Revealing the Multi-Faceted Correlations In AGNs with UV/Optical Variability

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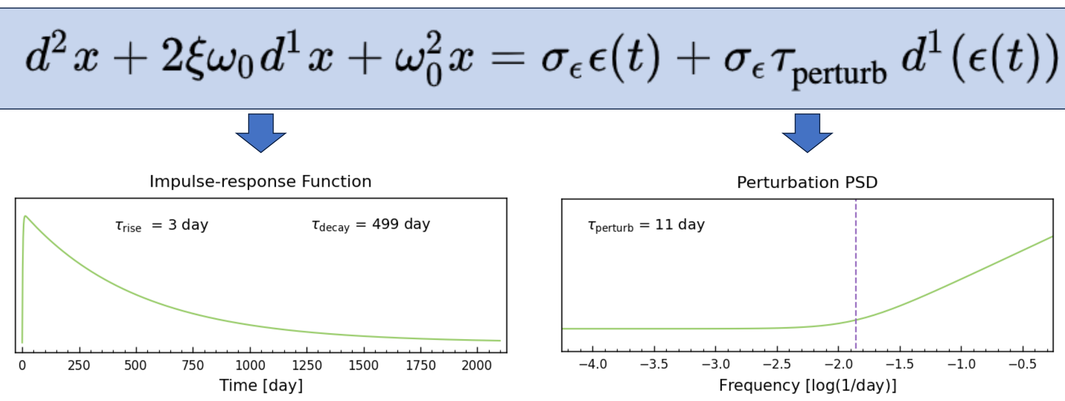
Background & Motivation

An AGN's UV/optical luminosity varies stochastically on timescales ranging from hours to years. This stochastic variability is known to originate from the accretion disks surrounding the supermassive massive black holes at the center of AGNs. Here, we explore how AGN UV/optical variability, characterized by a Damped Harmonic Oscillator (DHO) model, correlates with other empirical AGN properties, such as emission-line parameters and multi-wavelength fluxes. One of the ultimate goals is to learn how to best estimate physical properties, like black hole mass and accretion rate, from the least amount of empirical data.

Damped Harmonic Oscillator Process

A DHO process is defined as the solution to the stochastic differential equation (SDE) shown below. The SDE can be understood as describing a perturbation-response system, where the left-hand side (LHS) of the SDE characterizes the response component, and the right-hand side describes the perturbation component.

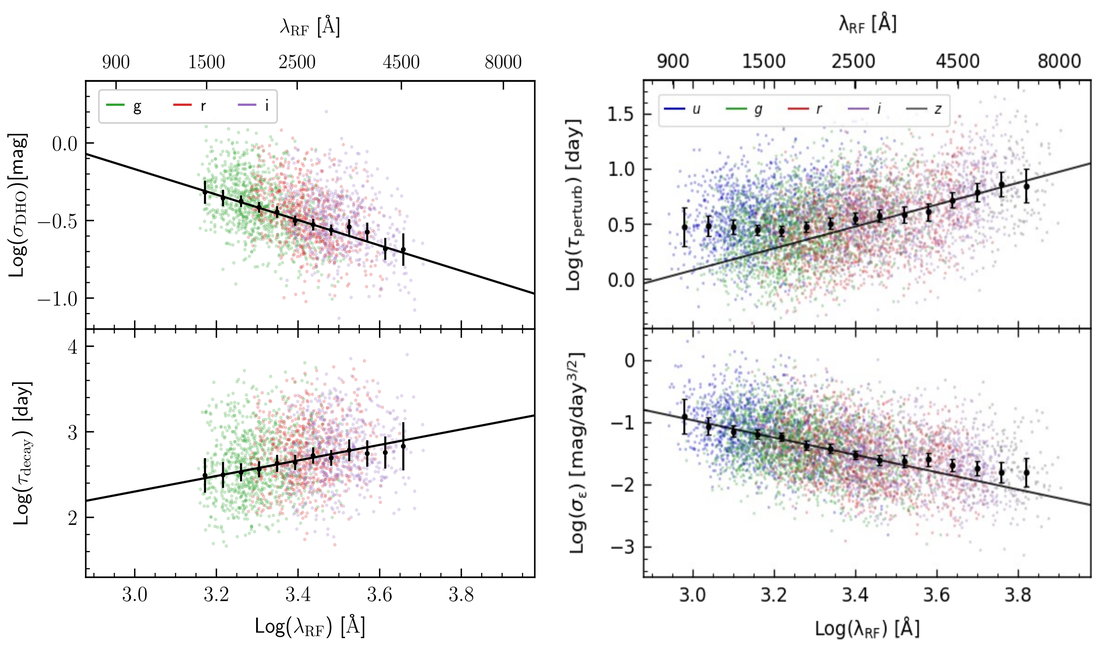
$$d^2x + 2\xi\omega_0 d^1x + \omega_0^2 x = \sigma_\epsilon \epsilon(t) + \sigma_\epsilon \tau_{\text{perturb}}\, d^1(\epsilon(t))$$



