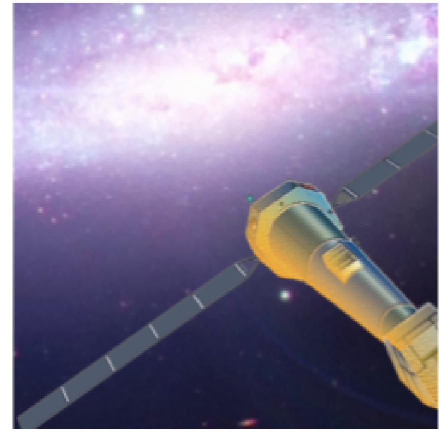
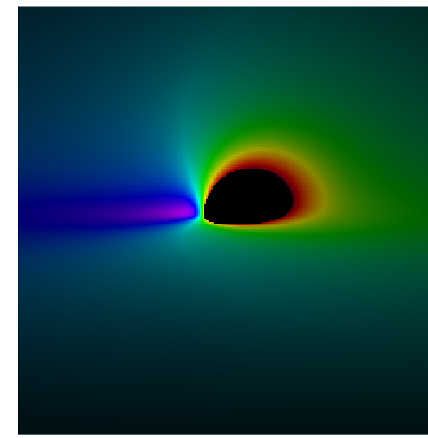
ATHENA



Relativistic Astrophysics with Athena



Michal Dovčiak

On behalf of SWG 2.4
Close environments of SMBH

Astronomical Institute of the CAS
Prague, Czech Republic

Astronomical Institute of the Czech Academy of Sciences
The Czech Academy of Sciences
Strategy AV21
Top research in the public interest
MINISTRY OF EDUCATION, YOUTH AND SPORTS

FERO IX, 23–25 May 2018, Heraklion, Greece

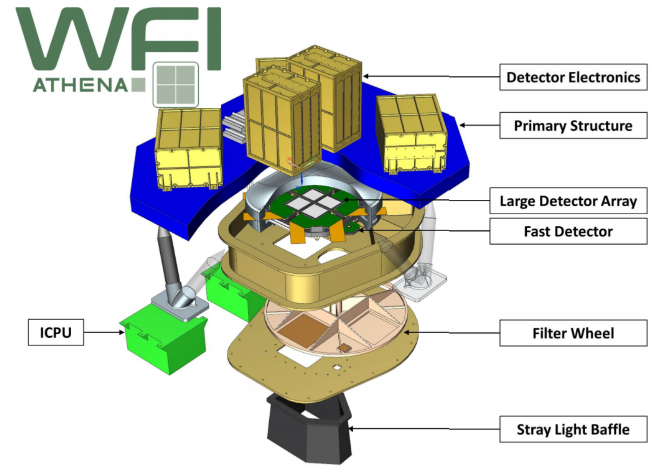
Advanced Telescope for High ENergy Astrophysics

- ESA Cosmic vision 2015-2025 – second large (L2) mission
- Launch in ≤2029 with Ariane 64
- Hot and Energetic Universe (2014)

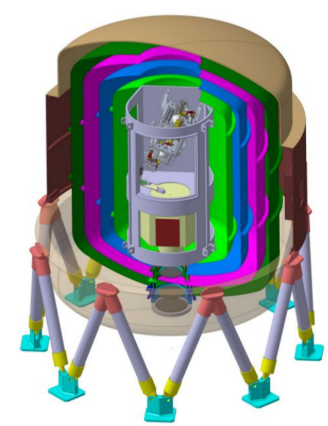
- Cost: €1.05bn
- Mass: 7 tons
- Lifetime: 4 years

Athena mission concept

- Single telescope
- Silicon Pore Optics technology
  - focal length: 12m
  - effective area: $1.4m^2$ @1 keV & $0.25m^2$ @6 keV
  - angular resolution: 5″ on axis
  - movable mirror assembly
- Wide Field Imager (WFI)
  - field of view: 40′x 40′
  - energy resolution: 120-150 eV @6 keV
  - energy range: 0.2-15 keV
  - time resolution: <5 ms
- X-ray Integral Field Unit (X-IFU)
  - field of view: 5′x 5′
  - energy resolution 2.5 eV
  - energy range 0.2-12 keV
  - time resolution: 10 μs



