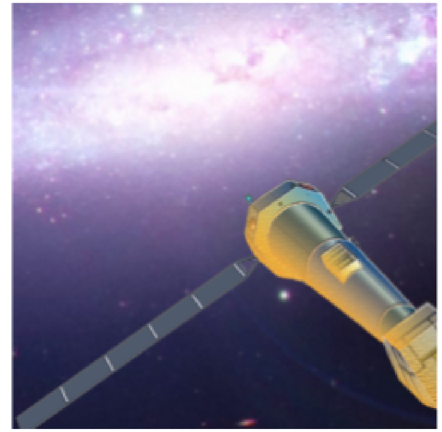
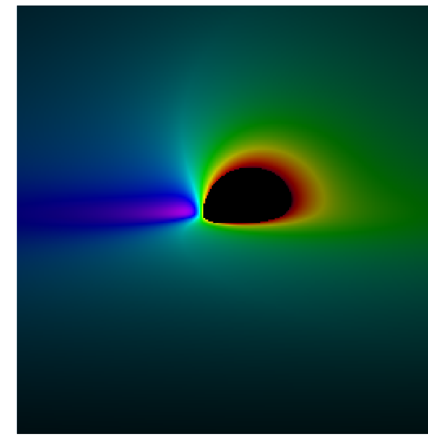
ATHENA



The close environments of supermassive black holes



Michal Dovčiak

On behalf of SWG 2.4
Close environments of SMBH

Astronomical Institute of the CAS
Prague, Czech Republic

10th years of the Czech Republic in ESA
12–15 November 2018, Praha, Czech Republic

Athena science

- **Hot Universe**

  How does ordinary matter assemble in the large-scale structures?

  How did it evolve from the formation epoch to the present day?

- **Energetic Universe**

  How do black holes grow and shape galaxies?

  How do accretion and ejection processes operate in the near environment of black holes?

- **Observatory**

  Observatory science across all corners of Astrophysics

  Fast response (≤4 hours) capability to study transient sources

Athena science

- **Hot Universe**
  - Evolution of galaxy group and clusters
  - Astrophysics of galaxy group and clusters
  - AGN feedback in galaxy group and clusters
  - Missing baryons and warm-hot intergalactic medium
- **Energetic Universe**
  - Formation and growth of earliest SMBH
  - Understanding the build-up of SMBH and galaxies
  - Feedback in local AGN and star forming galaxies
  - **Close environments of SMBH**
  - Physics of accretion
  - Luminous extragalactic transients
- **Observatory**
  - Solar System & exoplanets
  - Star formation and evolution
  - End points of stellar evolution
  - Supernova remnants & Interstellar medium
  - Multiwavelength synergy

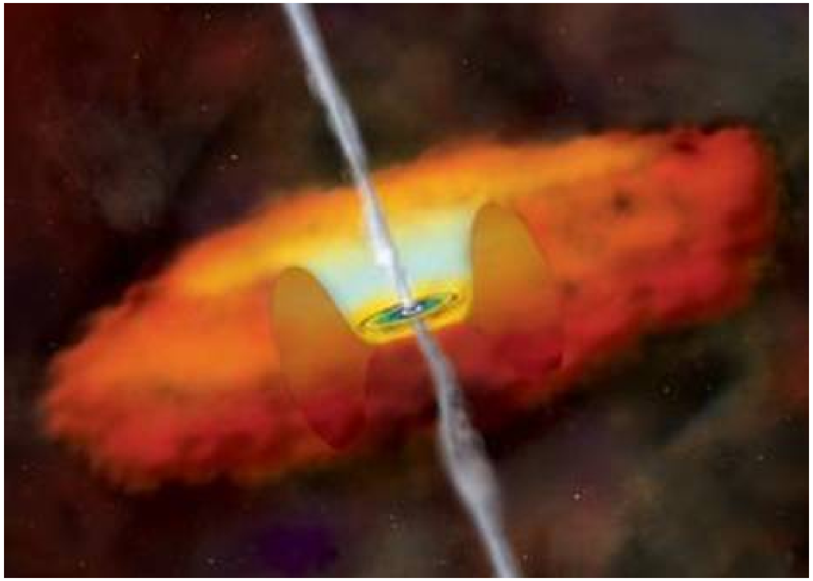
Close environments of SMBH

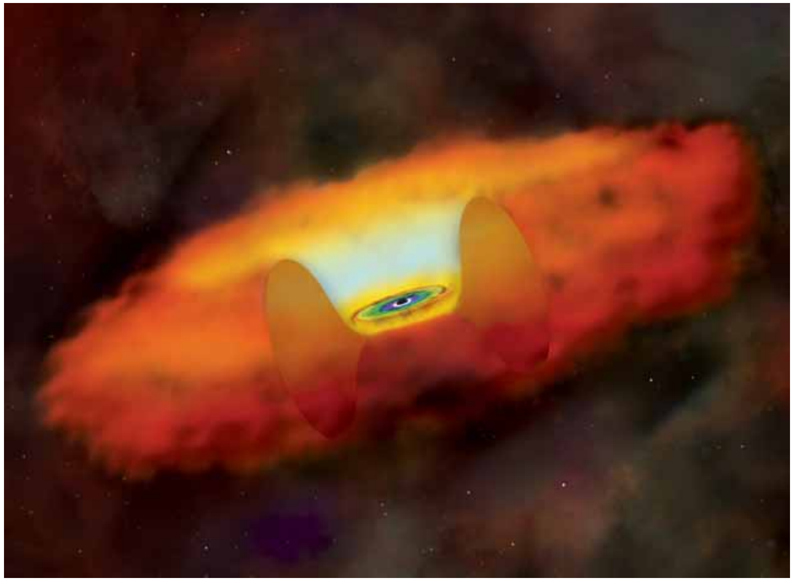
White paper: Dovciak et al. (2013) - arXiv:1306.2331

- AGN spin census
  - SMBH spin distribution in the local Universe as a probe of the growth process (mergers versus accretion, chaotic versus standard accretion)
- AGN reverberation mapping
  - determine the geometry of the hot corona-accretion disk system and constrain the origin of the hot corona in AGN
- Nature of the soft X-ray excess
- Mapping the accretion disk
- Mapping the circumnuclear matter
- Testing the General Relativity

Close environments of SMBH

- active galactic nuclei with central **supermassive black hole** of mass $10^6 - 10^{10}\,M_\odot$

