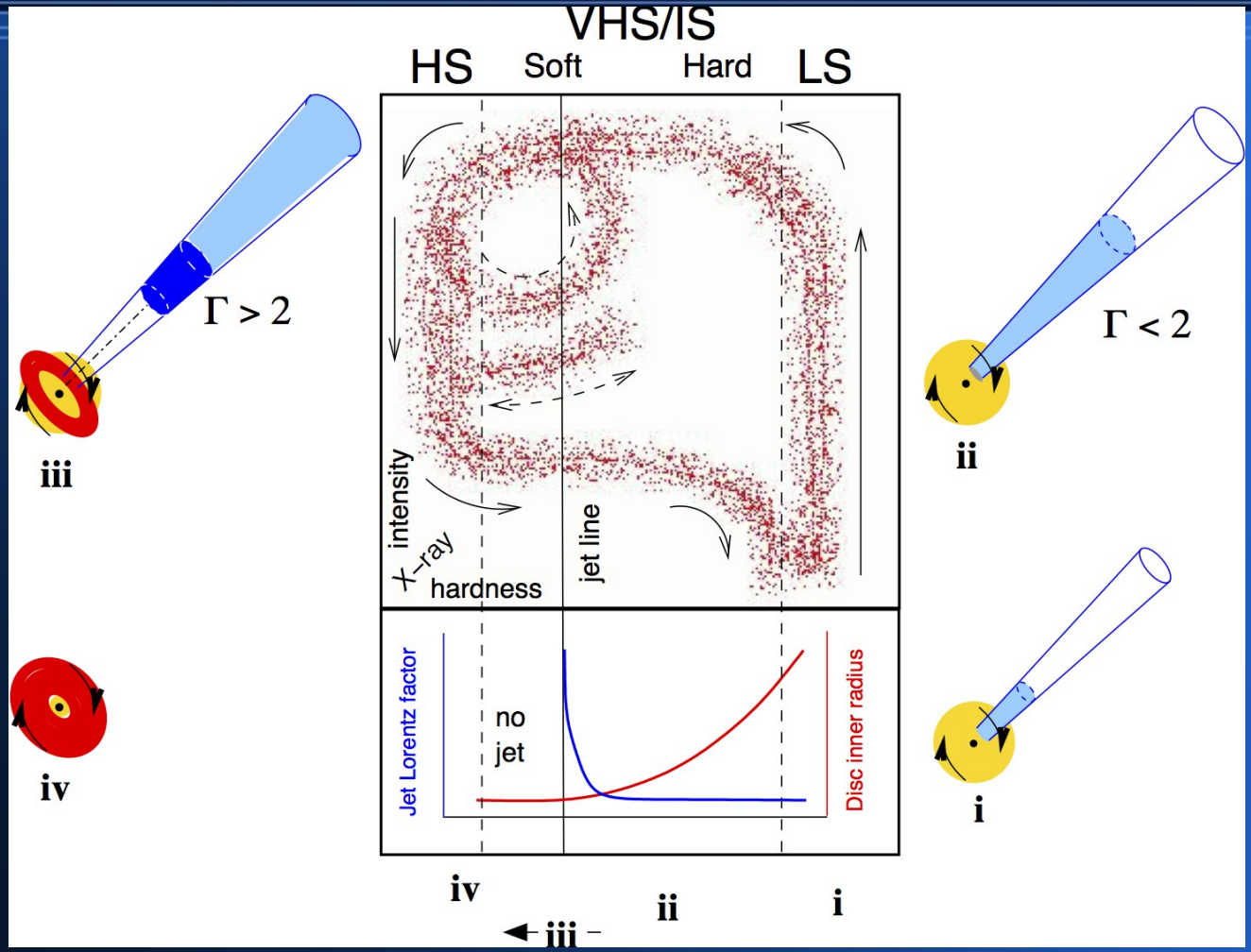
Best-fit parameters using the model KYNXILREV when we fit data with spin fixed to rapid and zero (left and right column, respectively). Primary isotropic flux in the (2-10 keV) X-ray energy range in units of L_{EDD} is fixed to L(2−10 KeV)= 0.001, 0.002, 0.007 (L_{Edd}) and photon index of Γ=1.5, 2.0, 2.5 for the LF, MF and HF states, respectively. From Caballero-Garcia et al. (2019b).