http://www.mpe.mpg.de/ATHENA-WFI/

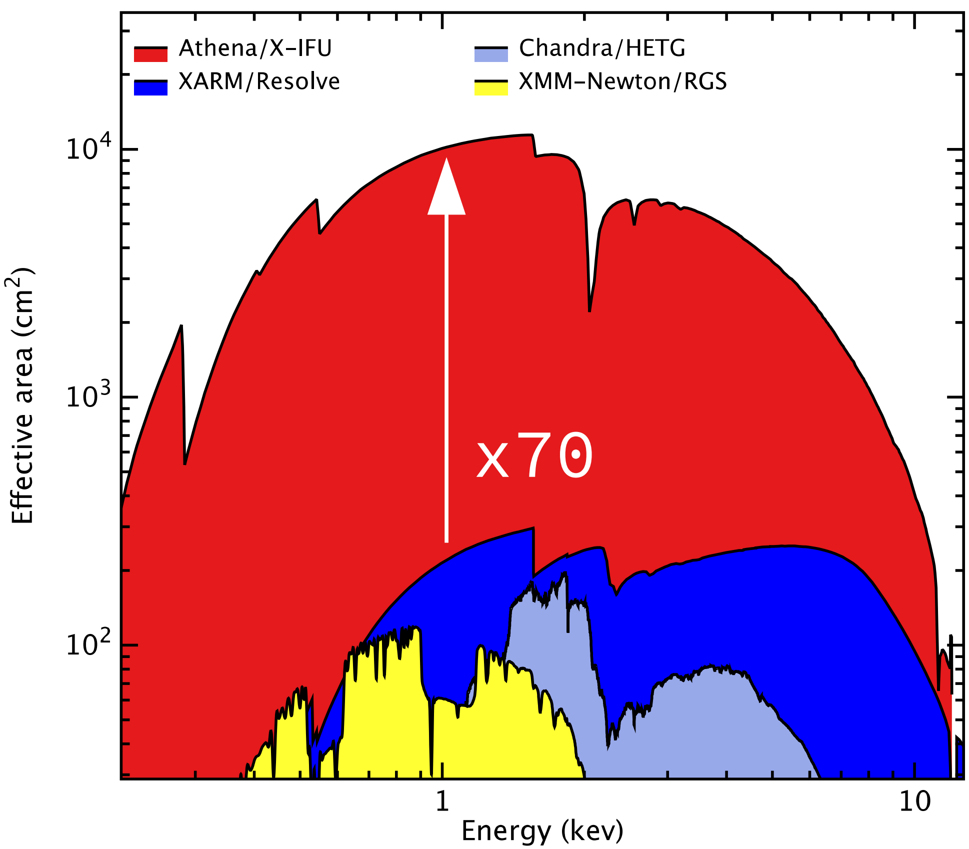


IFU
ATHENA X-ray Integral Field Unit

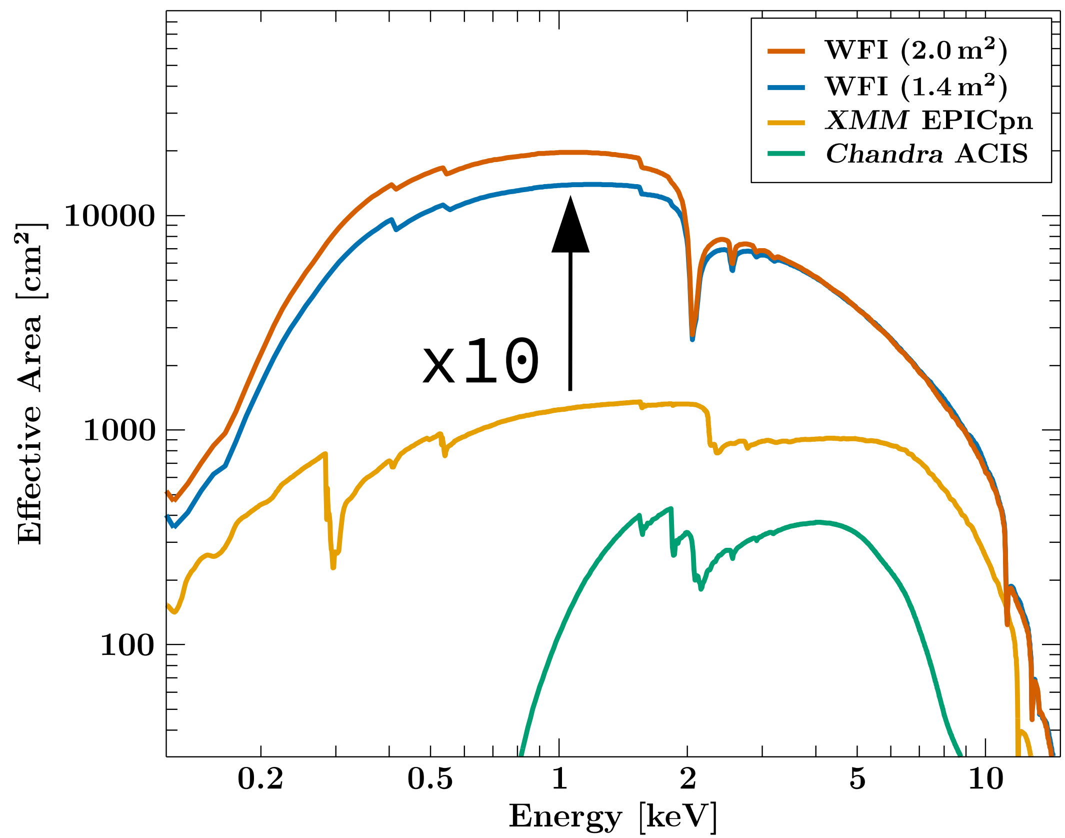
http://x-ifu.irap.omp.eu/

Athena comparison with other missions

X-IFU+mirror collecting area

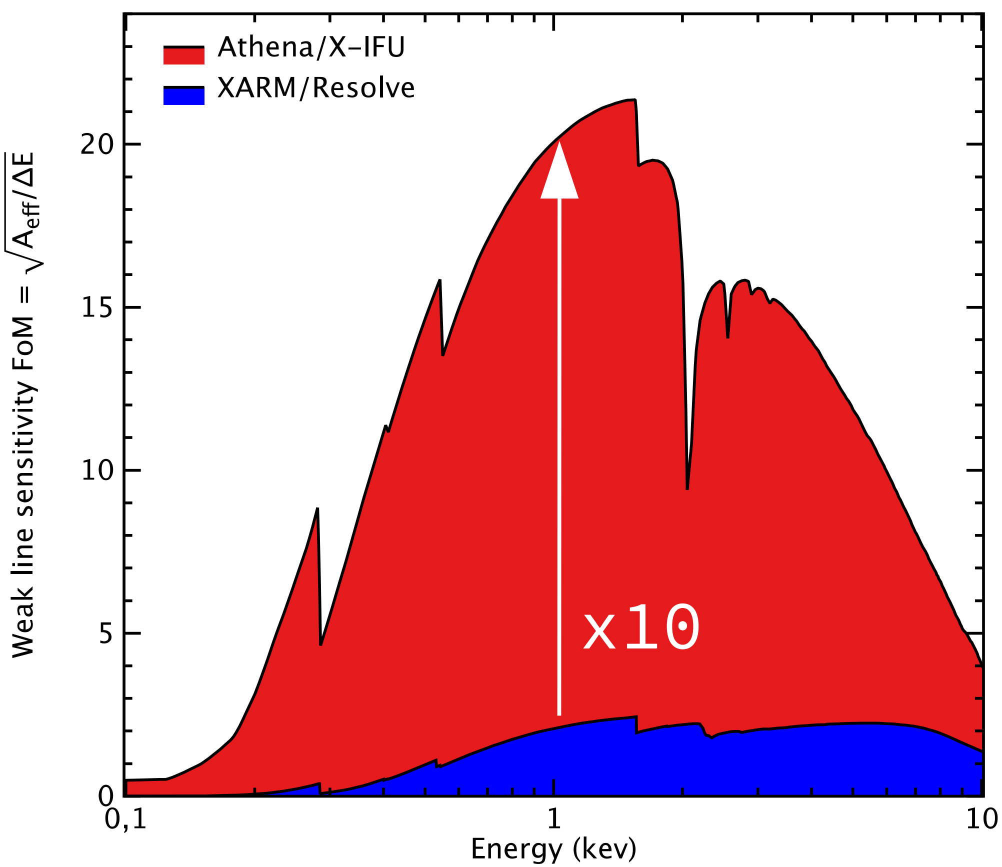


WFI+mirror collecting area

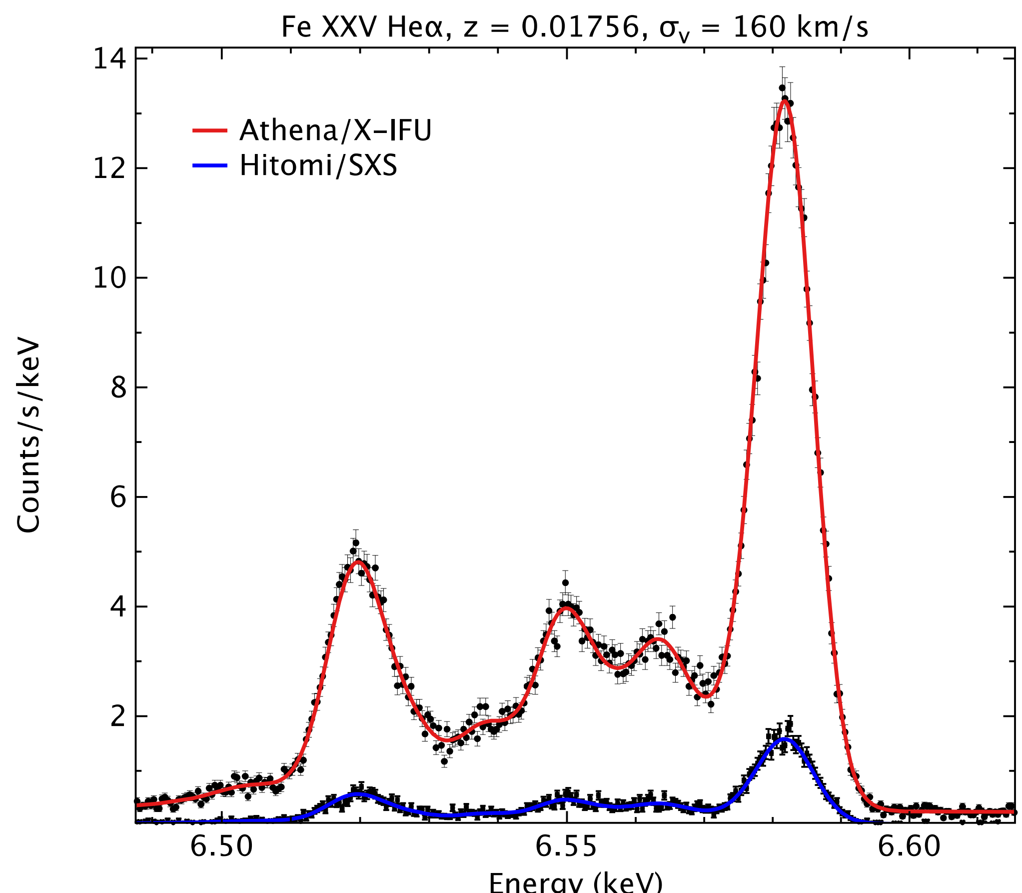


Athena comparison with other missions

X-IFU weak line sensitivity



X-IFU vs. the best-quality existing high-resolution spectrum @6 keV



©DB/X-FIU

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

Relativistic Astrophysics with Athena

- **Close environments of SMBH**
  - 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
- **Physics of accretion**
  - GBH and NS spins and winds
    - ➔ measure black hole spins, constrain neutron star radii, detect winds and outflows, and study the accretion disk and coronal physics
  - BH accretion at the highest and lowest rate
    - ➔ ULXs to understand the geometries that enable super-Eddington accretion
    - ➔ observe SgrA* (low accretion rate) in the longest continuous segment possible for spectrum of the quiescent flux level and to catch a flare event

Relativistic Astrophysics with Athena

- **Luminous extragalactic transients**
  - Formation of the first black holes
    - ➔ z>7 observations of GRB afterglows
  - Stellar disruption events
    - ➔ surge in accretion onto SMBHs, dynamics of tidal shearing near the event horizon, rapid accretion rate changes in AGN systems
- **End points of stellar evolution**
  - Double degenerate binaries
    - ➔ identify the most promising gravitational wave sources and Type Ia Supernova progenitors
  - Black hole birth
    - ➔ observations of Supernova

Close environments of SMBH

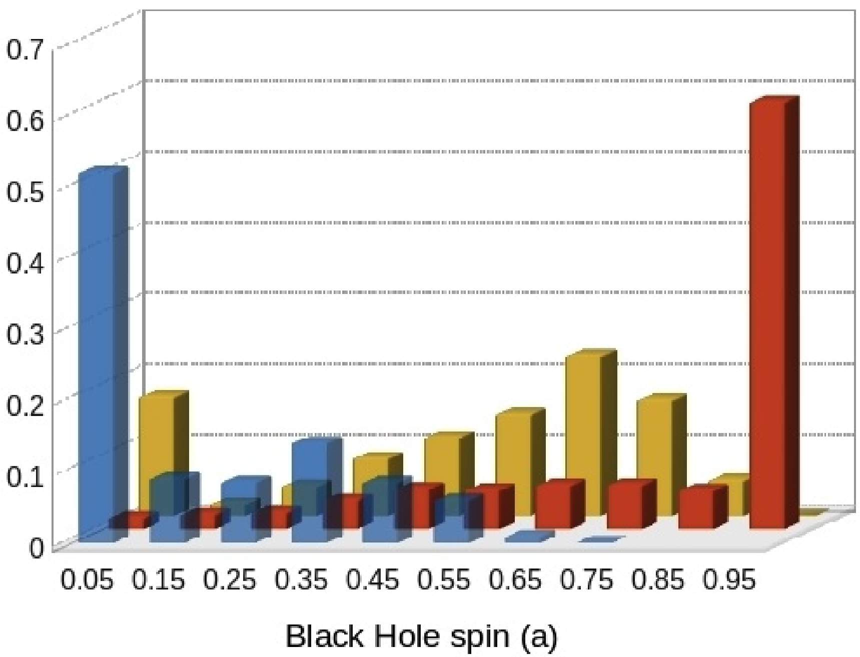
- AGN spin census
- AGN reverberation mapping
- Nature of the soft X-ray excess
- Mapping the accretion disk
- Mapping the circumnuclear matter
- Testing the General Relativity

Close environments of SMBH

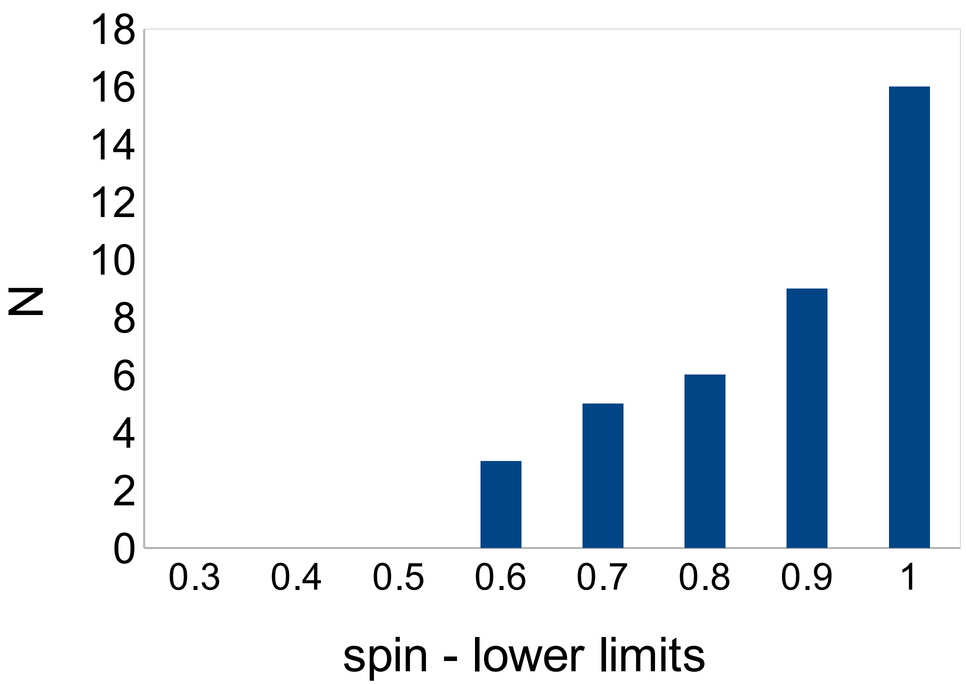
- **AGN spin census**
- AGN reverberation mapping
- Nature of the soft X-ray excess
- Mapping the accretion disk
- Mapping the circumnuclear matter
- Testing the General Relativity