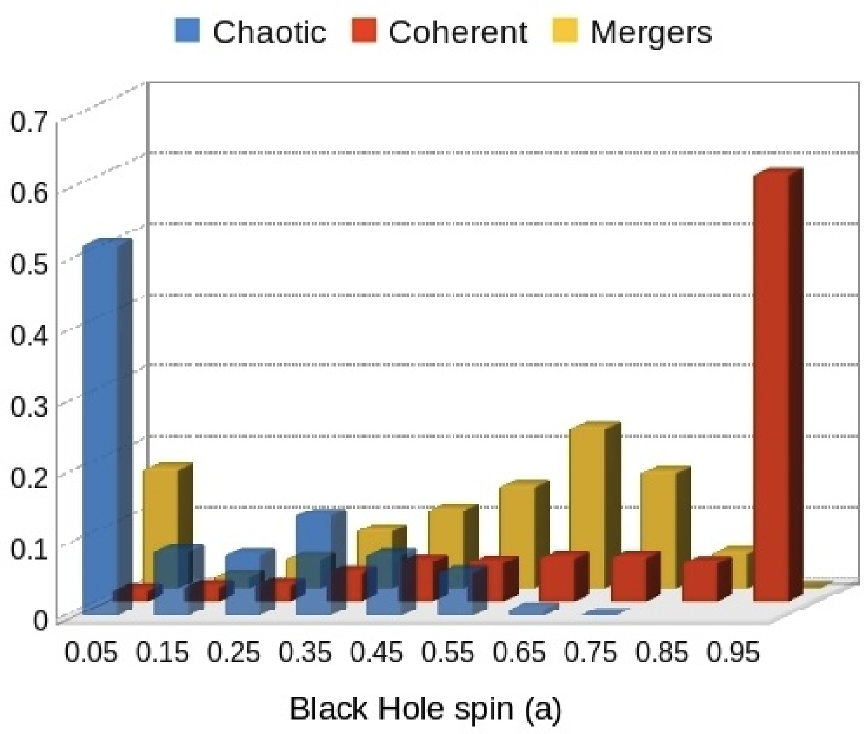




- Other components:
  - ➔ **accretion disc** (UV/optical)
  - ➔ **corona** (X-rays)
  - ➔ **torus**
  - ➔ **winds** (absorbing ionised material)
  - ➔ **jets** (radio emission)

Spin measurements

Theoretical spin distributions
Berti & Volonteri (2008)

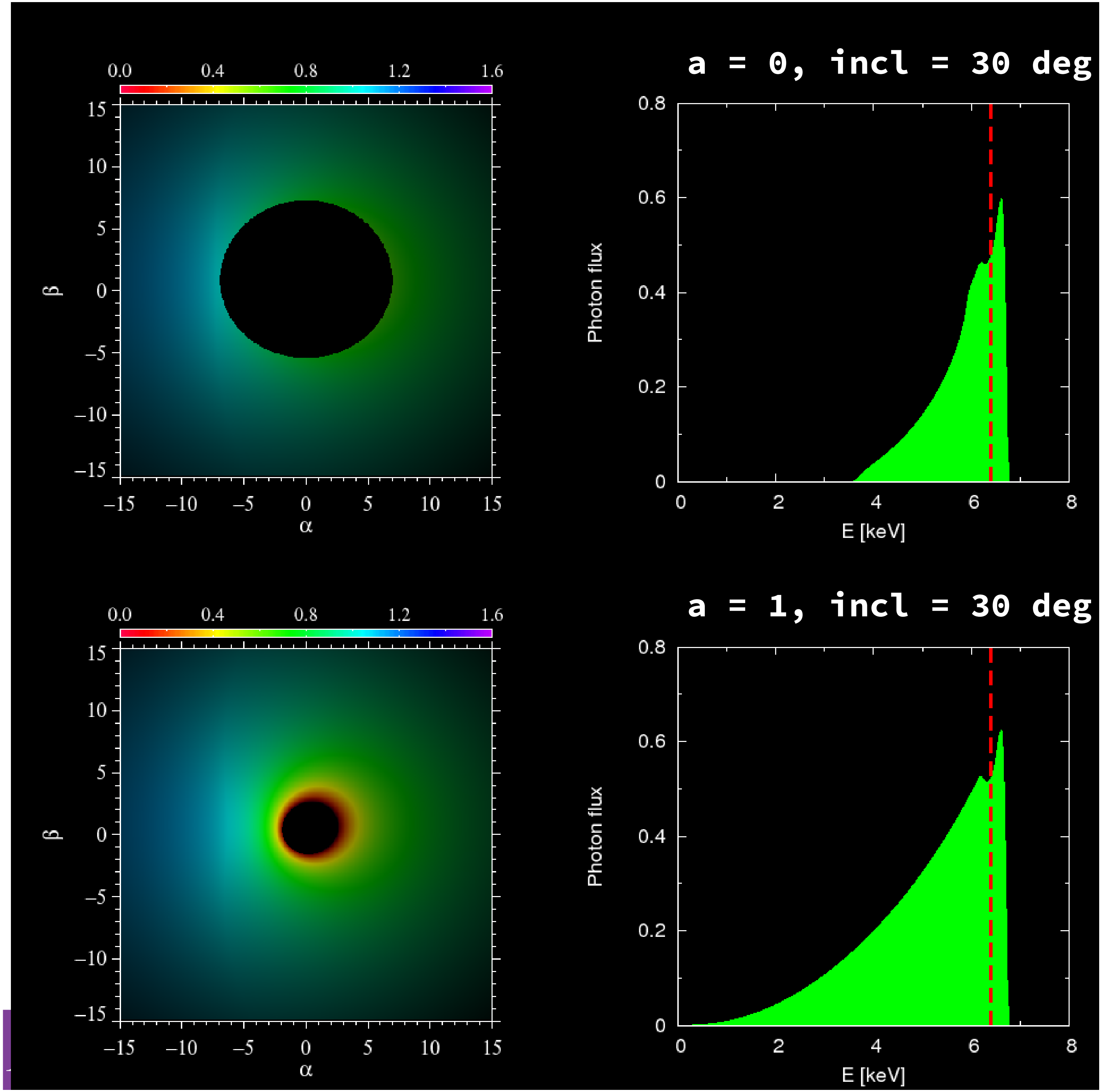


CHAOTIC: spin evolves through mergers and short-lived (chaotic) accretion episodes

