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Understanding AGN UV/Optical Variability through Quasi-periodic Large-scale Magnetic Dynamos

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The UV/optical light curves observed in active galactic nuclei (AGNs) are well-characterized by damped random walk (DRW) processes, where the damping timescale $\tau_{\rm d}$ shows correlations with both black hole mass ($M_{\rm BH}$) and photon wavelength (λ). However, the underlying physical mechanisms behind these scaling laws remain uncertain. We aim to understand the variability induced by a quasi-periodic large-scale dynamo in an accretion disk, and examine whether it reproduces the observed variability features in AGN UV/optical light curves. Using a one-dimensional, optically thick, geometrically thin disk model, we introduce variability into the viscosity parameter α by incorporating quasi-periodic large-scale magnetic fields. We calculate the power spectral densities (PSDs) of the accretion rates and disk thermal emission, and fit for their damping time scales. The disk and dynamo parameters are adjusted to explore how $\tau_{\rm d}$ scales with them. With reasonable dynamo parameters, our model successfully reproduces both the linear rms-flux relation and the log-normal distribution of flux variability. The PSDs of accretion rates and fluxes align well with DRW models, and yield consistent values for $\tau_{\rm d}$ at 2500 angstrom with observations. Analytical arguments, supported by numerical evidence, suggest that the flattening of flux PSDs at low frequencies is governed by the timescale at the inner boundary of the emission region for a fixed wavelength. For $M_{\rm BH} > 10^6 M_\odot$, variations in the Eddington ratio $\eta_{\rm Edd}$ flatten the $\tau_{\rm d}$-$M_{\rm BH}$ scaling, resulting in $\tau_{\rm d} \propto M_{\rm BH}^{0.5-1}$. For smaller black hole masses ($M_{\rm BH} < 10^6 M_\odot$), we find a steeper scaling, $\tau_{\rm d} \propto M_{\rm BH}$. Including further refinements, such as the dependence of dynamo properties on $M_{\rm BH}$ and AGN luminosity, and accounting for X-ray reprocessing, would further enhance the accuracy of the model.

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