Modeling Optical Variability in Quasars by Simulating Mass Accretion Rates as a Continuous Autoregressive Process.

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Background

- Quasar variability behaves stochastically and is dependent on local, random variations in the mass accretion rate [2].
- The effects of quasar physical parameters on variability can be used to study the relationship between those parameters and the variability.
- The Vera Rubin Observatory, or Large Synoptic Survey Telescope (LSST), will provide a large data set of sensitive observations of quasar targets.

Objective

This project aims to determine the effects of different physical parameters on quasar observations by simulating quasar light curves using standard models of accretion disks to predict LSST observations..

Methodology

- We assume the standard disk model from Shakura and Sunyaev [4].
- In the standard model, the flux is directly dependent on the temperature of the disk, which is dependent on four parameters [1]:
  - Position along the disk
  - Black hole mass
  - Wavelength of light
  - Local mass accretion rate
- We assume the variability is dependent on random perturbations in the accretion rate, simulated with a Continuous Autoregressive (CAR) Model.
- This introduces two additional parameters [3]:
  - Characteristic time scale: τ
  - The variance: σ^2

- $$T(R) = \left(\frac{(3GMM')}{R_s}\right)^{1/4}\left(\frac{R}{R_s}\right)^{-3/4} \qquad (1)$$
- $$T^* = \frac{hc}{\lambda kT} - 1 = 25\left(\frac{M'}{M'_E}\right)^{-0.25}\left(M_8\right)^{0.25} \qquad (2)$$
- $$F = \frac{4\pi^2 h\cos(i)c^2 * \Delta\lambda}{\lambda^5 D^2}\int_{R_*}^{R_{out}} \frac{2\pi R\, dR}{e^{T^* r^{0.75}} - 1} \qquad (3)$$
- $$dM = -\frac{1}{\tau}M(t)dt + \sigma\sqrt{dt}\epsilon(t) + bdt \qquad (4)$$

1. Radial distribution of temperature in the disk in terms of black hole mass (M), mass accretion rate (M'), and radius (R).
2. Parameterization of temperature.
3. Flux of a radial section of the disk for a wavelength (λ).
4. The CAR process produces random variations with a random variable sampled from a gaussian distribution, ϵ, centered around a mean, b.