COHERENT: spin evolves through mergers and prolonged accretion episodes

MERGERS: spin evolves only through mergers

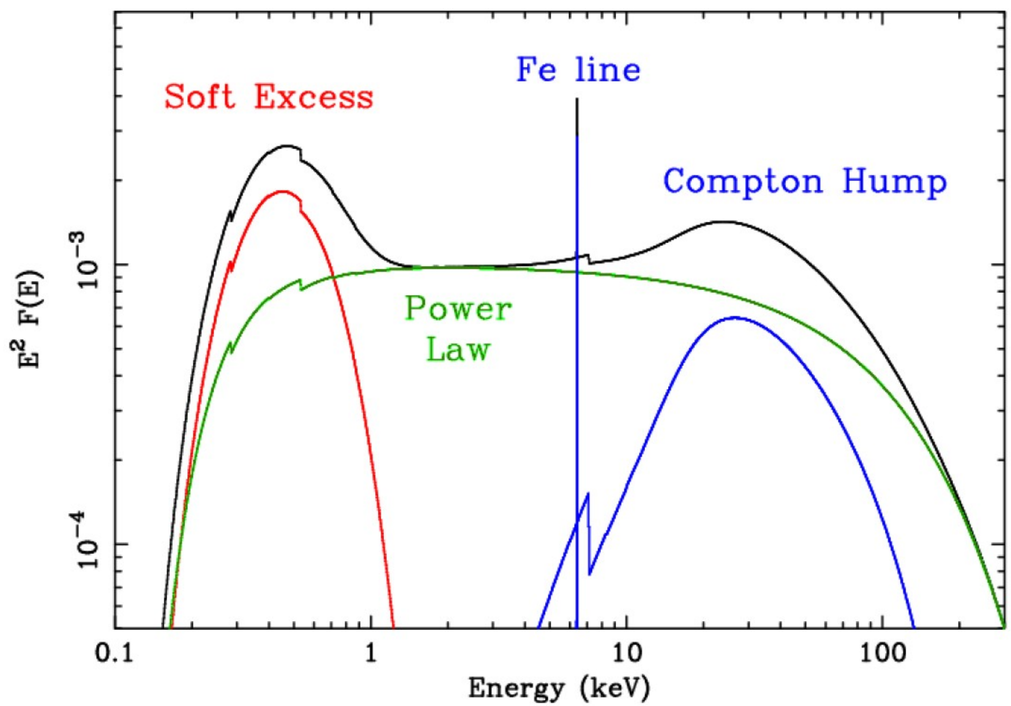
Fabian et al. (1989)



- reflection – the only spin measurement method for AGN
- red wing of Fe line depends on the inner disc edge
- inner disc at ISCO
- ISCO depends on the spin
- need for good estimate of the primary power-law radiation

Spin measurements

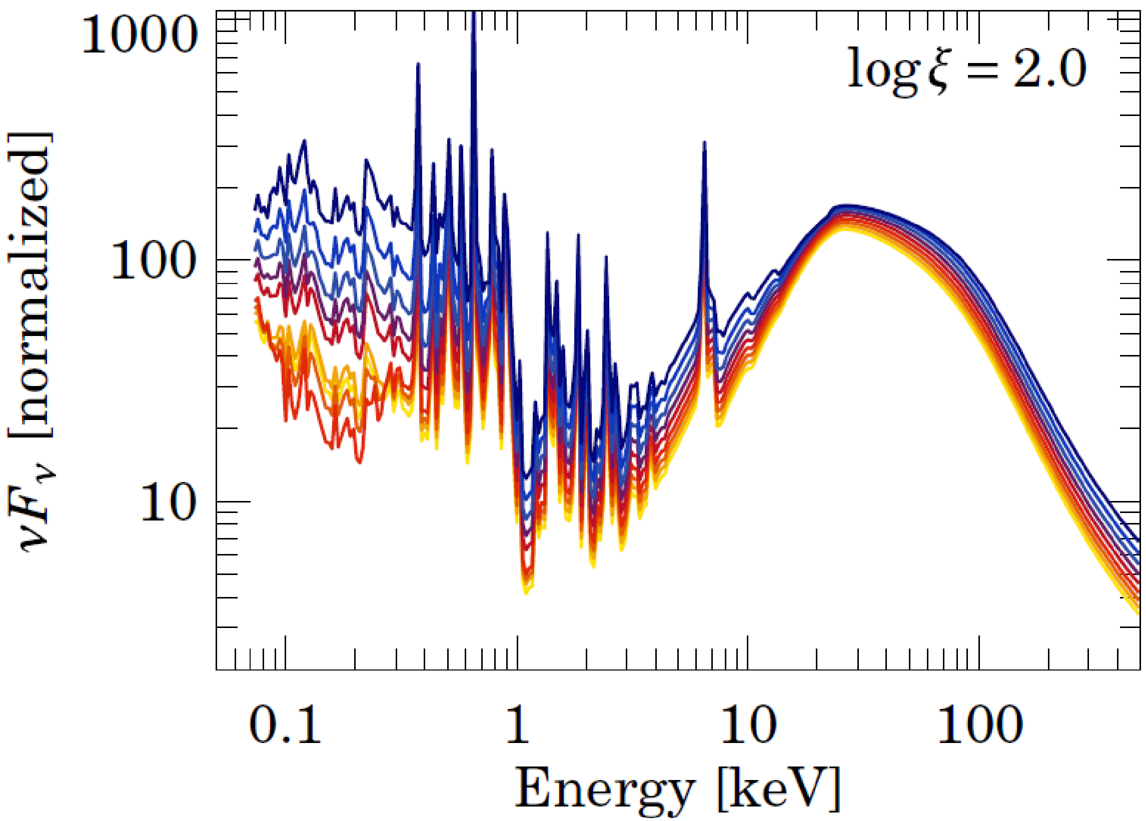
Spectral complexity and variability



- reflection on pc-scale torus
- reflection from ionised NLR
- ionised absorption (warm absorber, wind)
- **soft excess** (ionised reflection? warm corona?)
- to measure the broad line width, the continuum has to be very well constrained

Spin measurements

More complex reflection spectra models



Garcia et al. (2014)

- contribution of reflection, to **soft excess**
- ionisation (ionisation radial profile, Svoboda et al, 2012)
- emission directionality (Garcia et al, 2014)
- iron abundance
- disc density (Garcia et al, 2016)
- fits often driven by **soft excess** in XMM-Newton data

Spin measurements

How and why will Athena improve the spin measurements?

