Abstract

The discovery of supermassive black holes in the centres of galaxies is one of astronomy's most important discoveries. In particular, those systems in which matter is accreting onto the black hole or outflowing – Active Galactic Nuclei (AGN) – serve as laboratories for extreme physical conditions for a black hole — host galaxy co-evolutionary processes. AGN continuum emission can vary significantly across timescales ranging from ks to years; the study of this continuum variability can elucidate characteristic timescales that provide insight into accretion flow or jet physics. The similarities in broadband spectral and timing properties between Seyfert AGN & black hole X-ray binaries (BHXBs) suggest that both classes of systems have similar accretion processes, scaled by mass, luminosity, and timescale. However, AGN duty cycles are considerably longer in comparison to BHXBs and the accretion process likely occurs in an episodic nature. We observe some Seyferts undergoing extreme variations in X-ray/optical flux and optical spectral type, driven by strong accretion changes. These objects are likely undergoing a change between different accretion states. Multi-wavelength observations of these transients provide a way to study their evolving accretion flow structure and understand their transient behaviour. There are still unanswered questions about accretion in both persistent and rapidly-evolving AGN, such as how AGNs exhibits structural changes in accretion flow as a function of system parameters, how quickly the X-ray corona, disc, and broad line region (BLR) can evolve in response to changes in the global accretion supply, what is the typical AGN duty cycle, and do supermassive and stellar-mass black holes exhibit identical accretion flows and variability mechanisms. I have conducted studies to try to address these issues in the thesis.

In my thesis, the first project is to study the detection of periodic/quasi-periodic signals (QPOs) in red noise-dominated AGN light curves using selected statistical tools (Auto-Correlation Function and Phase Dispersion Minimization). The efforts to locate periodic signals (either strictly- or quasi-periodic) in both Seyfert AGN and blazars have involved studies using light curves spanning the EM spectrum. However, statistically robust detections of strictly- or quasi-periodic oscillations (SPOs or QPOs) remain a challenge due to limited data quality. Specifically, it is challenging to separate "narrow-band" SPO/QPO signals from the red noise "continuum." The periodogram can be used to identify QPO signals. However, alternate statistical methods are generally employed for the detection of periodic/QPO signals in AGN with sparsely sampled data points, such as the Auto-Correlation Function (ACF), Phase Dispersion Minimization (PDM), wavelet analysis, sinusoidal fitting, etc. Generally, QPOs claimed in AGN using these alternate methods are non-repeatable in additional observations, and are based on improper usage of statistical tools or improper calibration of the "false alarm probability." Given the community's access to large databases of monitoring light curves via large-area monitoring programmes, our goal is to provide guidance to those searching for QPOs via data trawls and enhance statistically significant & robust QPO detections. We perform Monte Carlo simulations to empirically test QPO detection feasibility in the presence of red noise. We simulate evenly-sampled pure red noise light curves to estimate false alarm probabilities; false positives in both tools tend to occur towards timescales longer than (very roughly) one-third of the light curve duration. We simulate QPOs

mixed with pure red noise and determine the true-positive detection sensitivity; in both tools, it depends strongly on the relative strength of the QPO against the red noise and on the steepness of the red noise PSD slope. We find that extremely large values of peak QPO power relative to red noise (typically $\sim 10^{4-5}$) are needed for a 99.7 per cent true-positive detection rate. Given that true-positive detections using the ACF or PDM are generally rare to obtain, we conclude that period searches based on the ACF or PDM must be treated with extreme caution when the data quality is not good. We consider the feasibility of QPO detection in the context of highly-inclined, periodically self-lensing supermassive black hole binaries.

My second work in the thesis focuses on AGNs undergoing extreme variations in X-ray/optical flux and optical spectral type, driven by strong accretion changes. We explore the multi-wavelength nature of a continuum flare in a Seyfert galaxy; the eROSITA all-sky X-ray survey showed that its X-ray flux increased by ~ 6 over six months; concurrent optical photometric monitoring with ATLAS showed a simultaneous increase by a factor of 4. We complemented the eROSITA and ATLAS data by triggering a multi-wavelength follow-up monitoring program (XMM-Newton, NICER; optical spectroscopy) to study the evolution of the accretion disk, broad-line region, and X-ray corona. During the campaign, X-ray and optical continuum flux subsided over $\sim$ six months. Our campaign includes two XMM-Newton observations, one taken near the peak of this flare and the other one when the flare had subsided. The soft X-ray excess from both XMM-Newton observations was power law-like (distinctly non-thermal); using a simple power-law, the photon index varies from a steep value of $\Gamma \sim 2.7$ at the flare peak to a relatively flatter value of $\Gamma \sim 2.2$ later. We successfully model the broadband optical/UV/X-ray SED at both flare peak and post-flare times with models incorporating thermal disk emission in the optical/UV and warm thermal Comptonization in the soft X-rays. In the context of the AGNSED model, the accretion rate falls by ~ 2.8, and the radii of the hot and warm Comptonizing regions increase from the flaring state to the post-flare state. Additionally, from the optical spectral observations we found the broad He II $\lambda 4686$ emission line fades significantly as the optical/UV/X-ray continuum fades, and the broad He II line flux tracked the evolution in the >54 eV continuum, and is consistent with an origin in the inner BLR. A likely explanation for the flare is that a sudden strong increase in local accretion rate in this source manifested itself via an increase in accretion disk emission and in thermal Comptonization emission in the soft X-rays, followed by a decrease in accretion and Comptonized luminosity.