We can extract additional DHO parameters from the LHS of the SDE, such as a characteristic decay timescale (τ_{decay}) and an asymptotic variability amplitude (σ_{DHO}).

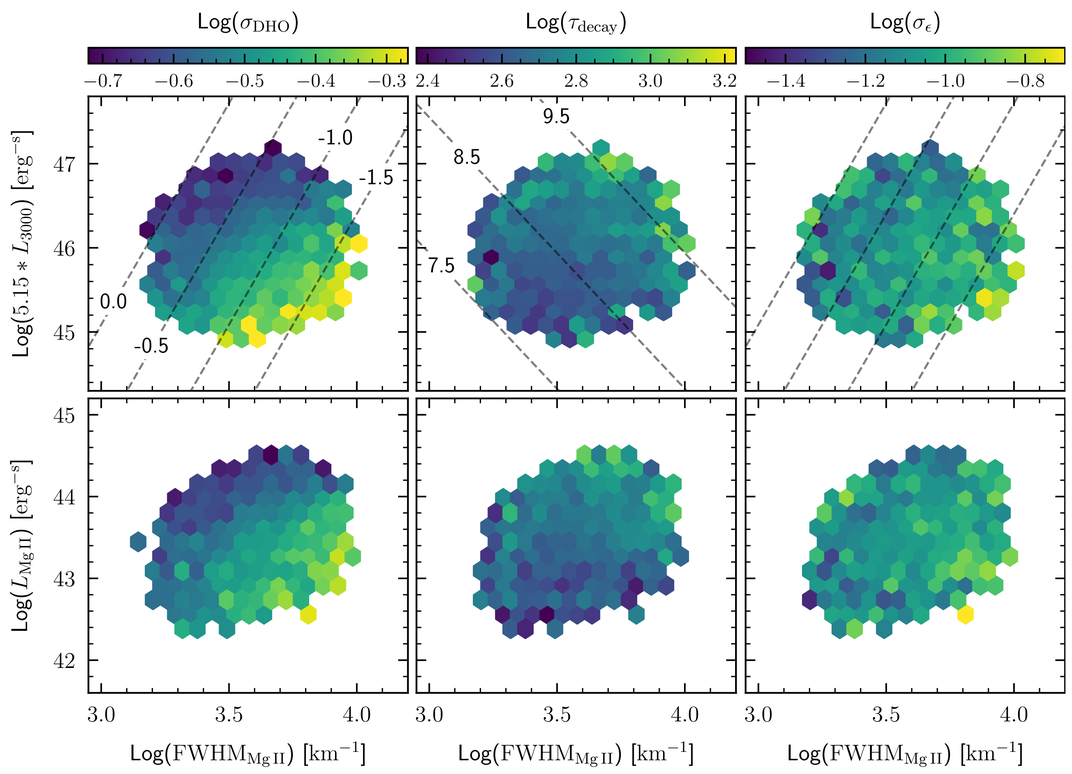
DHO Parameters vs. Wavelength

We fit SDSS (*ugriz*) and SDSS-PanSTARRS1 (*gri*) light curves of known quasars with our DHO model and examine the empirical scaling relationships between DHO parameters and the rest-frame wavelength. As shown below, DHO parameters scale with wavelength. Thus, we need to calibrate DHO parameters to a single wavelength before correlating them with AGN properties.