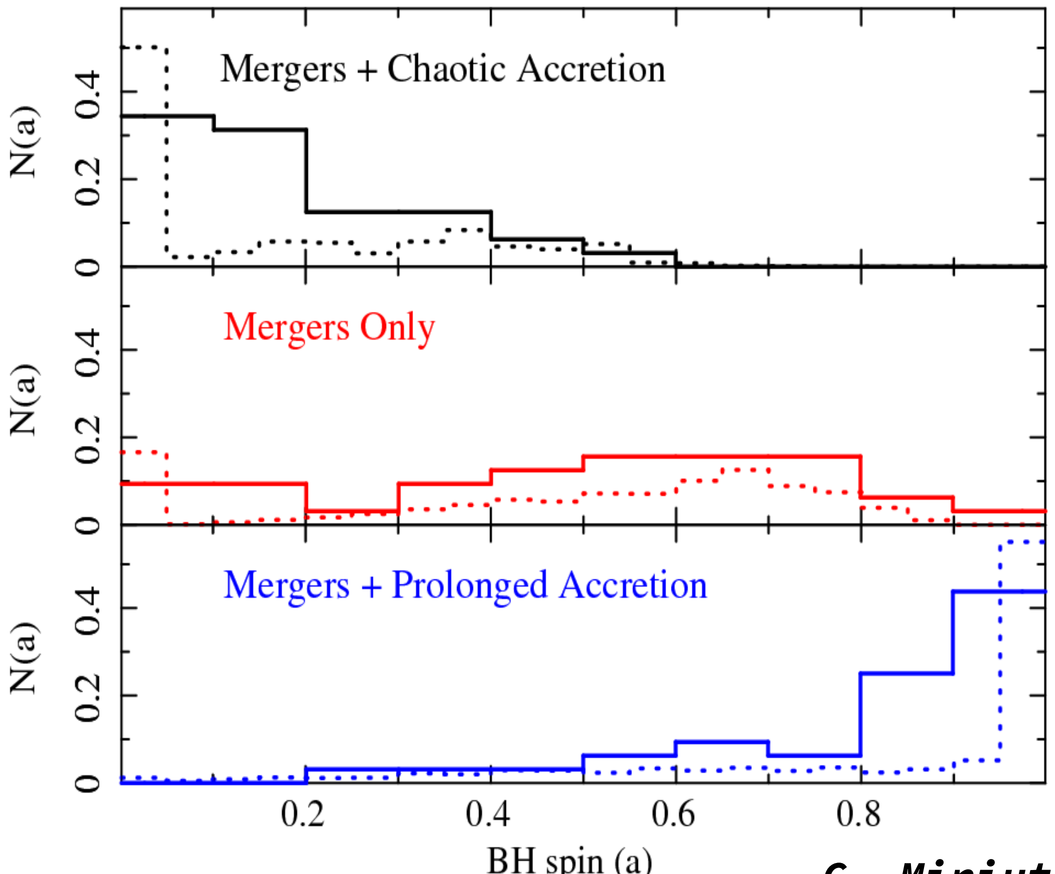
- larger effective area in the Fe line band (2.5x EPIC PN)
  ➔ and better estimate on the iron line flux and shape

- unprecedented resolution with X-IFU complemented with very large effective area in soft energy band
  ➔ better estimate of systematic errors, i.e. contributions from distant reflection, absorption features from winds, etc.

- for better spin measurements hard X-ray mission at the Athena time would be more than helpful (NuSTAR-like)!

Spin measurements

Theoretical expectations (dotted histograms)
vs.
simulated Athena measurements (solid histograms)



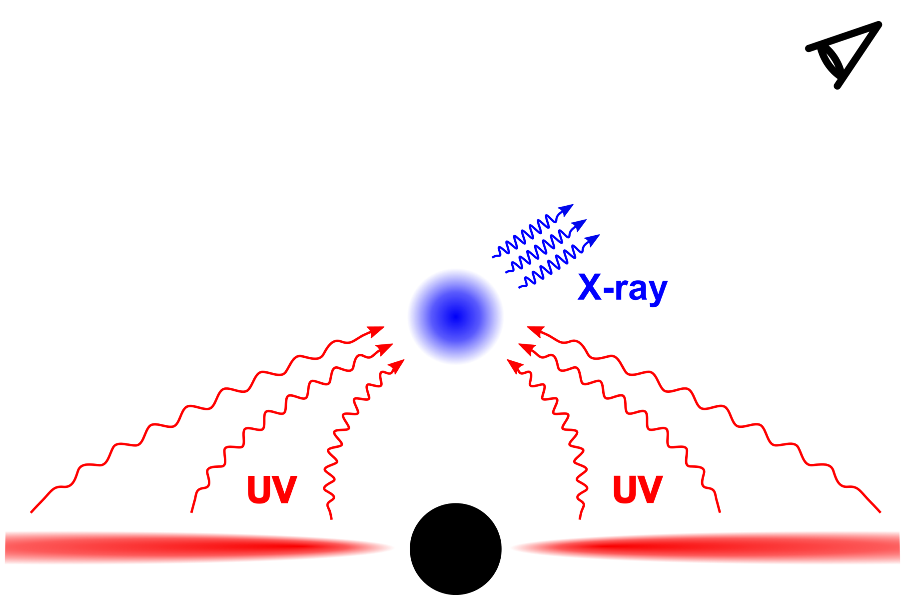
G. Miniutti

- measure spin in ~30 objects with uncertainties Δa≤0.1
- plot accounts realistically for all observational errors and spectral complexities
- plot is made in the assumption that 50% of the brightest Seyfert 1 galaxies in the sky have a reflection component relativistically distorted (De la Calle Perez et al. 2010)
- mean exposure time per source is 100 ks