IRAS 13224-3809



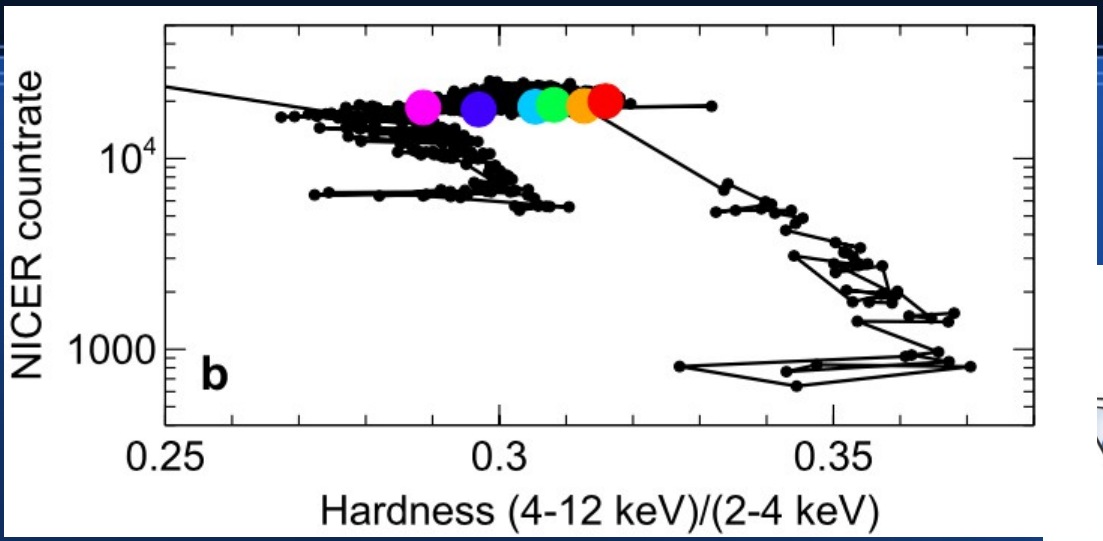
The 2-blob corona from Chainakun & Young (2017) in reality can be understood as the ***base of the jet that is moving up-wards from LH to HF state****. The lower blob is what makes the reverberation at* ***high frequencies*** *(response of the inner parts of the disc) and the high blob is what produces reverberation at* ***low frequencies*** *(response of outer parts of the disc).*

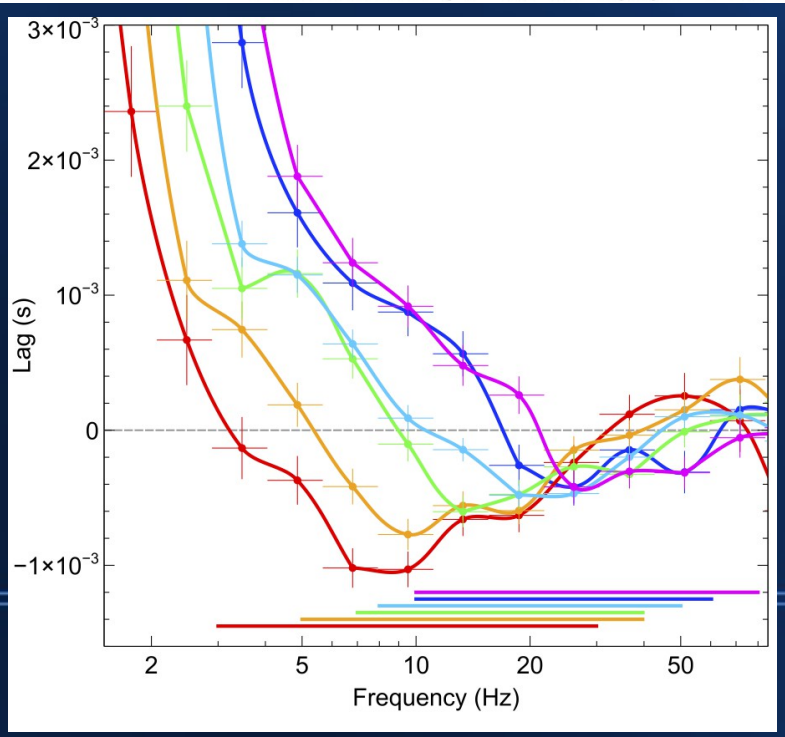
Black Hole Binaries (BHBs)