Spin measurements

Theoretical spin distributions
Berti & Volonteri (2008)

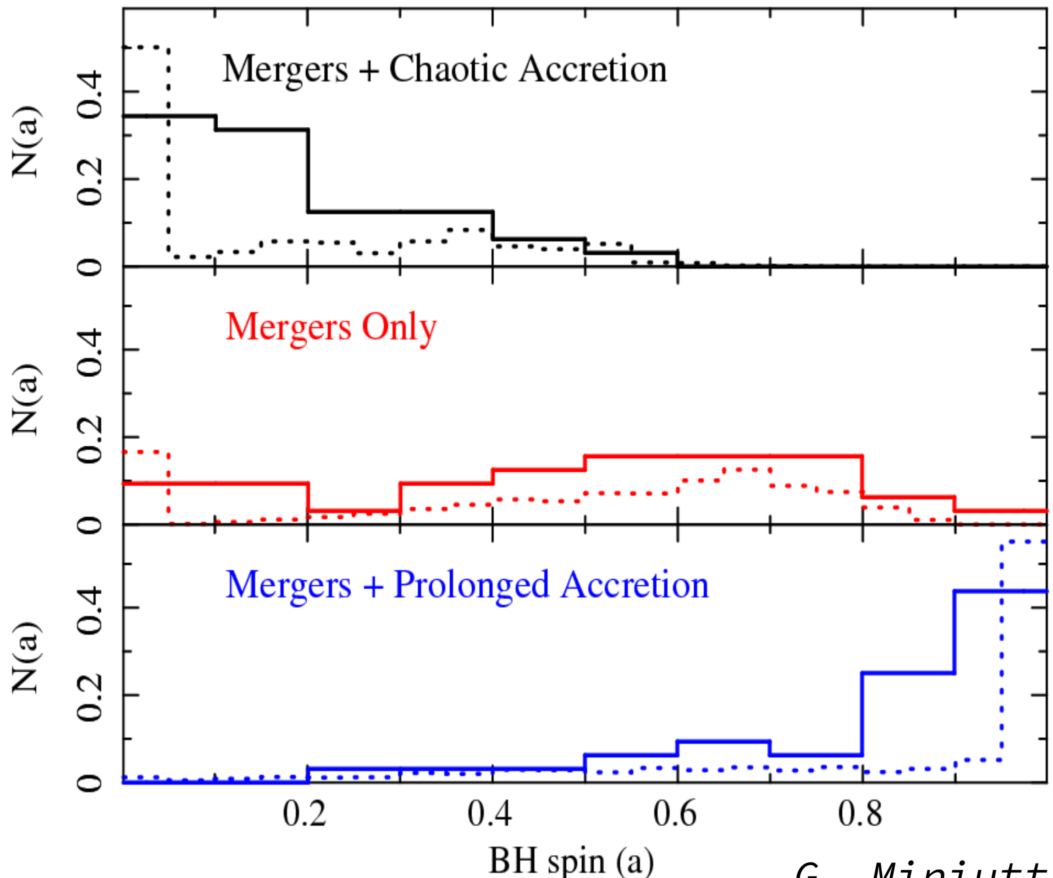


Current spin measurements
based on data from Reynolds (2013)



Spin measurements

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

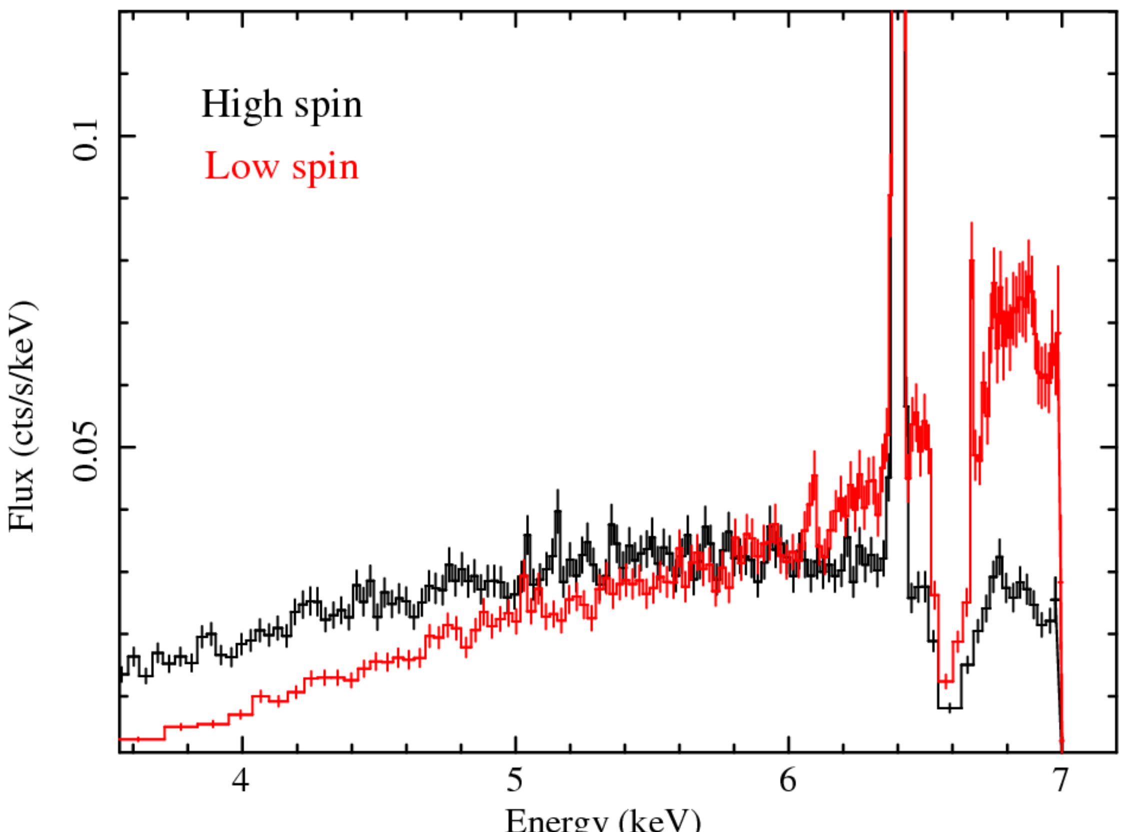


G. Miniutti

- 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

Spin measurements

Simulated Athena/X-IFU **150 ks** Fe line profile for a low and high spins (a = 0, 0.998)



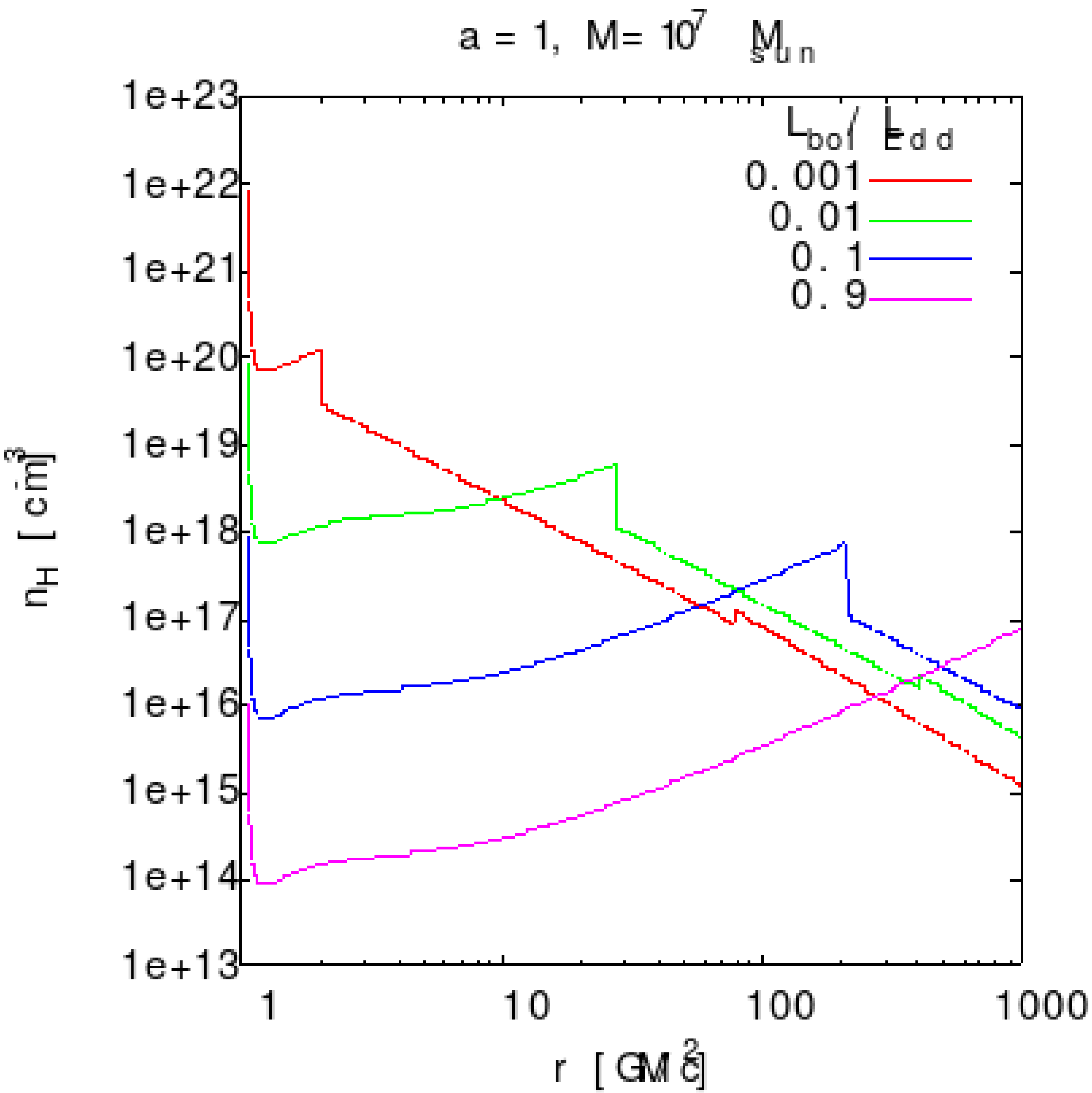
G. Miniutti

- plus a narrow emission feature at 6.4 keV emitted from a distant reflector (molecular torus)
- plus an ionized absorption from a wind (Fexxv at ~6.6keV)
- the flux of the source is ~10-11 cgs (moderately bright AGN)
- inclination is 40°
- equivalent widths of the lines are 100 and 200 eV for the broad and narrow components
- moderately thick and highly ionized wind were used
- Athena/X-IFU will easily separate any narrow features from those produced by strong gravity.