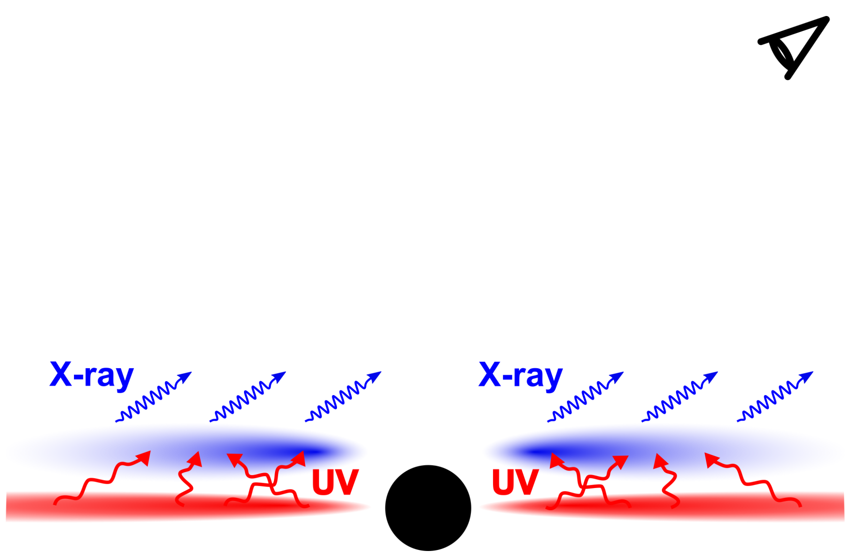
X-ray reverberation mapping

Estimate the geometry of X-ray
emitting and reflecting regions

Compact corona above the disc

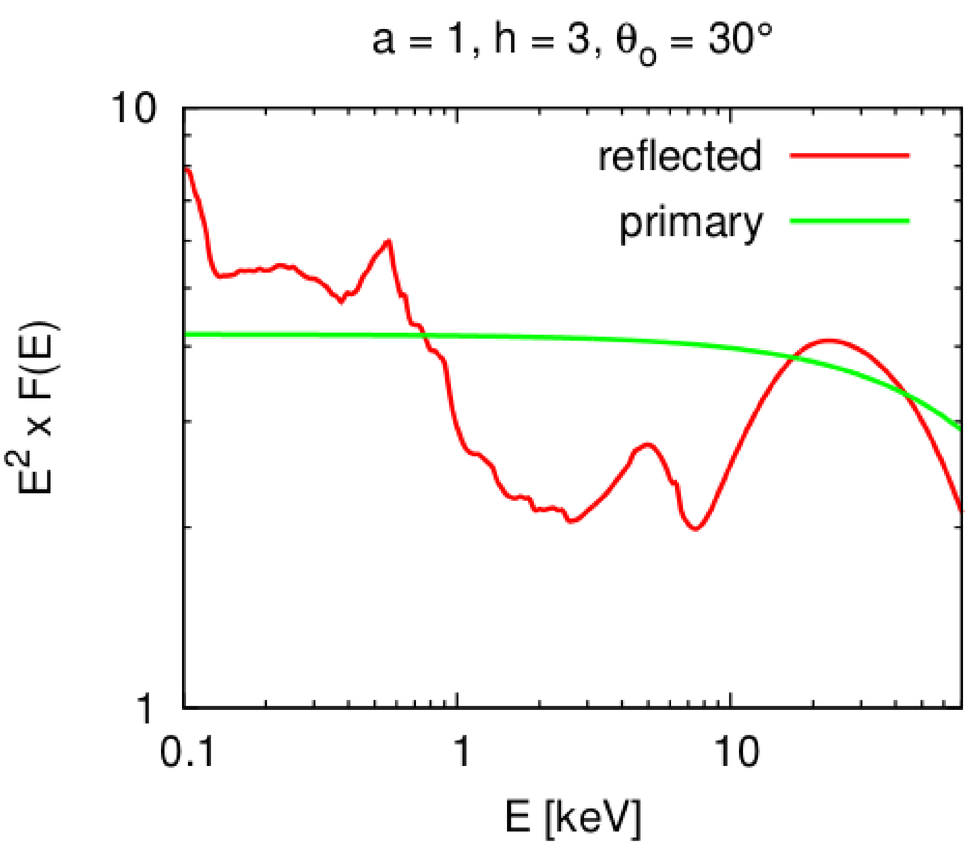


Extended corona above the disc

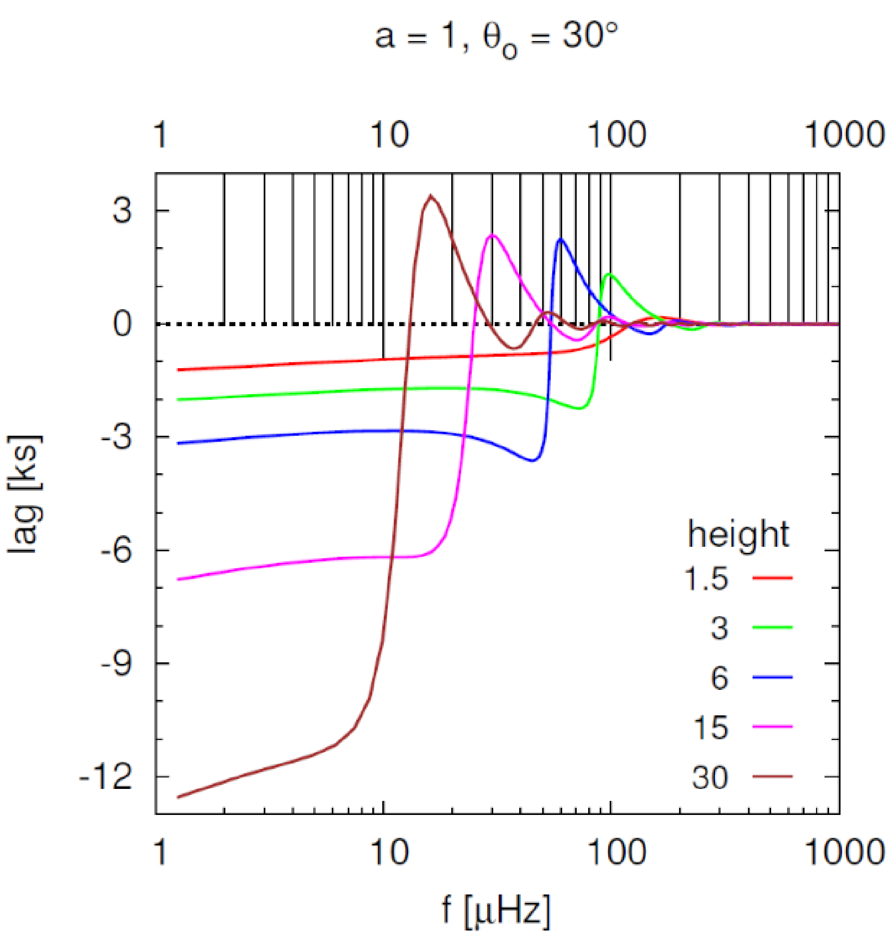


X-ray reverberation mapping

- primary powerlaw fluctuations are followed by reflection fluctuations
- lag between the two signals is given by the phase shift between their Fourier transform
- both signals are visible at the same time so one chooses two different energy bands where one of the signal dominates
- 1-3keV (2-4keV) where the primary power-law is prevailing and soft excess band below 1keV (0.3-0.8keV) and measure the lag between these two energy bands
- complication: the signal in the soft energy band contains large contribution from the primary power-law – this dilutes the lag (makes it smaller)