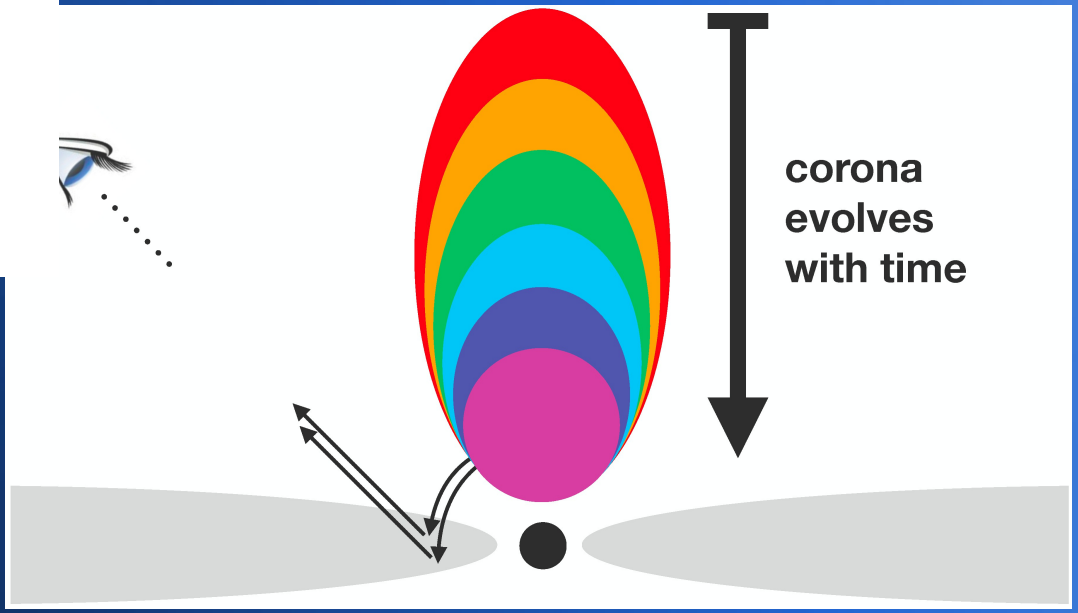


Schematic of our simplified model for the jet-disc coupling in ***black hole binaries****.*
(Fender, Belloni & Gallo, 2004).