DHO Parameters vs. AGN Properties

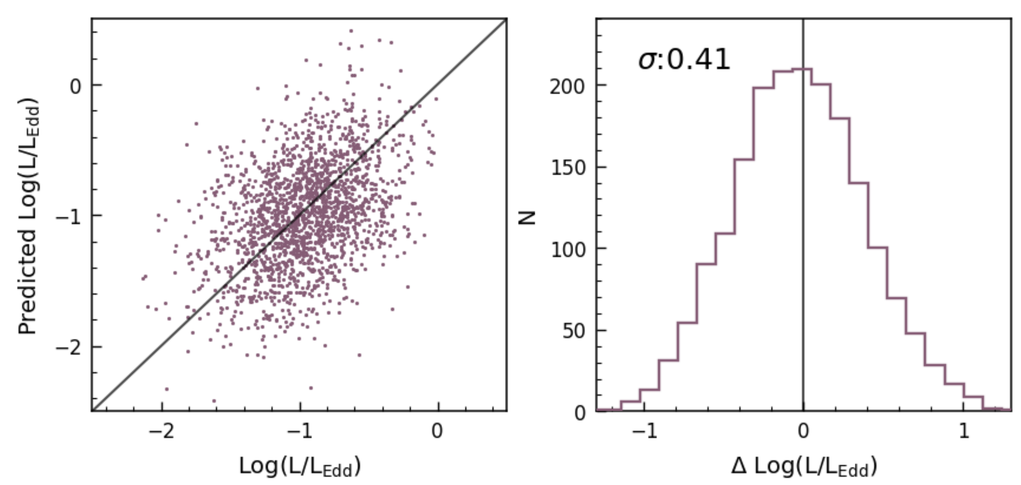
The hex-bin histograms below present how σ_{DHO}, τ_{decay}, and σ_ϵ (all scaled to 2500Å) evolve in the $\text{FWHM}_{\text{Mg II}}$-$L_{3000}$ space (top row) and in the $\text{FWHM}_{\text{Mg II}}$-$L_{\text{Mg II}}$ space (bottom row), where the colors indicate the median DHO parameters. The displayed color gradients demonstrate that DHO parameters (time-domain) exhibit correlations with $\text{FWHM}_{\text{Mg II}}$, $L_{\text{Mg II}}$, and L_{3000} (spectroscopic).



AGN Property Estimation

Lastly, we exploit the observed correlations to experiment with estimating AGN fundamental properties (L/L_{edd} in this case) using DHO parameters. We first fit L/L_{edd} as a linear function of DHO parameters and then try to recover L/L_{edd} using the best-fit coefficients.

$$\log(\text{L}/\text{L}_{\text{Edd}}) = a * \log(\sigma_{\text{DHO}}) + b * \log(\sigma_\epsilon) + c * \log(\xi) + d$$



Future Work & References

- Refine the modeling techniques, e.g., develop scalable algorithms that will fit light curves in different bands simultaneously
- Apply the DHO model to the light curves of AGNs with lower luminosity and smaller black hole masses

1. Yu, W., Richards, G.T., Vogeley, M.S., Moreno, J., Graham, J.M. 2022, "Examining AGN UV/optical Variability Beyond the Simple Damped Random Walk", The Astrophysical Journal, 936, 132
2. Yu, W., Richards, G.T., et al. 2023, "Characterizing Quasar UV/Optical Variability in a Five-Dimensional Space", (in prep)

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