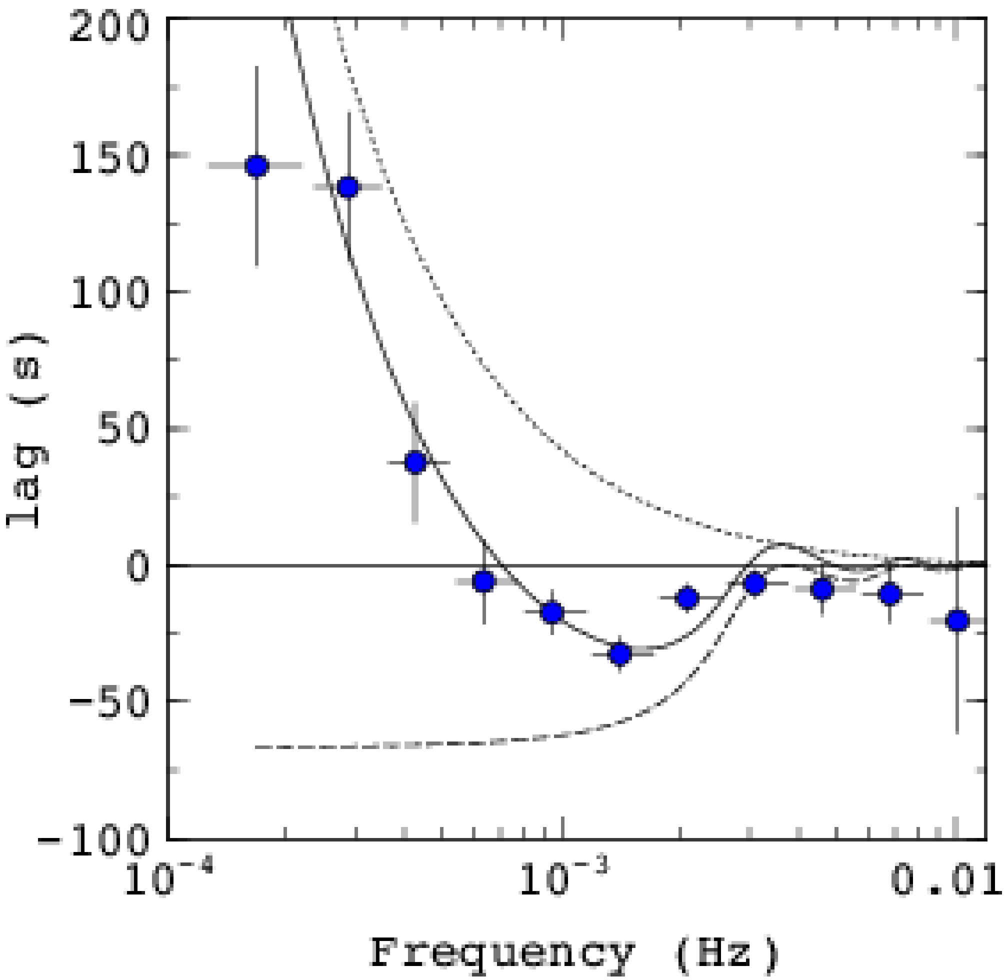


X-ray reverberation mapping



- the lag is a measure of the distance between the two regions (emitter and reflector)
- the reverberation lag depends on the corona geometry
- the effect of the dilution is large:
  - lag/energy dependence follows the spectral shape
  - all effects that change the reflection ratio (disc ionisation, disc density) influences the estimate on the distance between the corona and the disc
  - lag does not directly translate into distance – proper modelling is needed