Simulation Results

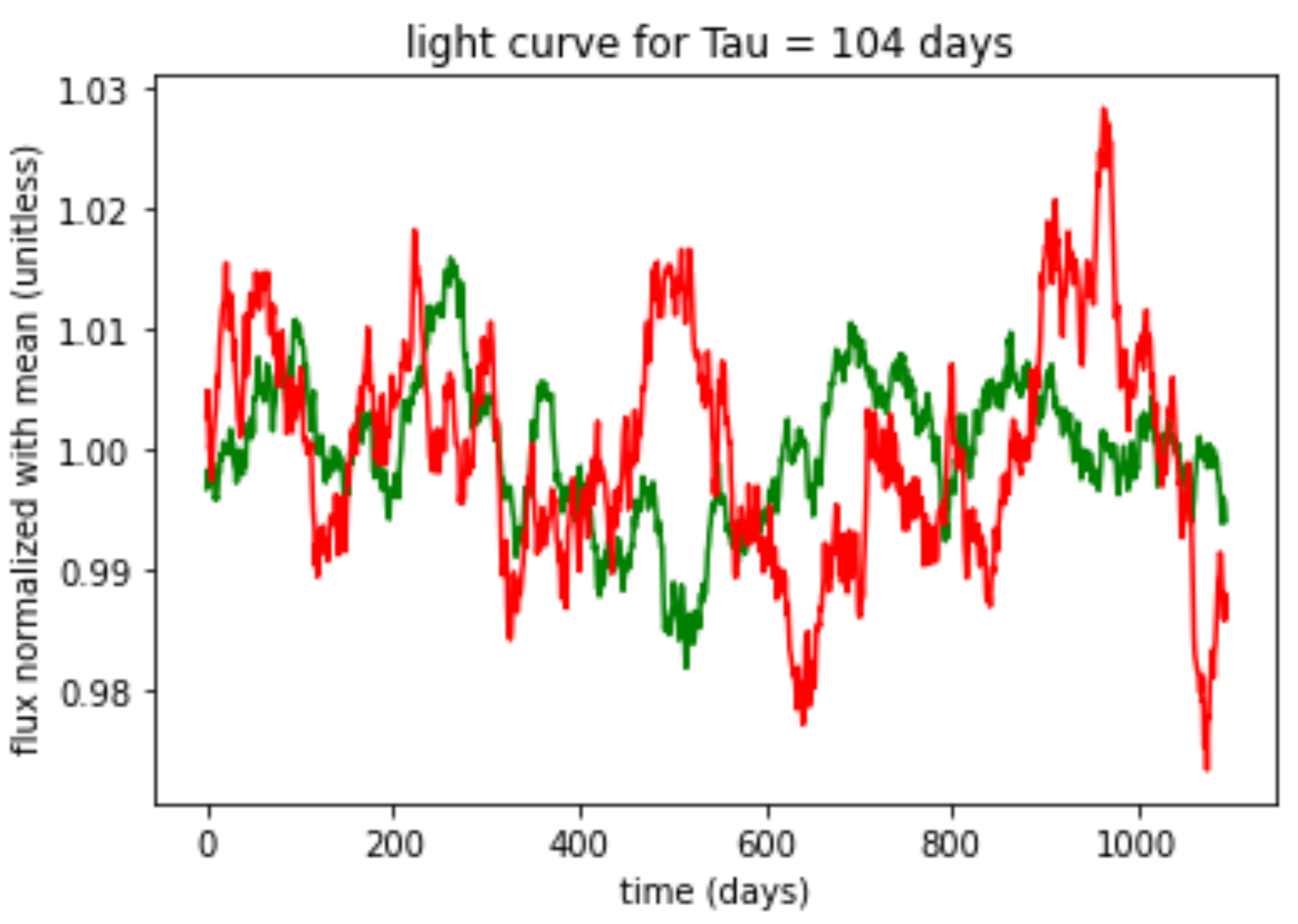


Figure 1: Light curve for two quasars with T* values of 60 and 120. The amplitude of variability is larger for when T*=120. .