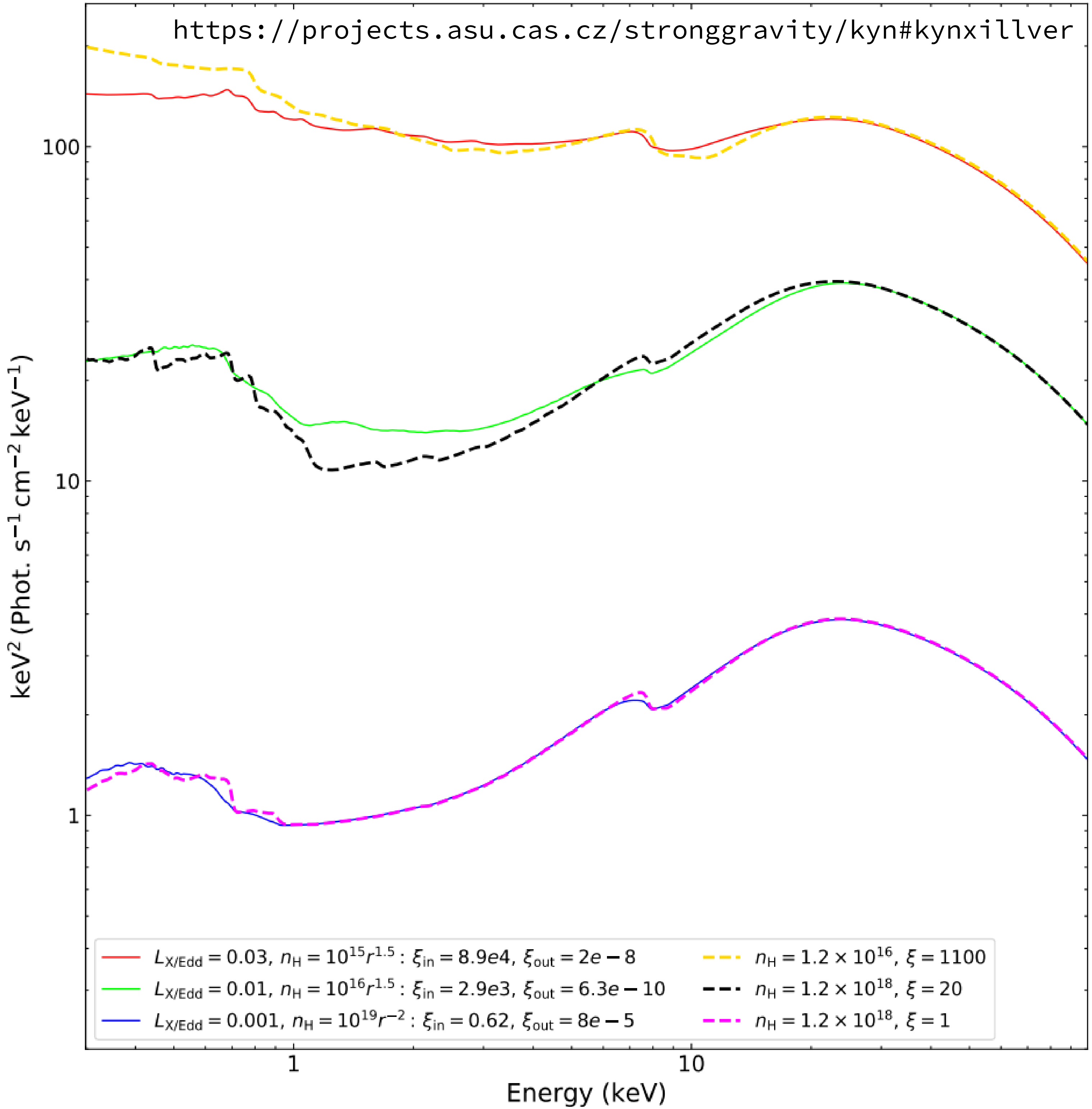
Spin measurements

Influence of radial density profile on spectra

- Low flux: high density, radial decrease of density → neutral disc
- High flux: low density, radial increase of density → ionised disc with steep decrease of ionisation



Influence of radial density profile on spectra



Spin measurements

- do we have only single ionisation discs?
- or the models are complicated enough (include other components) to “get rid of signatures of radial ionisation profile”
- do we get high spins to hide inconsistences (by smoothing them out) at low energies

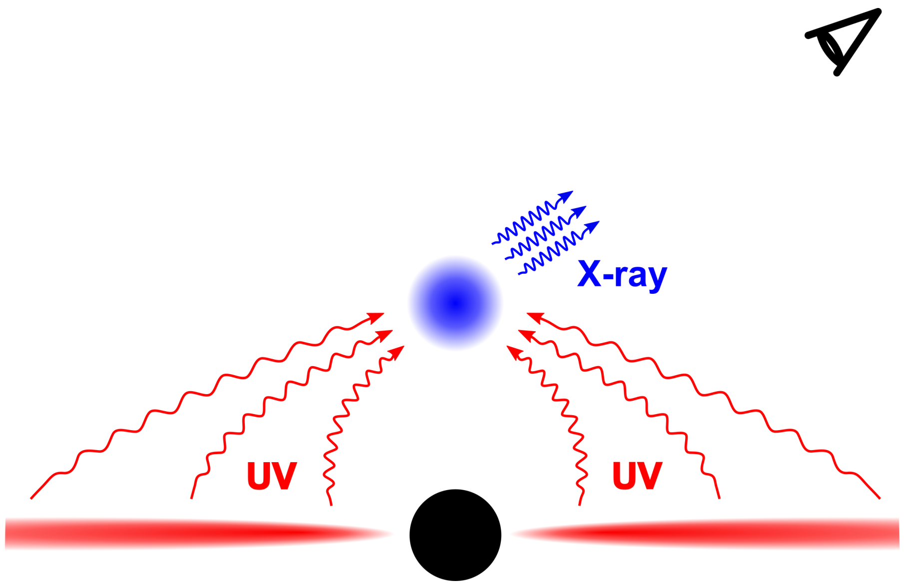
Close environments of SMBH

- AGN spin census
- **AGN reverberation mapping**
- Nature of the soft X-ray excess
- Mapping the accretion disk
- Mapping the circumnuclear matter
- Testing the General Relativity

