X-ray Emission from Accreting Black Holes

The intense X-ray continuum is emitted from a corona of energetic particles surrounding the black hole and the inner regions of the accretion flow. These particles accelerate the magnetic fields anchored to the inner regions of the disc, and Compton scatter thermal UV photons emitted from the disc up to X-ray energies. The X-ray continuum illuminates the accretion disc and is reflected. A number of absorption and emission features are imposed on the spectrum, the most prominent of which is the Kα emission line of iron, at 6.4keV (as measured in the rest frame of the emitting material). Photons reflected from the inner regions of the disc are also spatially resolved, forming a disc-like structure around the black hole. The X-ray emission from AGN is extremely variable and measurements of the variability have added a further dimension to the study of accreting black holes. Notably, reverberation maps are also sensitive to the variability in the continuum emitted from the accretion disc, offering a powerful probe of the extreme environment around the black hole.

Probing the Corona through X-ray Reverberation

The measured time lags between variability in energy bands following lagged reflection from the accretion disc are sensitive to the vertical distance between the corona X-ray source and the disc. The corona is extended vertically just 2r\textsubscript{S} from the disc (Wilkins & Fabian 2013, Cackett et al. 2014, Uttley et al. 2014). The X-ray reverberation lag is seen in the high frequency components of the variability, at least in the high energy bands simultaneously lagged by soft bands. Kara et al. 2013, thought to correspond to the propagation of luminosity fluctuations through the corona with energy initially injected in the less energetic outer parts as fluctuations acrerate inward through the disc (as e.g. Arévalo & Uttley 2008). Detailed modelling of the propagation of fluctuations in luminosity through the corona, revealing how and where energy is injected into the powerful X-ray source from the accretion flow.

Where reverberation is detected from the accretion disc, the measured shift in photons in broadened emission lines depends on the location of reflection on the disc while the measured lag reveals the distance to the illuminating corona, allowing a 3D image to be built up of the immediate vicinity of the black hole.

Resolving the Accretion Disc Using the Spectrum

The illumination pattern of the accretion disc by the corona (the emissivity profile) can be deduced from the measured changes in the continuum power generated by Doppler shift (due to the varying orbital velocity of material in the disc) and gravitational redshift as a function of radius from the black hole. The corona is modelled as the sum of the contributions from successive radii on the disc and the best fitting contribution of each to the observed spectrum reveals the emissivity profile (Wilkins & Fabian 2012). General relativistic ray tracing simulations (Wilkins & Fabian 2012) allow the observed emissivity profile of the accretion disc to be interpreted in terms of the geometry and extent of the corona. Observed emissivity profiles in a number of AGN, including that in the narrow line Seyfert 1 galaxy 3C273, are compared to model results presented by Markarcik 335 & Wilkins & Gallo 2014). Markarcik et al. 2013 & Wilkins & Gallo 2014) are interpreted by coronae extending radially over the inner regions of the disc to a few tens of gravitational radii. Several observational constraints, such as low gravitational radii vertically above the plane of the disc, guided by theoretical results from ray tracing simulations, high resolution measurement of the accretion disc emissivity profile will all do the geometry of the accretion disc and the inner regions of the accretion flow to be measured in detail.

Variability in the Corona: The Driving Force behind the Luminous X-ray emission

The X-ray emission from AGN is seen to be highly variable with the count rate from many Seyfert galaxies (in particular the narrow line Seyfert 1 galaxy 3C273) varying by factors of 10\textsuperscript{2}–10\textsuperscript{3} on timescales of minutes. This is a consequence of the variability of the accretion disc emissivity profile, which is known to be a function of the geometry of the accretion disc and the changes in the coronal height. The X-ray emission from Seyfert galaxies is known to be highly variable, with measurements of the variability at low flux states revealing a radially extended corona extending radially out to around 30r\textsubscript{S} from the black hole. The large collecting area of Athena would allow precise measurement of the count rate and variability that would be expected using the Athena XIFU. Photon noise was added and lag spectra were computed from the simulated light curves as a function of time lag.

Prospects with Athena

In order to assess the prospects of the Athena X-ray observatory to make detailed measurements of the X-ray emitting corona, an observation of an object with an accretion disc similar to 1H0707-495 was simulated. The resulting variability of the disc was divided into four flux levels corresponding to different disc emissivity profiles. While the high flux state corresponds to the corona having collapsed down to a compact region close to the black hole (Wilkins & Gallo 2015). Similar behaviour has been observed in 1H0707-495 (Wilkins et al. 2014).

During long observations (100ks or greater), Athena will be able to produce detailed measurements of the accretion disc emissivity profile, enabling high fidelity measurements of the corona and opening new windows into the possibility of measuring the disc geometry in bright sources. Comparison to error maps calculated by MMX-Newton in 2006 and 2009 and Suzuki in 2013, respectively more than an order of magnitude between the high and low flux states. Measuring the emissivity profile of the accretion disc during these epochs reveals that the flux state changes are correlated with the emission region changing corresponding to a radially extended corona, while in the low flux states, the corona had collapsed down to a compact region close to the black hole (Wilkins & Gallo 2015). Similar behaviour has been observed in 1H0707-495 (Wilkins et al. 2014).

On short timescales, analysis of the accretion disc emissivity profile can be used to probe the possibility of measuring the disc. Reverberation maps are used to map the corona, allowing a 3D image to be built up of the immediate vicinity of the black hole.

References

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Right: Simulated measurement of X-ray source spectrum from an object similar to 1H0707-495 but with a point source x-ray continuum. Left: Measured emissivity map along a vertical line passing through the disc and the corona extended vertically just 2r\textsubscript{S} from the disc (Wilkins & Fabian 2013, Cackett et al. 2014, Uttley et al. 2014).}