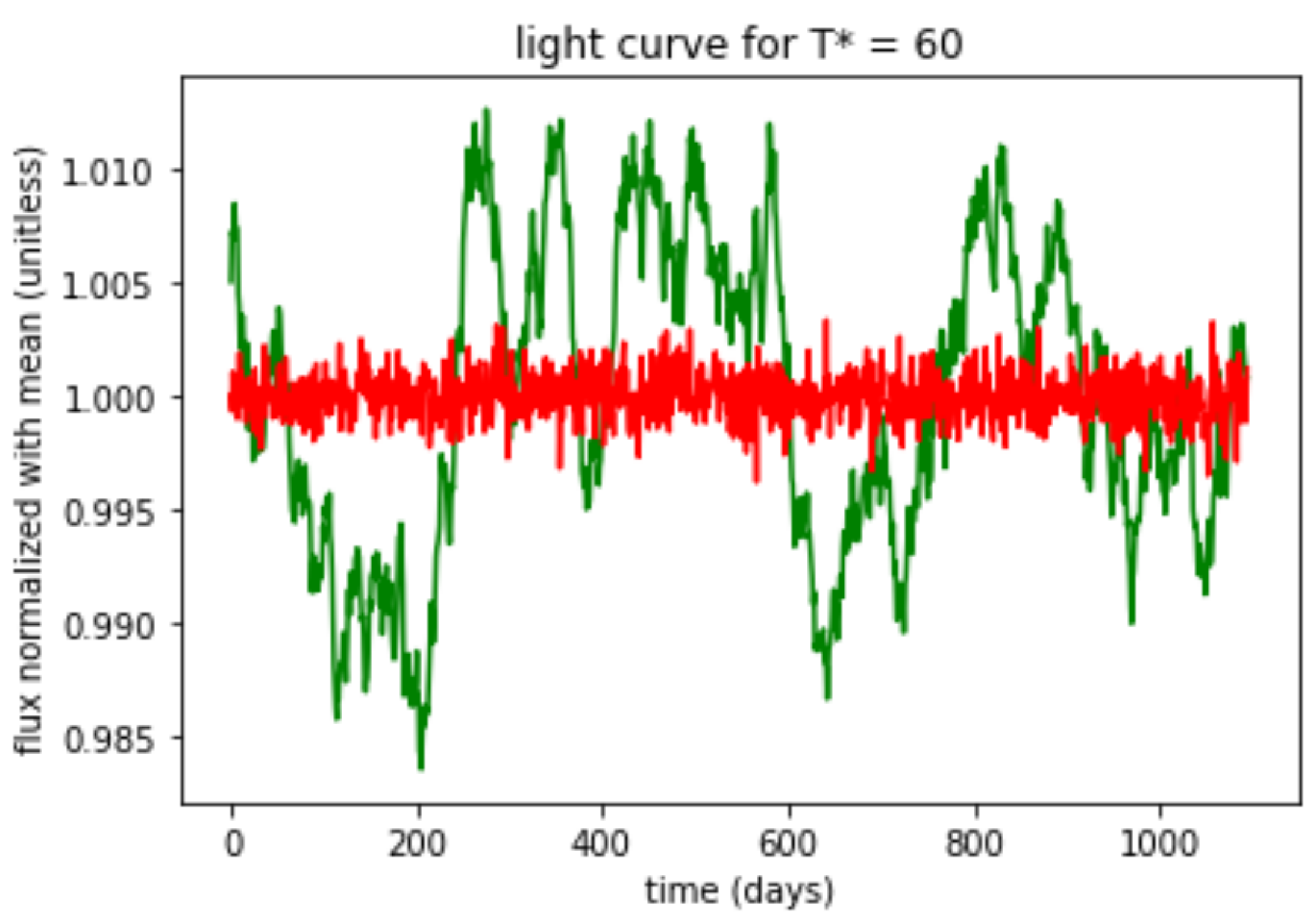


Figure 2: Light curve of a quasar at a time scales of 104 days and 1.1 days. The larger time scale is associated with a larger amplitude of variability.