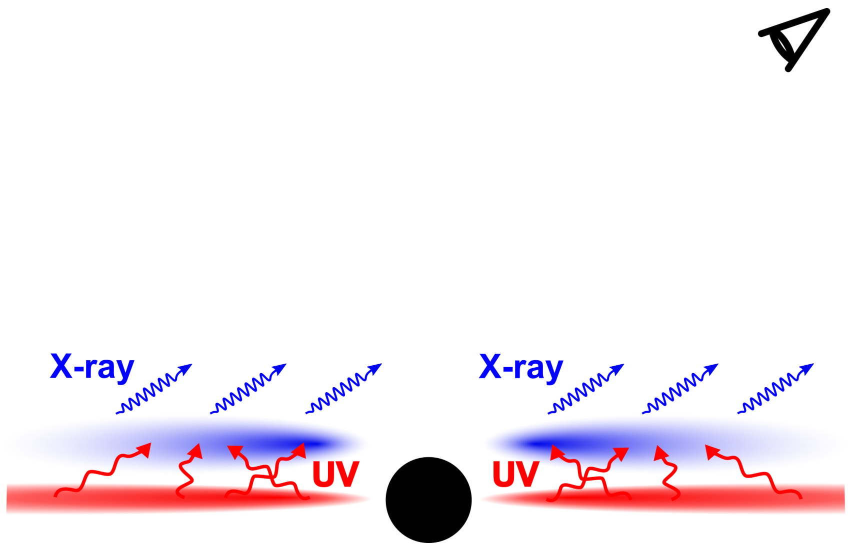
X-ray reverberation mapping

Estimate the geometry of X-ray emitting and reflecting regions

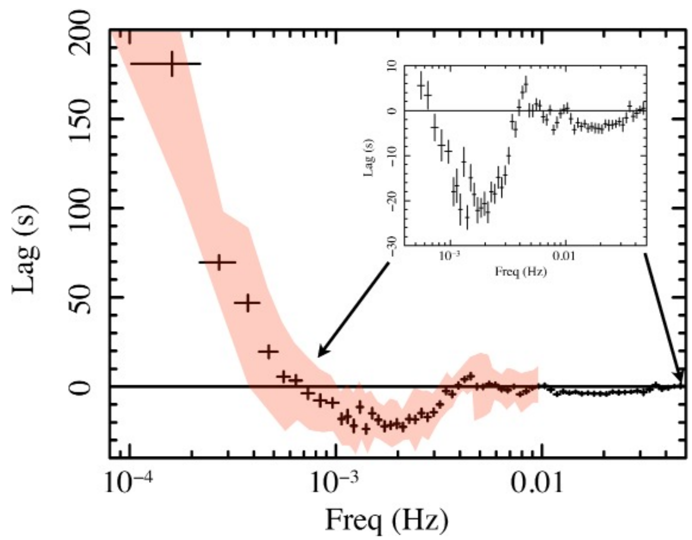
Compact corona above the disc



Extended corona above the disc

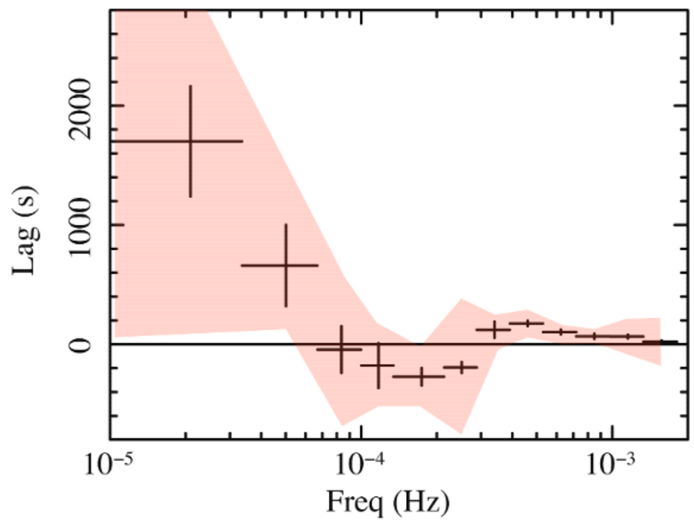


X-ray reverberation mapping



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

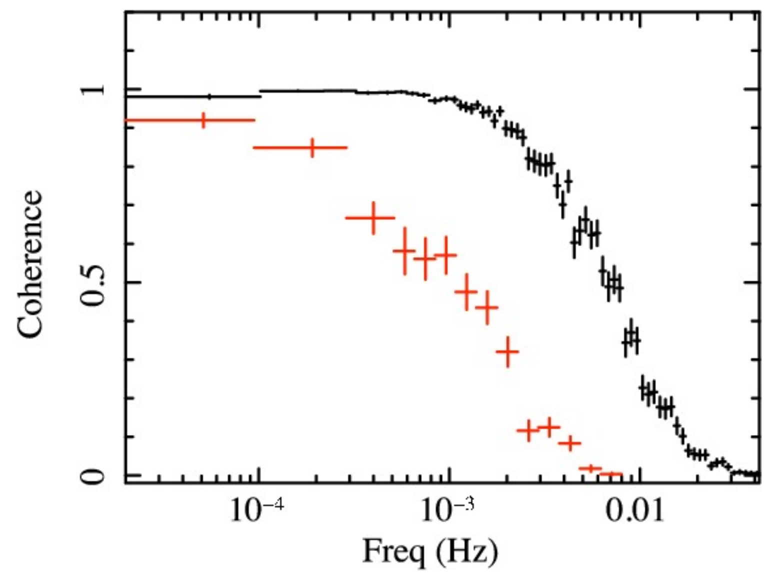
Seyfert galaxy IC4329A – expected time lags with Athena

- 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

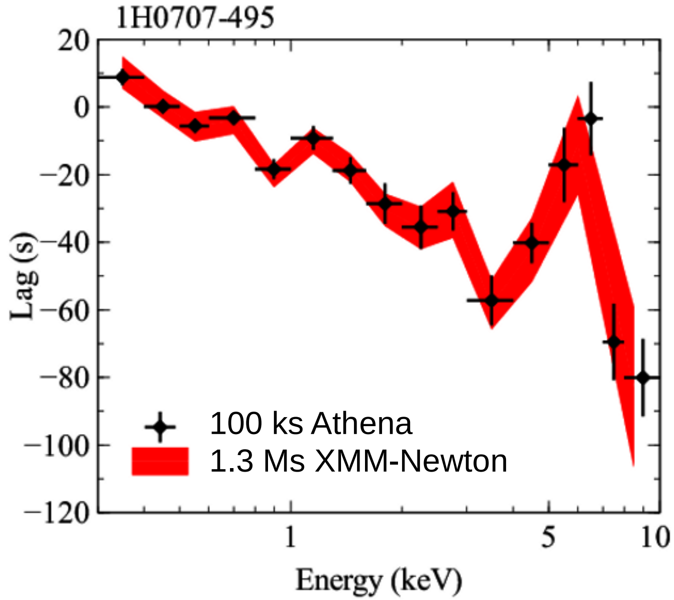
The raw coherence function
for XMM (red) and Athena (black)

- the drop due to Poisson noise is shifted to higher frequencies, which allows detection of lags in a much broader frequency range.



The expected time lag vs. energy
for 1H0707-495 with Athena

- the full line profile will clearly emerge in the observed energy dependence of lags
- the lag spectrum will complement the photon spectrum allowing for an unambiguous decomposition into the various emitting components