The BHB *MAXI J1820+070*





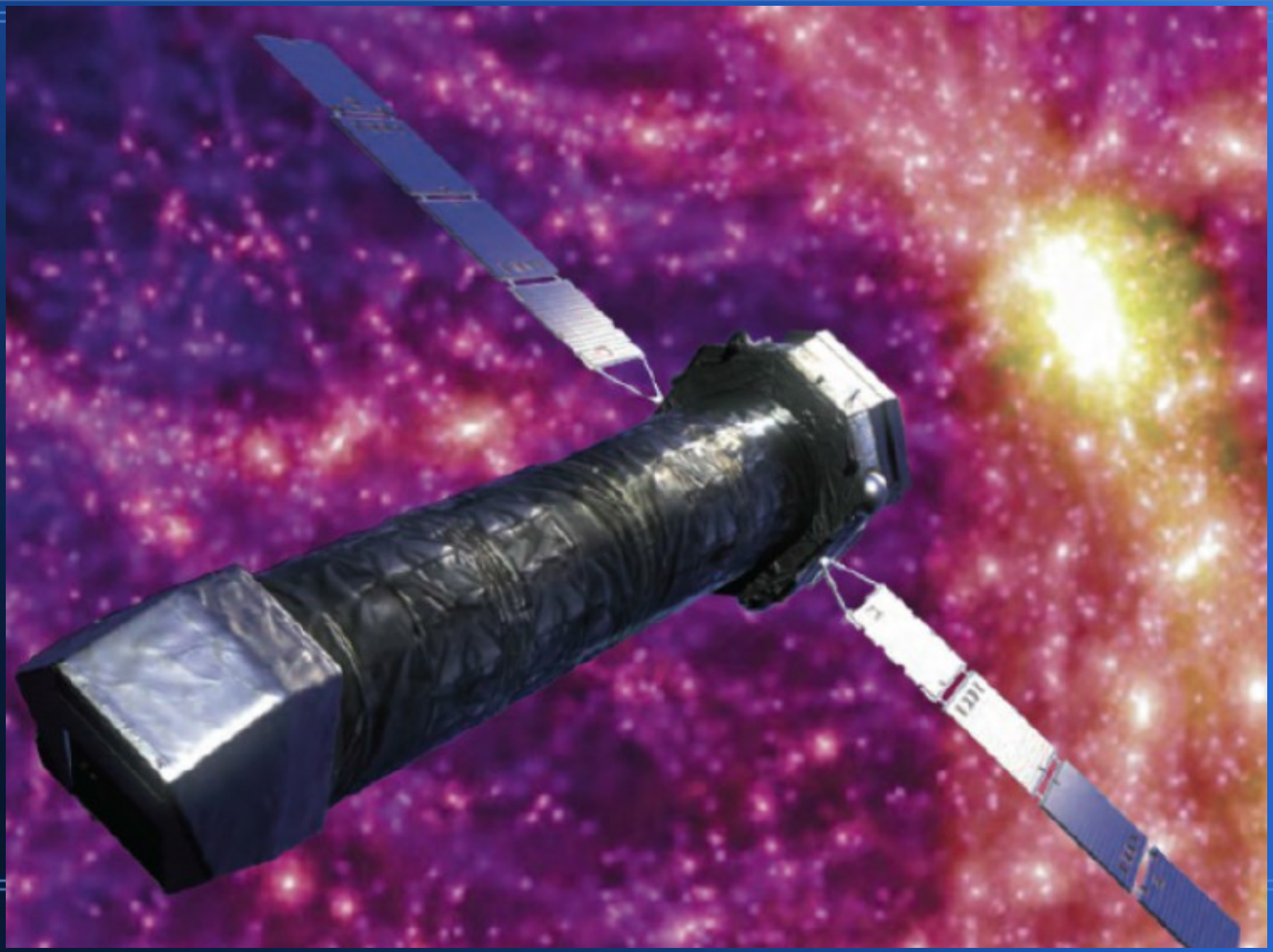


Evolution of the geometry of the corona of the BHB MAXI J1820+070 during a bright low-hard state ***(Kara+19, Nature).***

Conclusions

- First lamp-post reverberation model taking into account all known physical aspects is **ready for use into XSPEC** (Dovčiak+19, in prep.).
- **The (last) KYNXILREV code includes thermal reverberation from the accretion disc and new XILVER tables (Garcia+16).**
- KYNXILREV is very **well suited for obtaining the mass M_{BH} and height *h* of the lamp-post corona.**
- KYNXILREV is probably **well suited for obtaining also the spin of the BH**. But further (observational modelling) with “much better” time-lag vs. freq. data need to be obtained (up to higher frequencies).
- The lamp-post is the first approximation. *Very likely a blob-like corona moving upwards as the luminosity increases is the right description (Alston+19, submitted, including MCG)*.
- More (high-sensitive, longer and continuous) X-ray observations (*Athena*) are needed to confirm the proposed scenario.

Future telescope *Athena* (ESA)



Acknowledgements

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