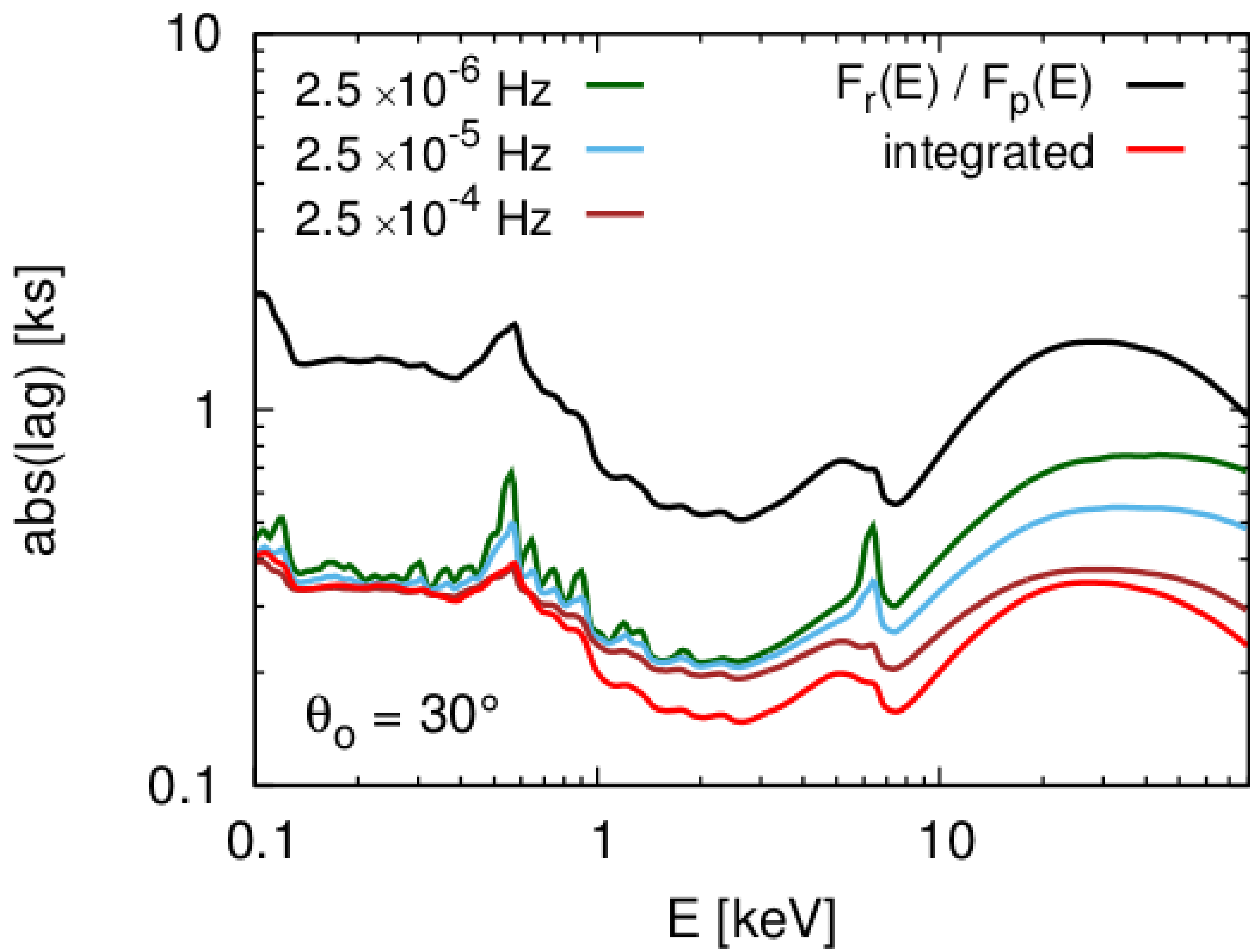
X-ray reverberation mapping



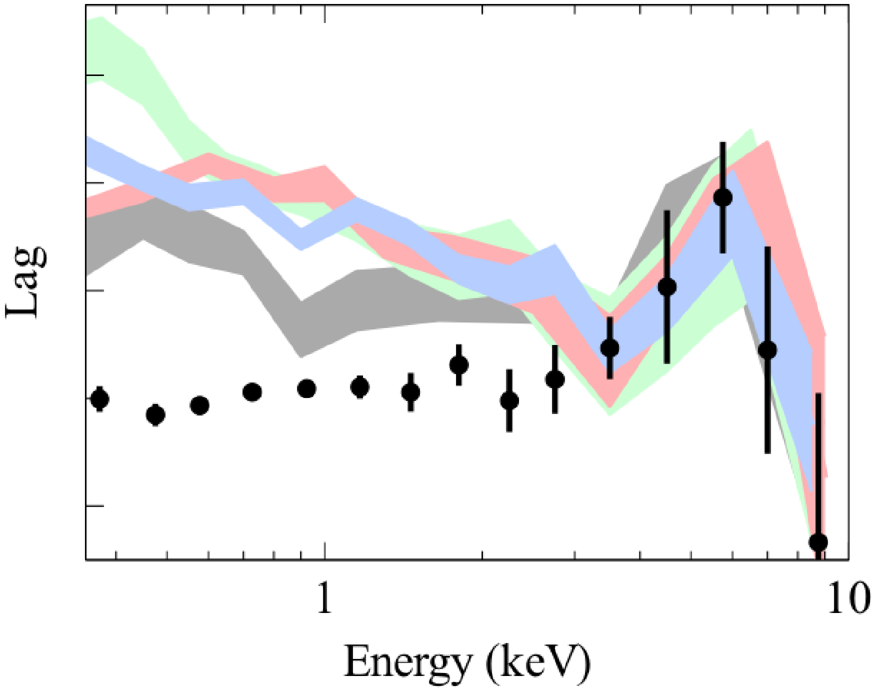
Hard lag due to accretion flow fluctuations visible at low frequencies

X-ray reverberation mapping

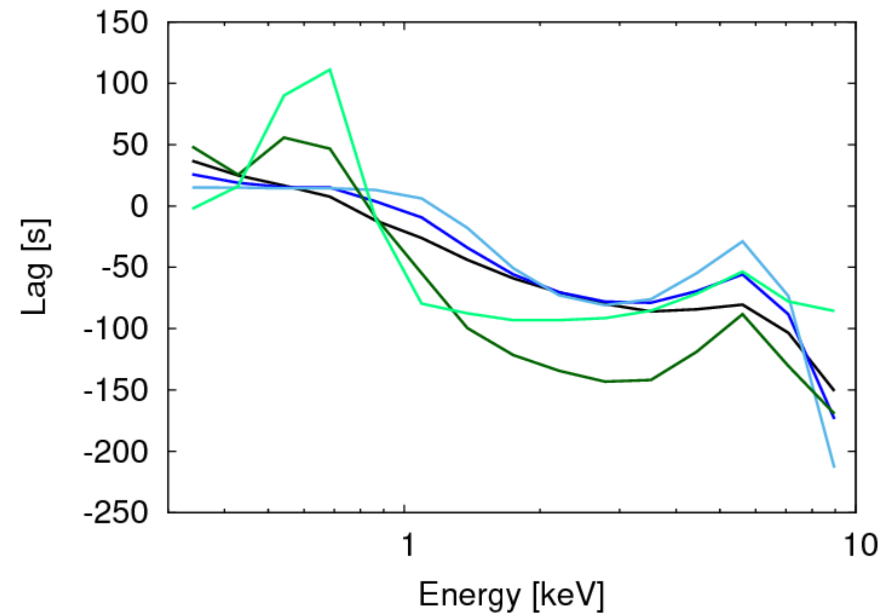
Lag vs. energy



X-ray reverberation mapping



Kara et al. (2014)



https://projects.asu.cas.cz/stronggravity/kynreverb

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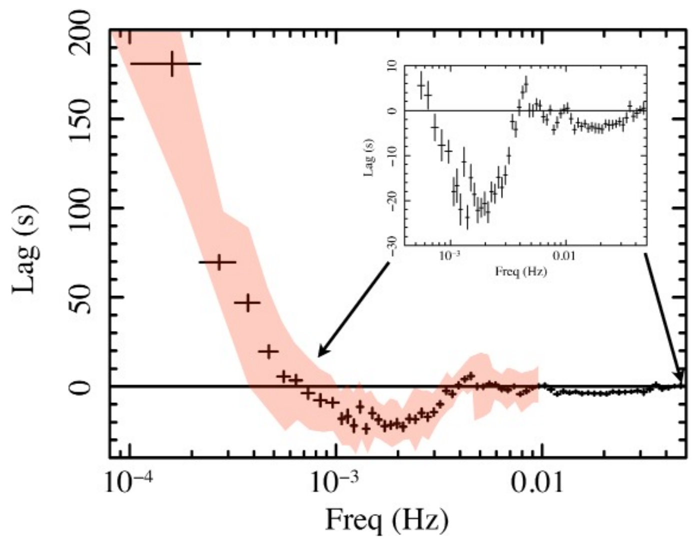
X-ray reverberation mapping

How and why will Athena improve
the X-ray revereberation measurements?