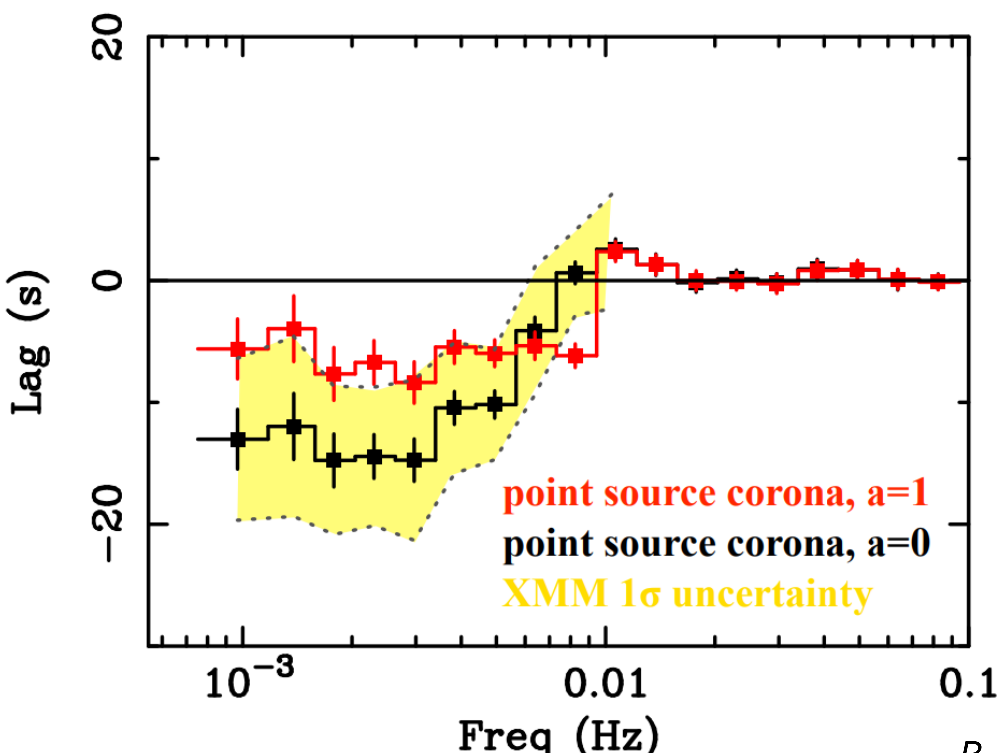


E. Kara

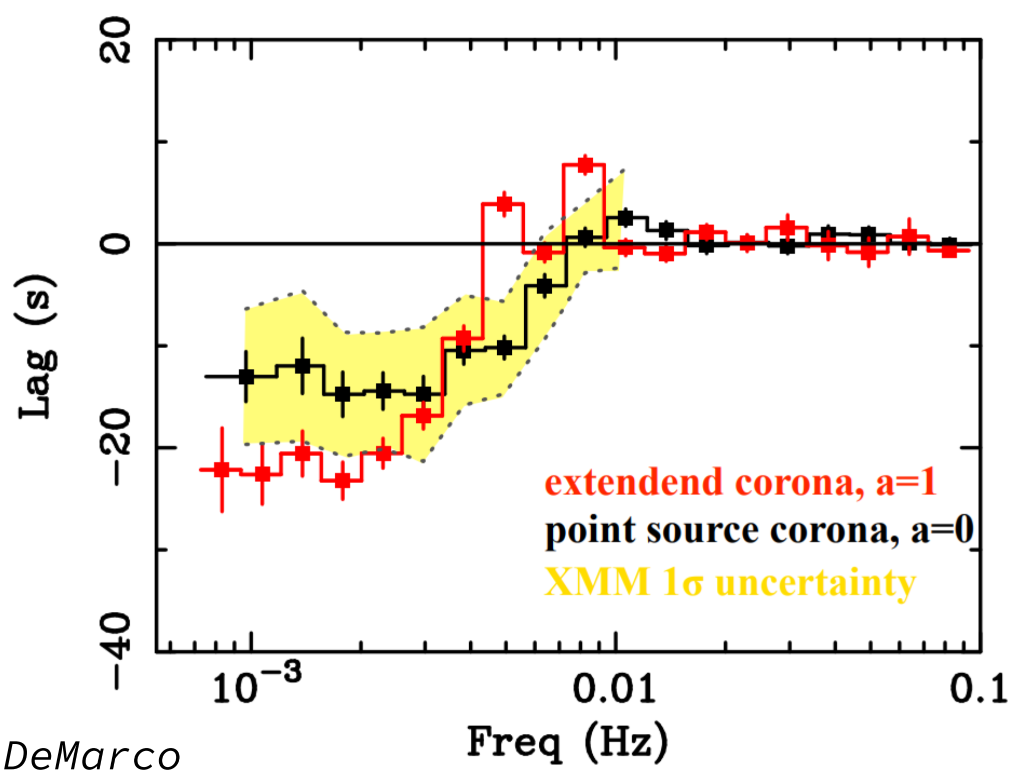
X-ray reverberation mapping

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

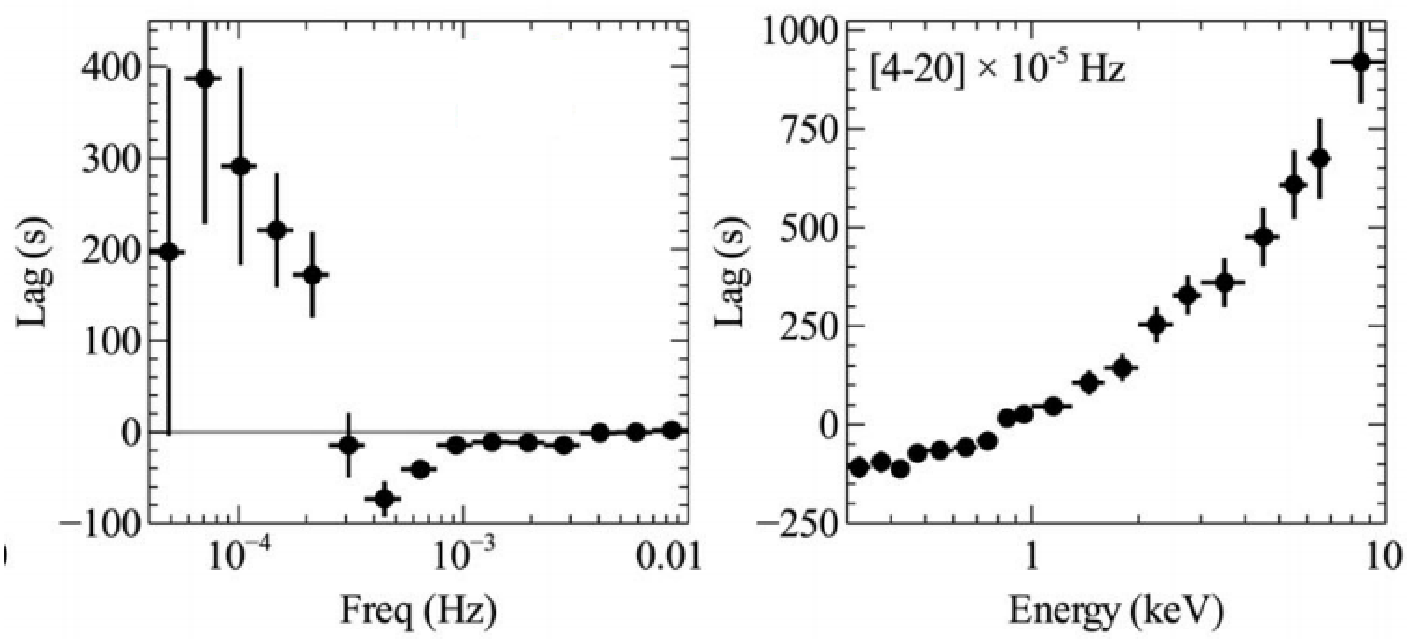


B. DeMarco

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

X-ray reverberation mapping

- **soft excess** and **warm corona** model
  - ➔ additional power-law component at soft X-ray energy
- low-frequency **lag-energy dependence**
  - ➔ power-law (phase follows the ratio of the spectra, $E^{\Delta\Gamma}$)
- low-frequency **lag-frequency dependence**
  - ➔ oscilatory behaviour (due to phase wrapping)
  - ➔ decrease of lag at low frequencies

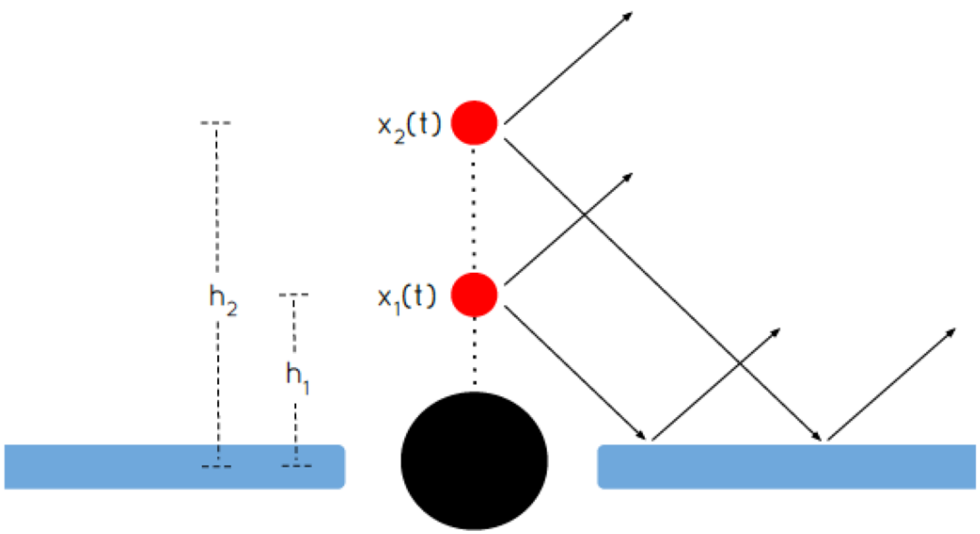


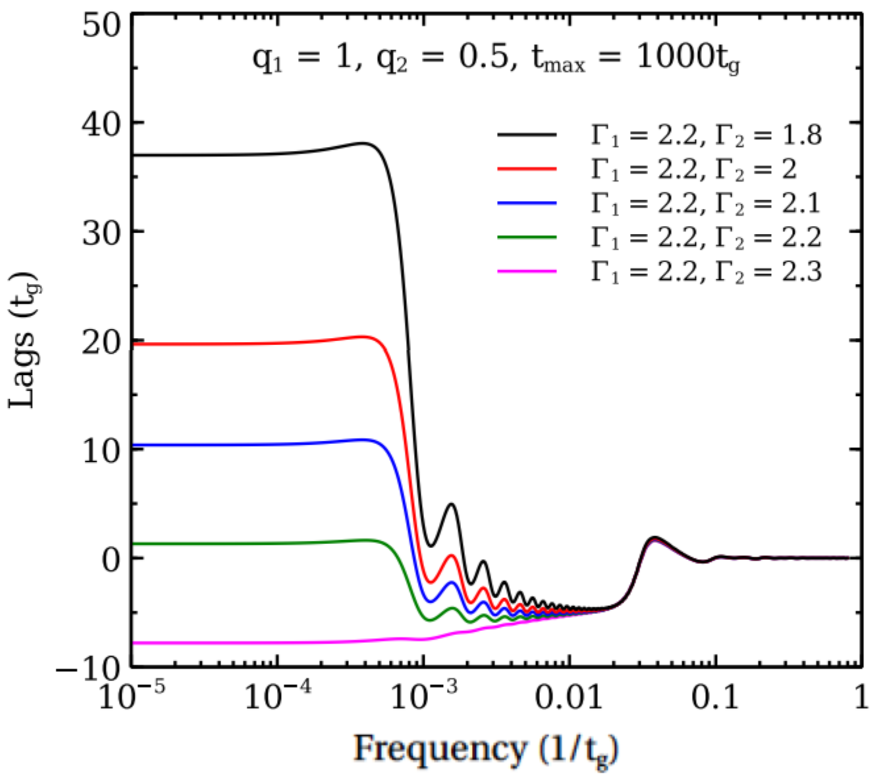
Ark 564
Kara et al (2017)

X-ray reverberation mapping

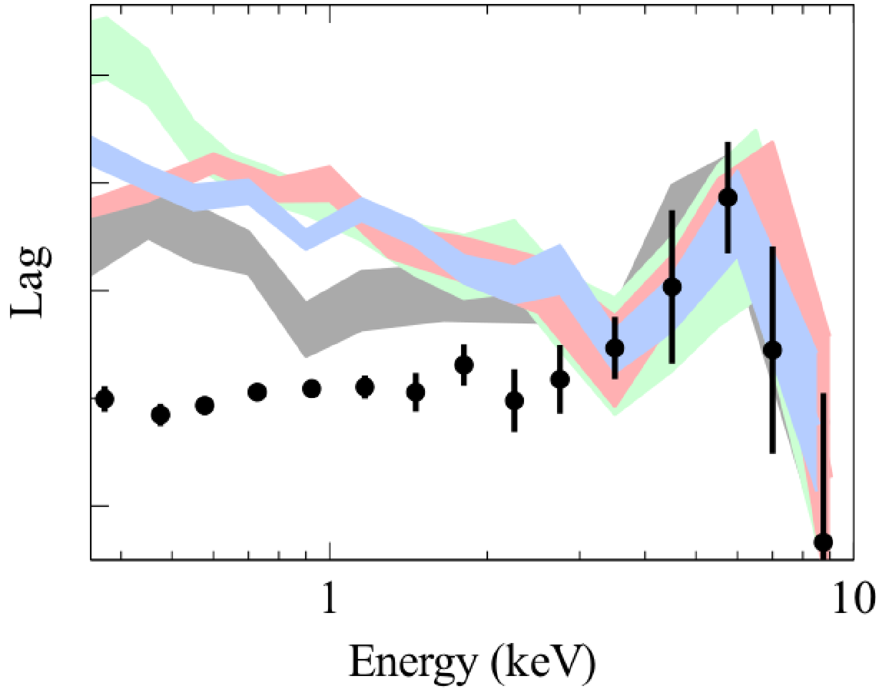
- **soft excess** and **warm corona** model
  - ➔ additional power-law component at soft X-ray energy
- low-frequency **lag-energy dependence**
  - ➔ power-law (phase follows the ratio of the spectra, $E^{\Delta\Gamma}$)
- low-frequency **lag-frequency dependence**
  - ➔ oscilatory behaviour (due to phase wrapping)
  - ➔ decrease of lag at low frequencies

Chainakun & Young (2017)