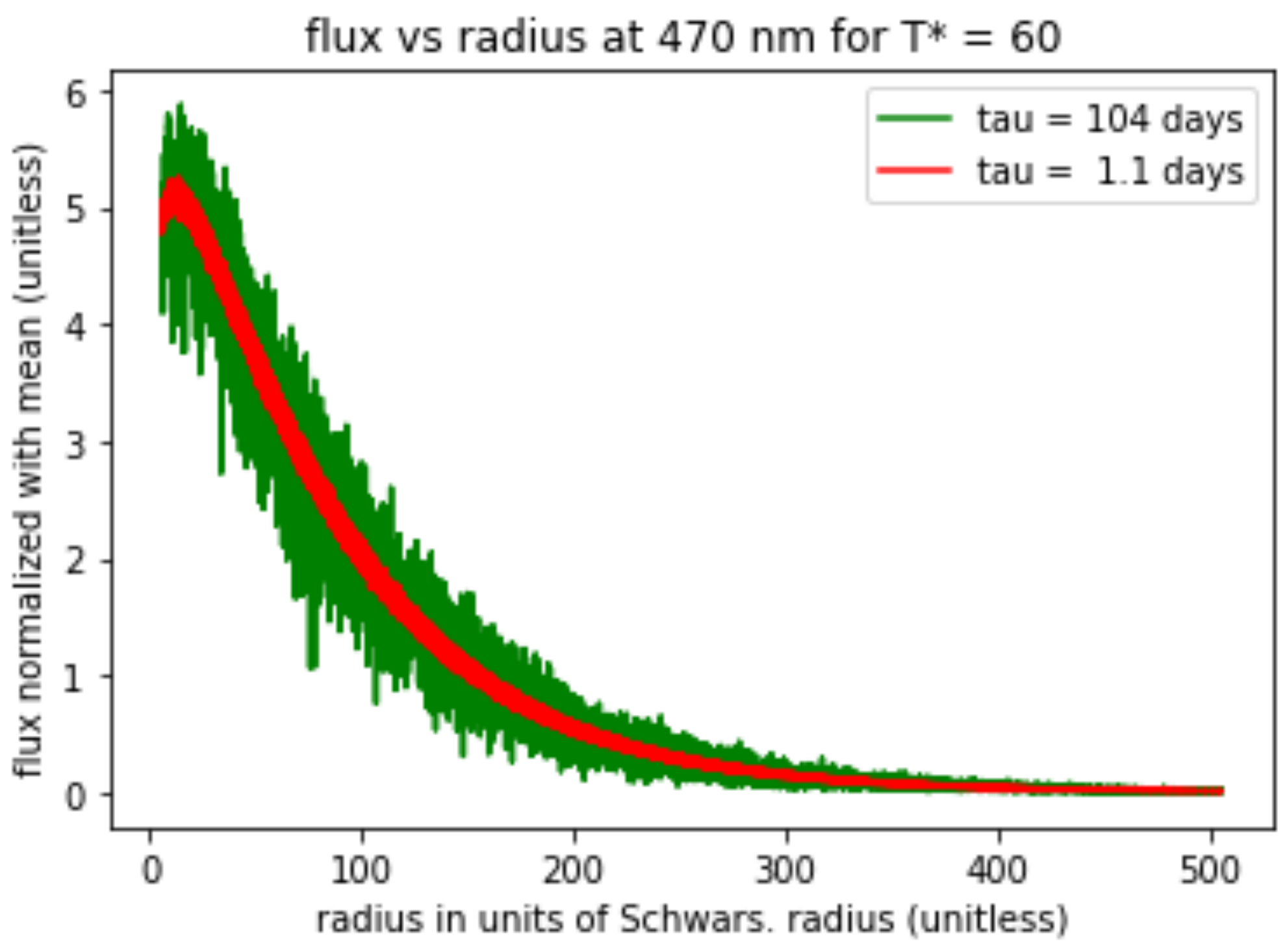


Figure 3: Flux for a quasar at T*=60 for two time scales. The simulation predicts that the amplitude of the flux for different time scales is dependent on the position on the disk.