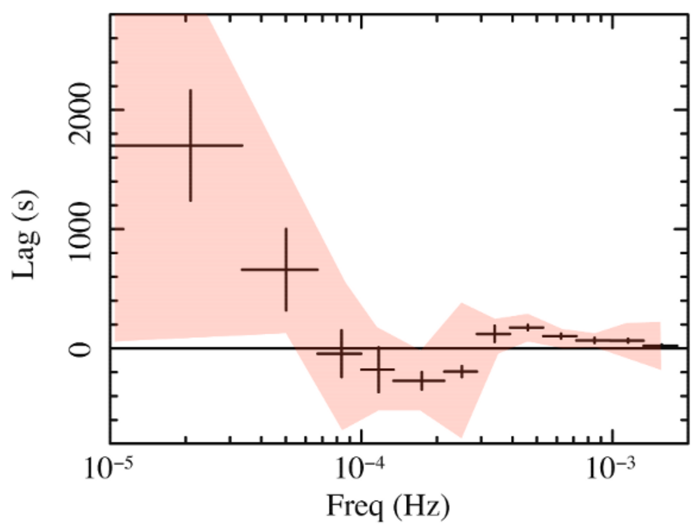
- larger effective area in the soft excess band (10x EPIC PN)
  - → more photons are observed and smaller statistical errors on the lag estimation
  - → we will be able to test change of the lag with time (e.g. due to change in corona geometry)
  - → the observations will still need to be long enough to probe low frequency lags for studying the hard lag shape (due to primary fluctuations or warm absorber)

X-ray reverberation mapping



1H0707-495 expected time lags with Athena

- 1-4 keV against 0.3-1 keV
- exposure time as in the XMM observation, i.e. 500 ks
- structures at frequencies larger than 0.01 Hz that are inaccessible with XMM-Newton



E. Kara

Seyfert galaxy IC4329A - expected time lags with Athena

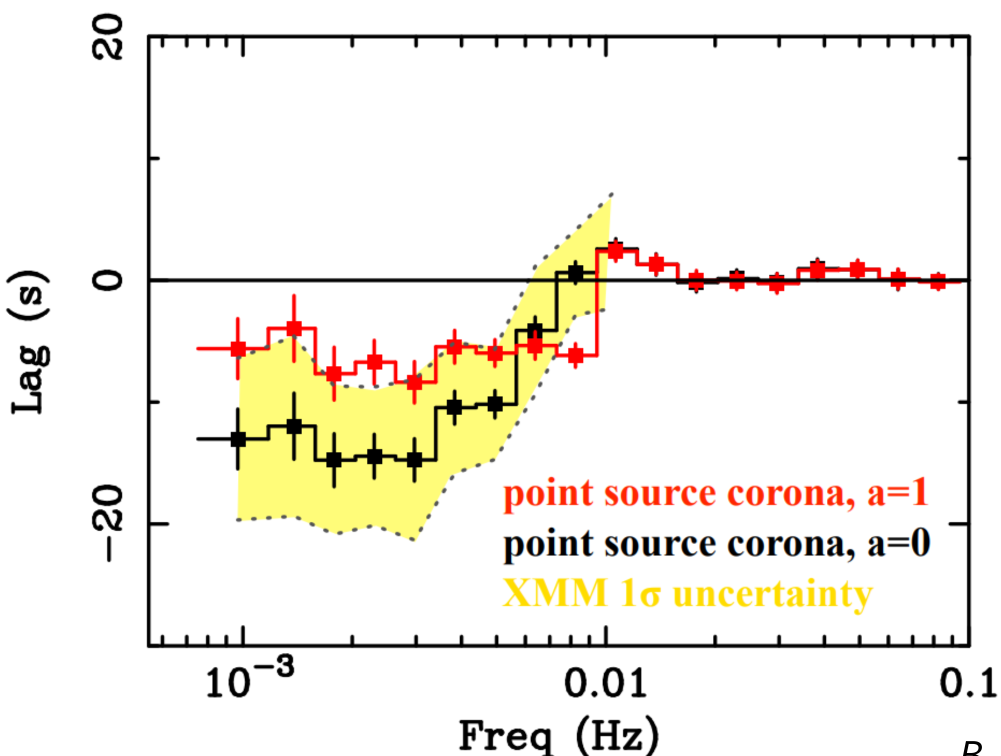
- using the XMM parameters as inputs.
- in XMM the detection was not significant
- the red region represents the XMM 1σ contour

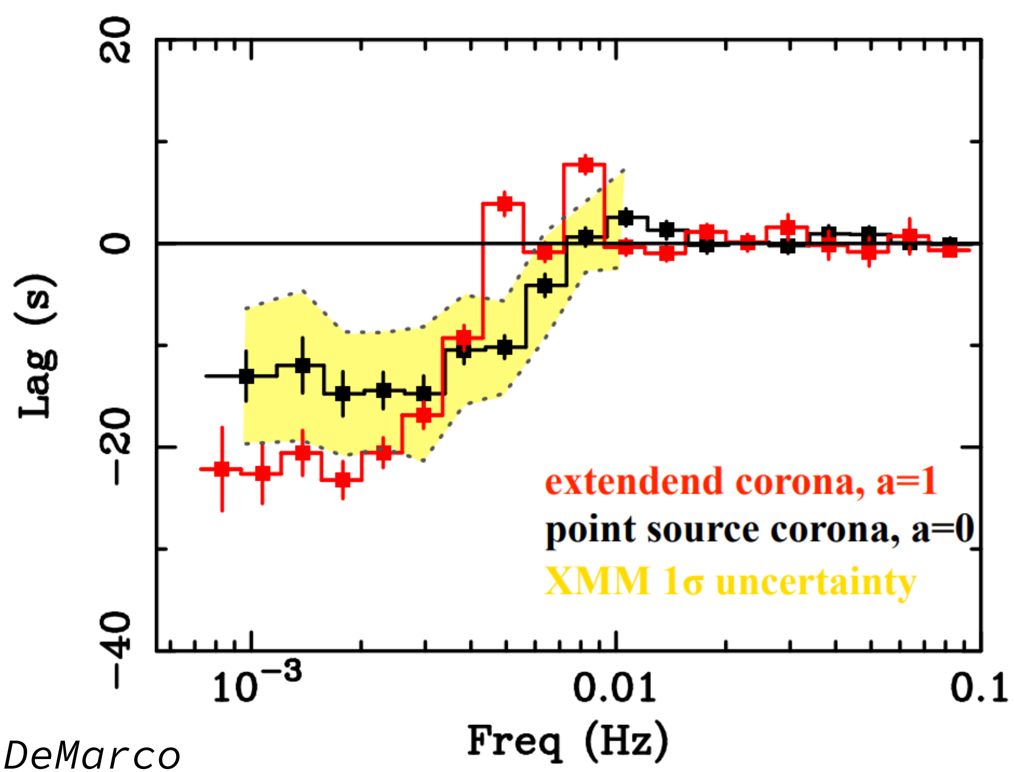
X-ray reverberation mapping

WFI simulations of soft X-ray lags

BH spin a=0 vs. a=1
for point source corona
at a height h=2.5rg

Point source corona (a=0) vs.
radially extended (up to ~35rg)
corona (a=1) geometry





B. DeMarco

➔ the yellow shaded areas mark the 1σ uncertainties of EPIC pn lag measurements