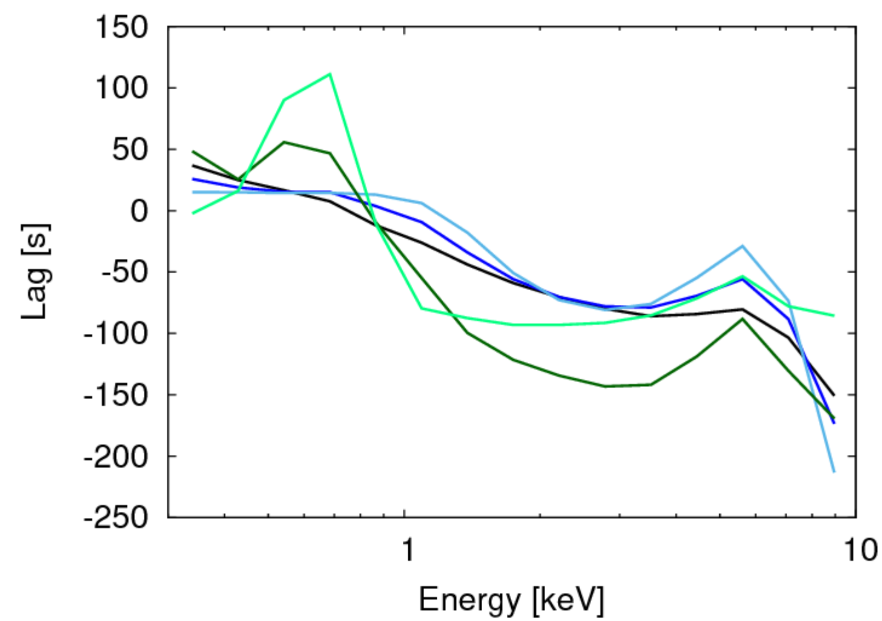
X-ray reverberation mapping



Kara et al. 14

Non-linear response due to

- ➔ disc ionisation
- ➔ corona extension

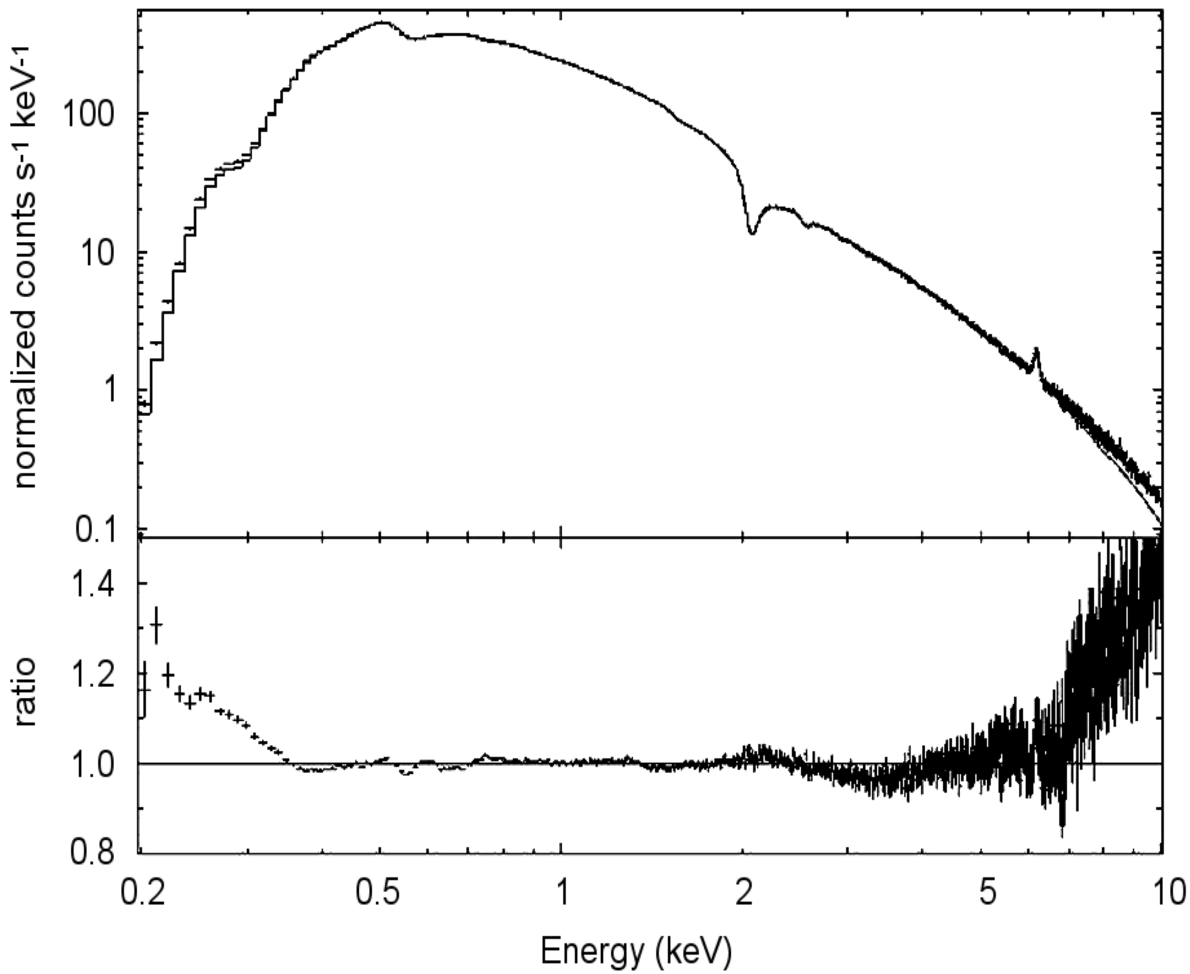


https://projects.asu.cas.cz/stronggravity/kynreverb

Close environments of SMBH

- AGN spin census
- AGN reverberation mapping
- **Nature of the soft X-ray excess**
- Mapping the accretion disk
- Mapping the circumnuclear matter
- Testing the General Relativity

Soft X-ray excess

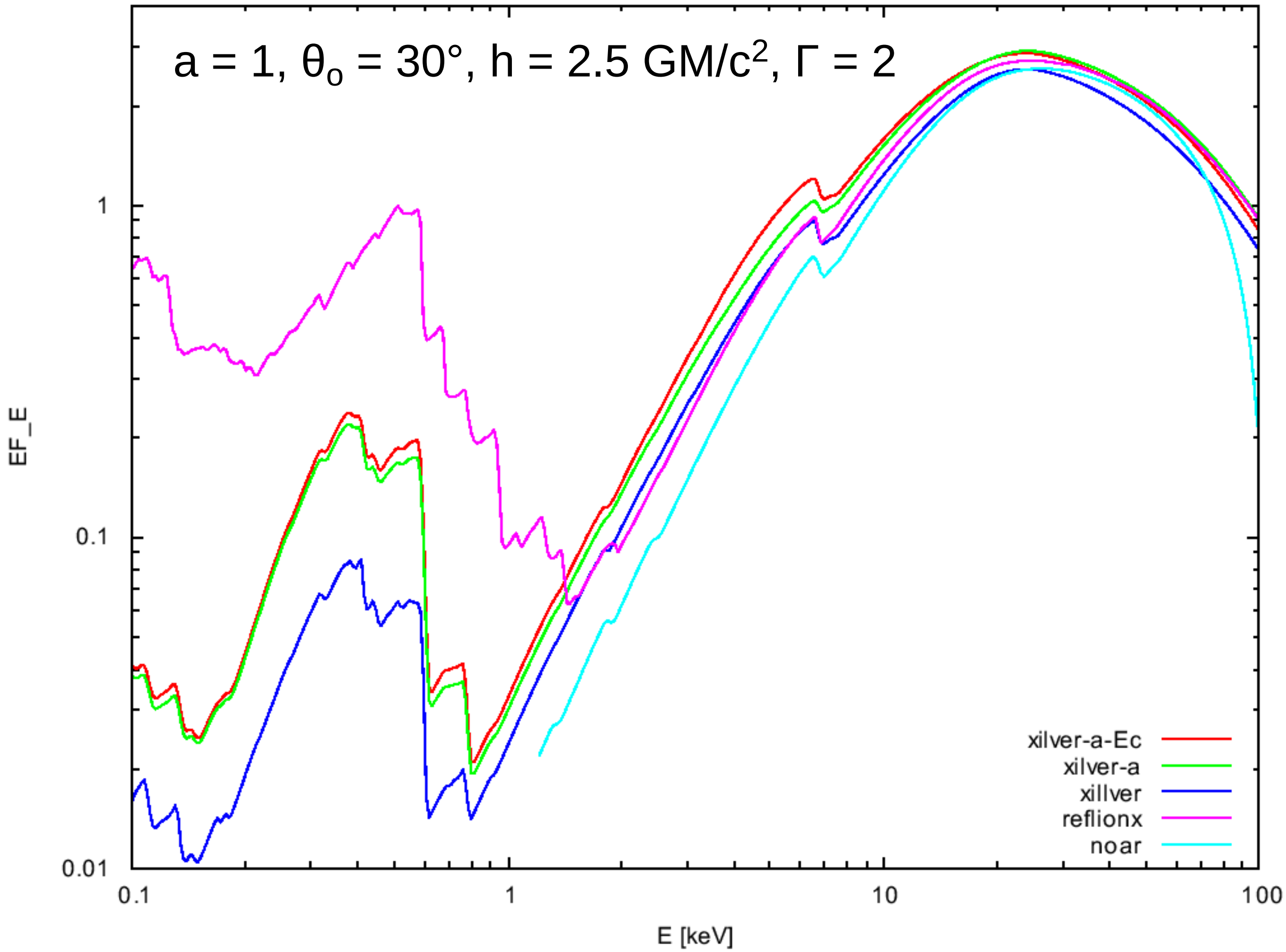


Simulated Athena 50ks spectrum with a Comptonization emission model for the soft X-ray excess

- a hard power law and a cold reflection component are included
- fitted with ionized relativistically blurred disk reflection components
- parameters are those of the Seyfert 1 galaxy Ark 120
- the two scenarios can be easily distinguished, data/model ratio shown in the bottom panel

Soft X-ray excess

Model comparisons for neutral disc



New tables computed with Monte Carlo **STOKES** code (Goosmann, Marin)

