TASER (Timing And Spectroscopy in the Eddington Regime)

Black holes are the most extreme solution to Einstein's General Relativity and may be found both in the centres of galaxies with masses of a million to over a billion times that of the Sun, and also in binary systems where the black hole mass is only around ten times that of the Sun. Whilst we have a sound understanding of where the 'stellar mass' BHs came from, the supermassive BHs (or SMBHs) are more of a mystery. Our deepest views of the Universe – which probe the earliest epochs – have revealed that SMBHs were fully-grown very early on. To have grown so quickly by swallowing material (through an 'accretion disc') they must have exceeded the classical limit set by the balance of liberated radiation against gravity – the Eddington limit. It is a mystery as to how this could occur yet is of clear importance for our understanding of how the Universe shaped itself.

We cannot study the growth of SMBHs directly, so we are instead forced to look at the local Universe for suitable analogs. Whilst we observe SMBHs accreting close-to or above Eddington in the active galactic nuclei (AGN) of some galaxies, their accretion-driven changes occur on very long timescales (decades to millennia), making their study impractical. Instead we can study those smaller BHs in binaries (BHBs), a few of which also appear to accrete material, fed from a companion star, at or above Eddington. These systems undergo accretion driven changes on much shorter timescales and so, by observing their behavior, we can better understand the nature of Eddington accretion. In practice this requires studying the joint spectral (energy) and variability (time) properties; this is the aim of the project TASER.

The project was initially broken into two sections, identifying suitable sources and epochs where they accrete at or above Eddington, and the development and application of spectral-timing analysis tools.

Just prior to starting work at the University of Amsterdam (Anton Pannekoek Institute - API), an international team I was leading discovered the first extragalactic microquasar – a BHB which launches a powerful, relativistic jet of plasma when the accretion rate jumps to high rates. This was found in our nearest neighbour galaxy Andromeda (M31) and appeared as an Ultraluminous X-ray source (ULX). ULXs are a contentious set of objects, which were once thought to represent a new class of intermediate mass BHs (of intermediate mass between stellar and supermassive). Our work provided strong evidence that the compact object in this source (and by extension similar sources) was stellar mass with accretion rates around Eddington. This major result was published in Nature (Middleton et al. 2013) and precipitated a large press release, several seminars and public lectures. Building on this result I also determined the spin (angular momentum) of the black hole by fitting models to the emission from the source's accretion disc. This showed that the angular momentum was either very low or counter-aligned to the accretion disc (retrograde spin). One of the most hotly debated ideas is whether the jet can tap the angular momentum of the black hole, with higher spins leading to more powerful jets. By comparing our spin value and jet brightness we showed that this scenario is unlikely unless the jets are faster than thought or the spin of the BH is indeed retrograde (Middleton, Miller-Jones & Fender 2014). Studying how the jet and inflow couple together in real-time is key to finally determining the launching mechanism - also a key component of Eddington accretion - and our work has shown that this can be studied in extragalactic microquasars in nearby galaxies. This has the benefit of providing a larger number of such sources than found in the Milky Way and also that the X-ray bright inflow (the accretion disc) can be more easily studied (as the amount of absorbing material is lower out of the Galactic plane). I am leading an ongoing VLA campaign to discover more extragalactic microquasars and study them through multi-wavelength follow-up (radio, mm, optical/IR and X-rays).

With regards the explicit aims of the project I have written a series of codes to analyse the spectral-timing characteristics of sources and, in collaboration with scientists at the University of Amsterdam (API) intend to use these to study those Galactic Eddington XRBs and specifically those sources showing powerful uncollimated outflows (winds). I have continued my studies of the brightest (and most contentious) ULXs and have recently identified what may be the signature of powerful winds, launched from a 'super-critical' (i.e. above Eddington) inflow (Middleton et a. 2014b). Through developing my understanding of how variability operates in accreting systems I have composed a model, which accounts for the changing nature of such super-critical winds with accretion rate, and their structure. The model can explain the range of spectral-timing evolution seen in bright ULXs and I have used the spectral-timing codes to support the model through analysis of X-ray observations (Middleton et al. submitted). Although there remains a wealth of analysis still to do, I am optimistic that the aims and ambitions of the TASER project will be met.