Abstract

The centers of all galaxies host a supermassive black hole. In many of the galaxies, the central black holes are persistently accreting matter from the surroundings, resulting in the continuous generation of high-luminosity electromagnetic radiation across the electromagnetic spectrum. The centers of these galaxies are known as Active Galactic Nuclei (AGN). The accretion process in AGNs is connected to the formation of various substructures around the supermassive black hole; these structures span a range of length scales from the accretion disk and hot corona out to the pc-scale dusty torus. The spectral and temporal study of AGN emission has broadly revealed the physical properties of these structures and how they interact. However, open questions remain. For example, the morphology of the distant parsec-scale, geometrically thick, dusty AGN torus remains unclear. The torus serves as the reservoir of the accreting gas and a source of obscuration of emission originating from the central regions of an AGN. Current research on AGN tori focuses on understanding the level of its clumpiness, the distribution of clumps, the shape and density profile of individual clumps, and the physical mechanisms connected to the formation and kinematics of these clumps. Meanwhile, over the past decades, extreme variability (greater than a factor of 10) events, wherein the X-ray and/or optical wavebands vary more than expected from normal variability in AGNs (a few percent to a factor of few), have been detected in large numbers. Many of these events have been linked to major variations in the global and/or local accretion rates. A multi-wavelength study of extreme-variability transient events in AGNs can help understand the morphological properties of substructures like the accretion disk, the X-ray emitting corona, the broad line region, or the distant dust distribution in these sources and in particular their evolution in response to major changes in accretion rate. In this thesis, I address the statistical challenges associated with determining the structure of the AGN obscuring torus given the current X-ray data quality, study the mechanism driving extreme variability in a flaring AGN and the properties of its inner accretion flow and geometry of its broad line region, and partially develop and initiate the development of and test a pipeline for detecting variable obscuration using X-ray spectrum from the eROSITA telescope.

In the first project, we tested the reliability of the AGN torus X-ray spectral models used by the community in X-ray spectroscopic studies of obscured AGNs. Several models of the X-ray reprocessing of the AGN torus have been recently developed. They span a range of assumed torus geometries and morphologies, e.g., smooth or clumpy. A few examples of such models are UXCLUMPY, CTORUS, MYTORUS, etc. We hypothesize that given the available data quality of the current X-ray instruments, various model parameters returned from a spectral fit are poorly constrained. The degeneracies in these models can limit reliable constraints of parameters of interest, such as the intrinsic photon index and parameters determining torus morphology. To investigate the effects of data quality on parameter constraints, we simulate synthetic data under XMM-Newton and NuSTAR response files based on six different models. We use the Bayesian Nested Sampling method implemented through the Bayesian X-ray Analysis package to analyze the simulated datasets with the same set of models. For exposure times and fluxes typical of nearby Compton-thick AGN, several morphological parameters of the torus remain unconstrained. In addition, a distinction of model or morphology using Bayesian methods is possible only if we have a high intrinsic value of flux for a typical exposure time. Our project aims to guide the X-ray community both in terms of the accuracy in applying the correct torus model with the implications for conclusions on the torus geometry and morphology and the robustness of estimation of model parameters with implications for limitations on precision of those parameters.

In the second project, we perform a multi-wavelength campaign on a flaring and changing-look AGN transient to investigate the flaring mechanism and study the time-dependent responses of the various accretion substructures – disk, corona, BLR, and torus. In 2020, the Zwicky Transient Facility detected a transient flaring event in the type-1.9 AGN 6dFGS gJ042838.8-000040, wherein a sharp peak of $\sim$0.55 and $\sim$0.29 magnitudes in *g*- and *r*-bands, respectively, occurred over $\sim$ 40 days. Spectrum Roentgen Gamma (SRG)/eROSITA also observed the object in X-rays as a part of its all-sky scans, but after the flare had started decaying. We performed a three-year, multiwavelength follow-up campaign of the source to track the evolution of its spectral and temporal characteristics. This campaign included multiple ground-based facilities for optical spectroscopic monitoring and space-based observatories including *XMM-Newton* and *Swift* for X-ray and UV observations. An optical spectrum taken immediately after the peak revealed a changing-look event wherein the source had transitioned from type 1.9 to 1, with the appearance of a double-peaked broad Hβ line and a blue continuum, both absent in an archival spectrum from 2005. The X-ray emission exhibits dramatic flux variation: a factor of $\sim$ 17, but with no spectral evolution. There is also no evidence of a soft X-ray excess which is commonly seen in multiple persistently-accreting Seyferts. After the event, the optical continuum evolves from being a blue continuum-dominated spectrum in 2020 to a galaxy-dominated spectrum after three years. Our detailed spectral and temporal study finds no apparent signatures of a tidal disruption event. Thus, we propose that the extreme multi-wavelength variability is triggered by an instability in the inner accretion disk. Our study of this source demonstrated how the disk instability drove extreme flaring emission originating from the accretion disk, which in turn drove the observed extreme variability in continuum and line emission emanating from the X-ray corona, BLR, and dusty torus.

In the third project, we exploit the large numbers of AGN monitored by eROSITA to search for changing-obscuring AGN events, which occur rarely on a per-object basis. Specifically, I am developing and testing a pipeline to detect changing obscuration events in the eROSITA archive. In this project, we adopt an X-ray hardness ratio-based methodology to detect changing obscuration AGNs. I tested the code using eROSITA responses, assuming simplistic models of obscured AGNs. We find that the detection of changes in line of sight absorption can be made only in nearby Compton-thin and mildly obscured sources having a flux above 1 mCrab in the 2–10 keV band. The pipeline will be effective in detecting the bright COAGN sources both in the eROSITA archive and subsequently for real-time detection of COAGN sources when eROSITA scans resume. The accumulation of such events supports our long-term objective of statistically deriving constraints on cloud properties and distributions to support clumpy-torus models. Additionally, when future real-time detections occur, this pipeline can yield alert triggers to initiate dense spectral and temporal follow-up campaigns that can enable us to measure the profile and distribution of matter in a cloud involved in a given occultation event while it is in-progress.