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
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


- 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
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
- 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

Fabian et al. (1989)
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

- 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

*Garcia et al. (2014)*
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 and 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)

➔ 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) influence 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

\[ 2.5 \times 10^{-6} \text{ Hz} \]
\[ 2.5 \times 10^{-5} \text{ Hz} \]
\[ 2.5 \times 10^{-4} \text{ Hz} \]

\[ F_r(E) / F_p(E) \]

\[ \theta_0 = 30^\circ \]

\[ E \text{ [keV]} \]
X-ray reverberation mapping

Kara et al. (2014)

https://projects.asu.cas.cz/stronggravity/kynreverb
X-ray reverberation mapping

How and why will Athena improve the X-ray reverberation 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

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 $h=2.5\text{rg}$

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

➔ the yellow shaded areas mark the $1\sigma$ uncertainties of EPIC pn lag measurements