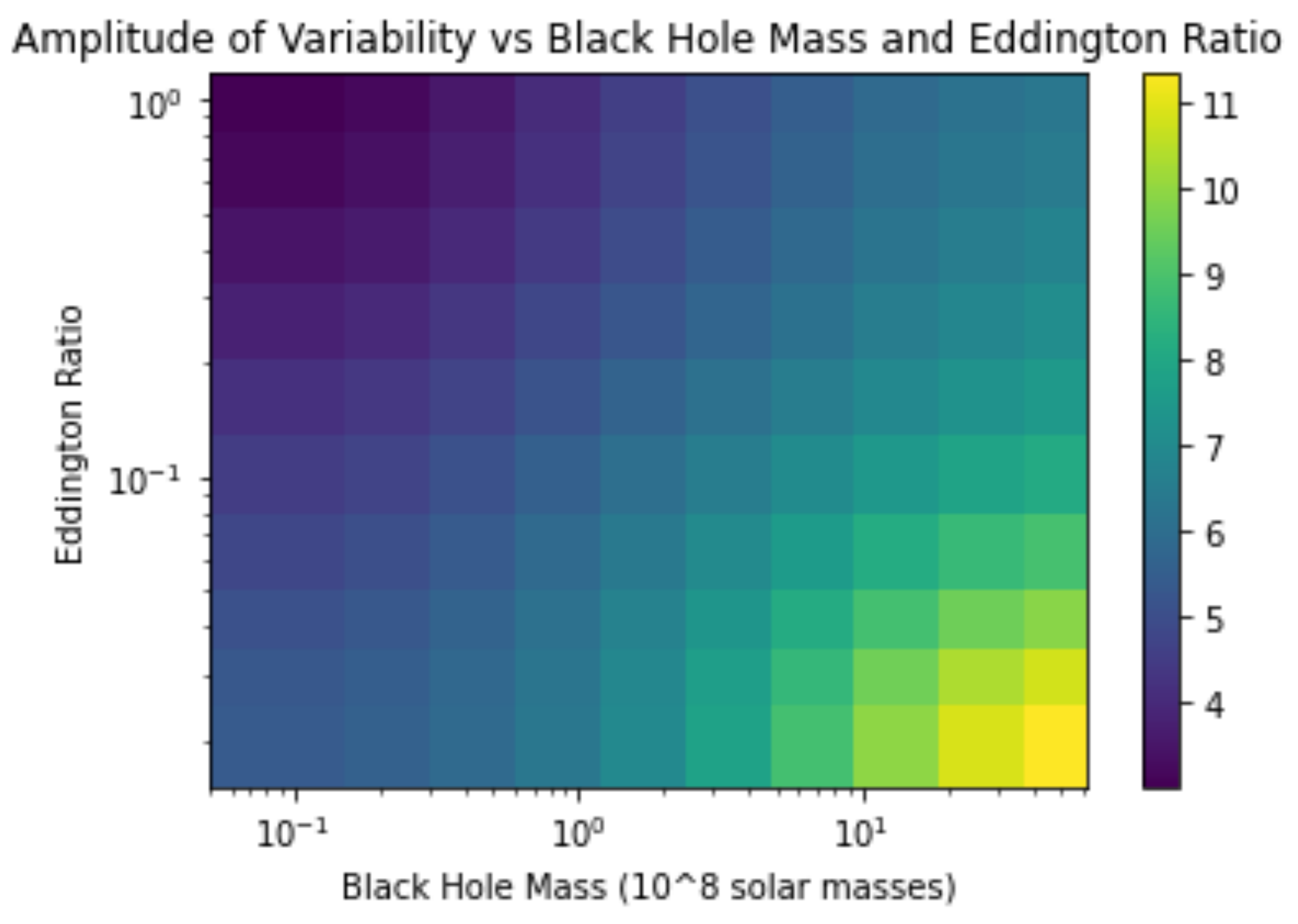