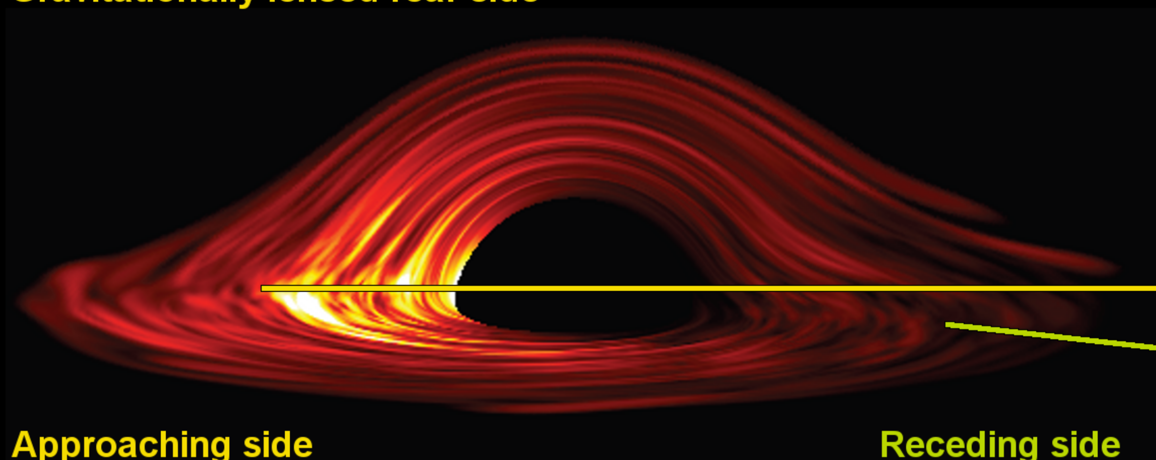
- ➔ How do they compare?
- ➔ Ionisation computed with TITAN

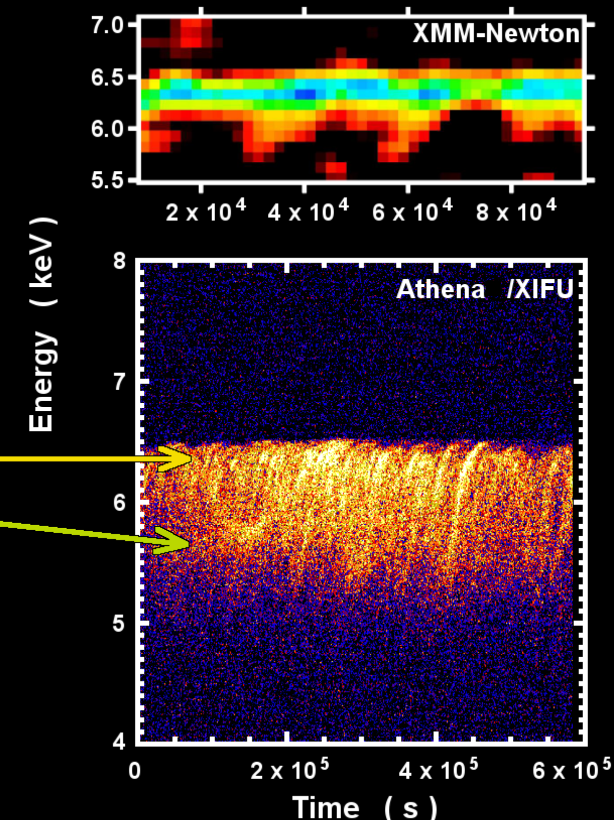
Close environments of SMBH

- AGN spin census
- AGN reverberation mapping
- Nature of the soft X-ray excess
- **Mapping the accretion disk**
- Mapping the circumnuclear matter
- Testing the General Relativity

Mapping the accretion disk

Snapshot from a time-dependent MHD simulation
of an accretion disk around a BH
(Armitage & Reynolds 2003)



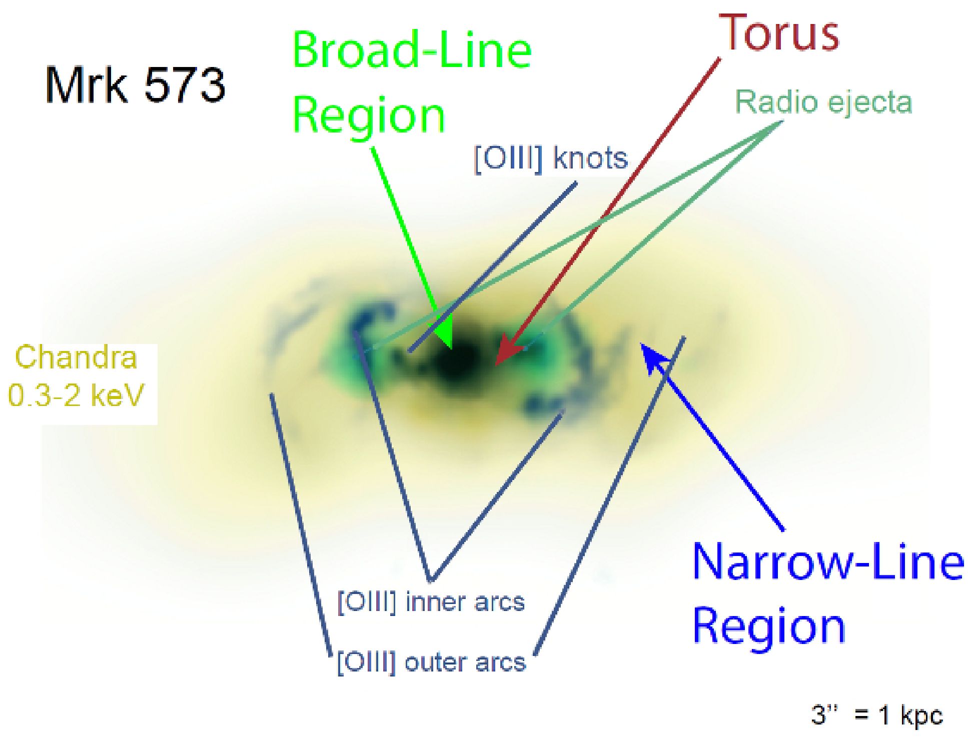


- rings and hotspots of emission are seen due to turbulence, the emission from which should be modulated on the orbital timescale
- the first hints of this behaviour seen in XMM-Newton data (Iwasawa et al 2004, upper panel)
- the simulation with Athena/X-IFU (the lower panel) with BH mass of 3×10^7 M_{sun}, 2-10 keV flux of 5×10^{-11} cgs, inclination of 20°

Close environments of SMBH

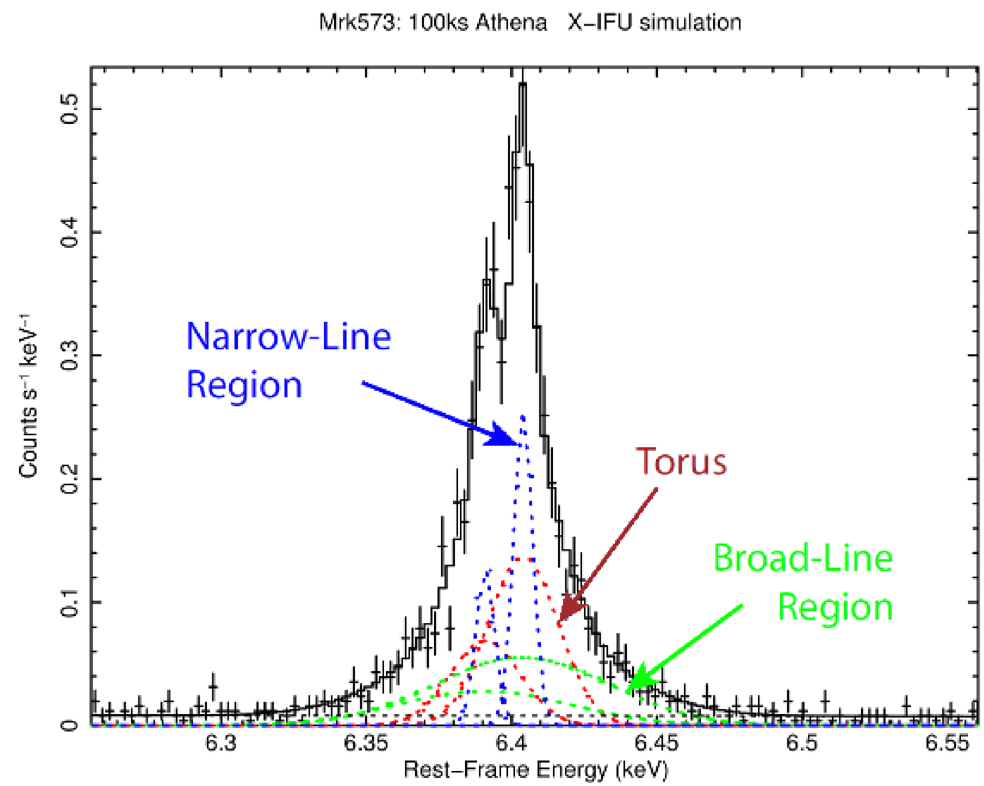
- AGN spin census
- AGN reverberation mapping
- Nature of the soft X-ray excess
- Mapping the accretion disk
- **Mapping the circumnuclear matter**
- Testing the General Relativity

Mapping the circumnuclear matter



The Seyfert 2 Mrk 573 multi-wavelength image

- soft X-ray with Chandra (yellow)
- radio 6cm with VLA (green)
- [Oiii] emission with HST (dark blue)



Simulated 200 ks Athena/X-IFU observation of Fe Kα line

- line arises from material at different distances from the BH
- the three components can be easily de-convolved

Close environments of SMBH

- AGN spin census
- AGN reverberation mapping
- Nature of the soft X-ray excess
- Mapping the accretion disk
- Mapping the circumnuclear matter
- **Testing the General Relativity**

Testing the General Relativity

- the disc “MHD arcs” and disc reflection may be used as a probe and test of General Relativity in the strong field limit
- compare the observations with the predictions of different gravity theories
  - ➔ in the so-called pseudo-complex theory the line emission from an orbiting spot should have different timing and spectral characteristics due to the different values of the gravitational redshift and Keplerian frequency (Boller & Müller 2013)
  - ➔ subtle differences in the line profile are also expected if the no-hair theorem is violated (Johannsen & Psaltis 2012)
- these kinds of measurements will certainly be very challenging, and their feasibility still needs to be fully addressed, their potential importance is large, especially for rapidly rotating black holes where relatively tight constraints on potential deviations from the Kerr metric are expected