Keri Heuer Summer Project

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1 Estimating Gamma and Alpha_ox For Quasars

1.1 Motivation

Properties like gamma, the hard X-ray slope, and alpha_ox, the optical-to-X-ray slope, calculated from X-ray data help us investigate the relation between optical and X-ray emission. However, X-ray data is only available for a fraction of the objects we would like to study because X-ray detectors are resource-limited and only able to observe certain parts of the sky for a limited amount of time. Even if an X-ray telescope has observed a part of the sky that is of interest, the exposure time may not have been long enough to robustly measure gamma or alpha_ox. Not only does obtaining these values require a significant number of photon counts, but accurately measuring gamma requires more X-ray photons than accurately measuring alpha_ox. This means that even if an object has been observed in the optical with a long enough exposure time, a short exposure time in the X-ray band will make gamma difficult to constrain.

We can, however, determine the median X-ray properties of subsamples of objects that are grouped by some other parameter such as UV luminosity or CIV properties and use those to estimate values for gamma and alpha_ox. Defining homogeneous subsamples allows us to stack the objects' spectroscopic or photometric data and compare the median X-ray properties of the subsample to catalogs of objects with known X-ray properties. Finding an object with a comparable UV luminosity or CIV distance to our subsample's median value will yield a reasonable estimate to gamma and alpha_ox for the objects in the subsample.

If we are to understand quasar properties and constrain models of quasar accretion across energies and redshifts, we need a larger catalog of quasars with well-defined X-ray properties. Obtaining values, or at least reasonable estimates, of gamma and alpha_ox will help us expand those catalogs in order to better understand the spectral diversity of quasars.

1.2 Methods

To calculate the median X-ray properties of a subsample of objects with similar other properties, I will use a two-pronged approach based on whether spectroscopic data is available for an object or not to obtain luminosities. For example, in order to estimate gamma, I need to extract the object's UV-luminosity at 2500 $\mathring{A}$ and the hard X-ray luminosity at 2 keV with *XSPEC*. For objects where spectra is available, I will stack their spectra, split up the hard-band photon counts into equal energy bands as well as separate counts into 100 counts per energy bin, and then calculate luminosities. Because we expect an uneven distribution of photon counts across X-ray energies, it is important to bin the counts not only by equal energy ranges but also by an equal number of counts per bin. For objects without spectra, I will use photometric data to estimate luminosities using composite spectral energy distributions (SEDs) and k-corrections. K-corrections bring observed magnitudes to a common effective rest-frame bandpass to allow for a comparison of X-ray parameters for objects at different redshifts. Because similar objects at different redshifts can have significantly different spectra or photometry (and thus X-ray properties such as UV-luminosity or CIV distance), it is especially important to first k-correct before determining homogeneous subsamples of objects based on X-ray properties. I will follow Wisotzski (2000) and Blanton et al. (2003b) and K-correct my objects to a redshift that is close to the median redshift of each homogenous subsample.

I will employ SDSS and *Chandra* catalogs of optical and X-ray spectra as well as SEDs for 259 quasars constructed by Richards et al. 2006 from SDSS and *Spitzer* (and near-IR, GALEX, VLA, and ROSAT data where available) for objects with photometric data only. I will also use various catalogs from Lusso et al. that catagorize objects with well-defined X-ray properties for estimating gamma and alpha_ox for my subsamples based on the mean X-ray properties I calculate.

1.3 Expected Outcomes

This research will produce a catalog of estimated gamma and alpha_ox values for quasars without enough X-ray data. It will also yield a suggestion of the best way to bin spectra for such estimations, *i.e.* binning by equal energy bands or equal counts per energy bin. Comparing results from these two approaches will help me determine if a subsample's mean alpha_ox and gamma of as a function of CIV distance changes across energies or if there is a specific energy range that these values are better constrained for (*i.e.* the energy corresponding to the 2500 $\AA$ luminosity).

2 Characterizing AGN X-ray Variability with Swift/BAT

2.1 Motivation

Studying the relationship between the variability of AGN X-ray light curves and spectral/physical parameters sensitive to variations in accretion phenomenon can address the question of black hole accretion. Currently, no single accretion model accounts for all observed AGN phenomena so the details of black hole accretion are still not fully understood. AGN variability could be due to oscillations of the accretion disk triggered by interactions with the surrounding medium (Harko and Mocanu 2012), flare processes that drive optical variability (Goosman et al. 2006), or stochastic viscosity in the accretion disk (Shakura and Sunyaev 1973). To better understand and characterize the stochastic, highly aperiodic nature of AGN variability, we will need to test for nonlinear behavior and trends of variability timescales with AGN type and physical parameters.

Classifying AGN variability is an important test of accretion physics and the various accretion models, especially since previous work has recently revealed the luminosity-dependence of AGN variability at optical wavelengths (Moreno et al. 2019). This luminosity-dependent variability behavior supports a model in which optical fluctuations in lower-luminosity AGN could are driven by X-ray variability (e.g., Leighly 2004, Luo et al. 2015). In order to test whether the variable X-ray emission from the corona drives the optical variability in the disk region, we must quantify AGN X-ray variability and analyze its dependence on AGN luminosity and type. Characterizing the statistical behavior for AGN X-ray variability will provide a clear comparison to the optical results (Moreno et al. 2019).

2.2 Methods

I will use light curves binned using monthly mosaics from the 157-month Swift/BAT catalog of AGN that have been spectroscopically confirmed (Lien et al. 2020). Because characteristics of variability probe timescales over which different processes dominate accretion flow, I will employ time-domain methods from a recent AGN analysis handbook (Moreno et al. 2019) to extract relevant timescales and accretion states from these observed light curves.

I will use recurrence analysis to reveal structures that correlate to specific types of dynamical behavior in a system (e.g., periodic motion, precession in the disk, disk geometry/viscosity, global magnetic instability) and underlying mechanisms driving accretion. By extracting relevant timescales and accretion states of different AGN types from their X-ray light curves, I can investigate flux-color and color-luminosity relations. Stochastic process analysis will compliment recurrence analysis as it reveals luminosity-dependent behavior. Stochastic models such as Continuous Auto-Regressive Moving Average (CARMA) reveal variations in inferred timescales that reflect properties of the luminosity source. In addition to using stochastic process and recurrence analysis to characterize aperiodic X-ray variability for this largest-to-date sample of AGN X-ray light curves, I will employ machine-learning methods such as density-based spatial clustering to examine subsamples of objects in variability parameter space to test for segregation of variability trends by AGN type or certain physical parameters.

2.3 Outcomes

Quantifying AGN X-ray variability will provide new constraints on complex accretion phenomena and disk geometry that affects AGN variability. Recurrence analysis will reveal how/if recurrence behavior varies with properties such as Eddington ratio, classify any nonlinear and chaotic behavior specific to a certain class of AGN (such as low-luminosity AGN), and provide a comparison of variability timescales derived from stochastic process modeling. Most importantly, comparing the statistical characterization of AGN X-ray behavior to previous statistical characterization of AGN optical variability will provide insight into whether X-rays drive the high frequency optical fluctuations of lower-luminosity objects.