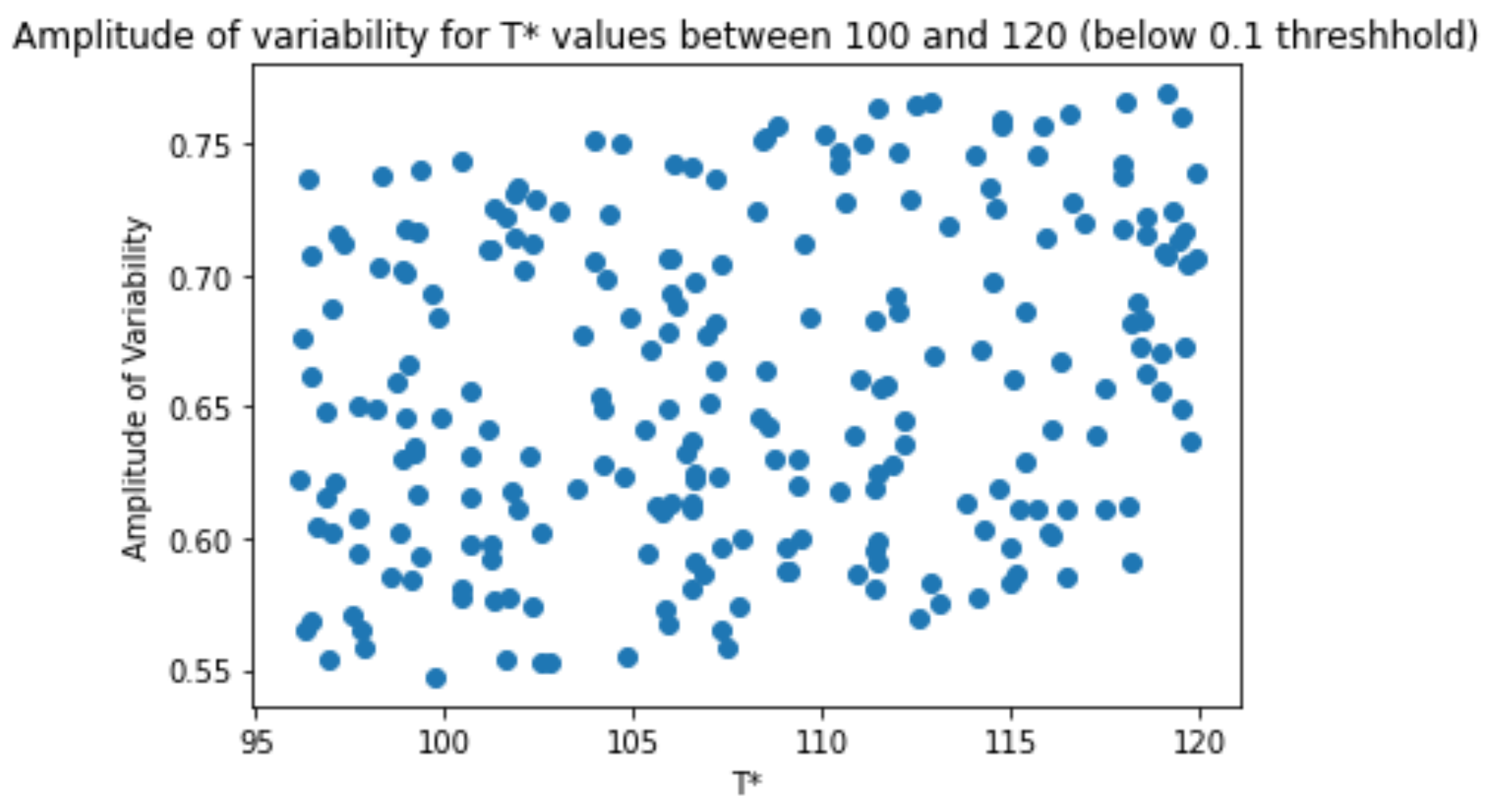


Figure 4: This is a plot that shows how the amplitude of variability changes with different values of the black hole mass and the Eddington ratio.

- A larger black hole mass corresponds to a smaller amplitude of variability and a larger Eddington Ratio corresponds to greater amplitude.



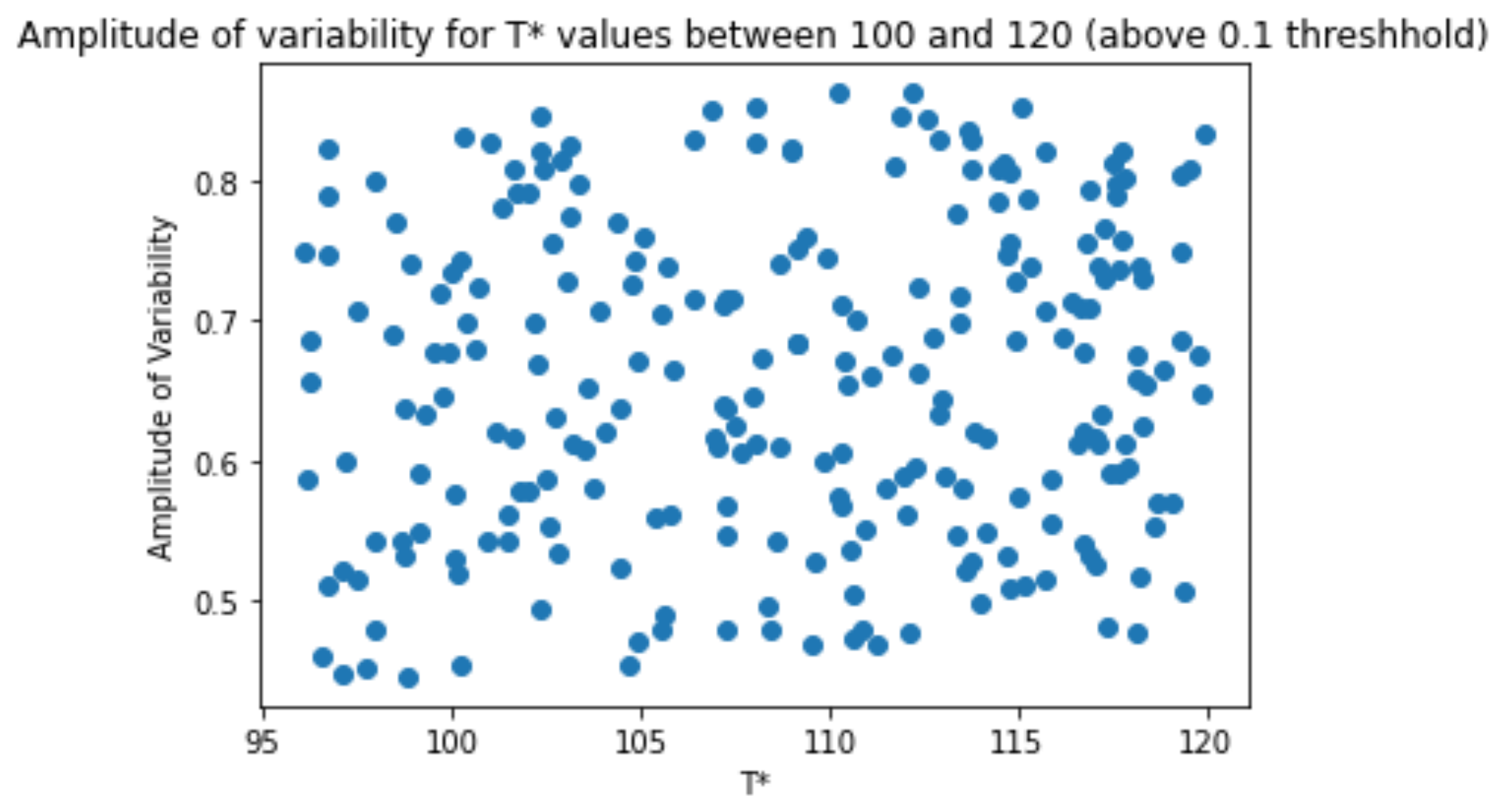


Figure 5: Amplitude of variability vs T* assuming 0.1 sensitivity with bin sizes of 24 T* values. A Spearman test returns with a correlation = 0.23 and a P-value of 0.0004. This is an appropriate bin size.

Figure 6: Amplitude of variability vs T* assuming 0.2 sensitivity with bin sizes of 24 T* values. A Spearman test returns with a correlation = 0.092 and a P-value of 0.15. This bin size is too fine for the given sensitivity.

Results

- The initial simulation results predict an increase in the amplitude of variability with an increase in black hole mass and a decrease in the Eddington ratio.
- The amplitude of variability is also affected by the time scale associated with the mass accretion rate perturbations. Larger time scales result in larger changes in the variability over time, while smaller time scales produce flatter light curves.
- We also demonstrate how the sensitivity of the LSST data will inform how fine we can bin LSST targets according to black hole mass and the Eddington ratio.

Bibliography

[1] Ansh, S. (2019). An Analysis of the Optical Variability of Active Galactic Nuclei Using Multi Band Sloan
[2] Kasliwal, V. P., Vogeley, M. S., & Richards, G. T. (2015). Are the variability properties of the Kepler AGN light curves consistent with a damped random walk?. Monthly Notices of the Royal Astronomical Society, 451(4), 4328-4345.
[3] Kelly, B. C., Bechtold, J., & Siemiginowska, A. (2009). Are the variations in quasar optical flux driven by thermal fluctuations?. The Astrophysical Journal, 698(1), 895
[4] Shakura, N. I., & Sunyaev, R. A. (1973). Black holes in binary systems. Observational appearance. Astronomy and Astrophysics, 24, 337-355.

Future Plans

- We intend to develop more sophisticated tests of synthetic LSST data.
- We plan to test other parameters, such as tau.
- We are also developing ways of using the PSD to analyze synthetic LSST data.

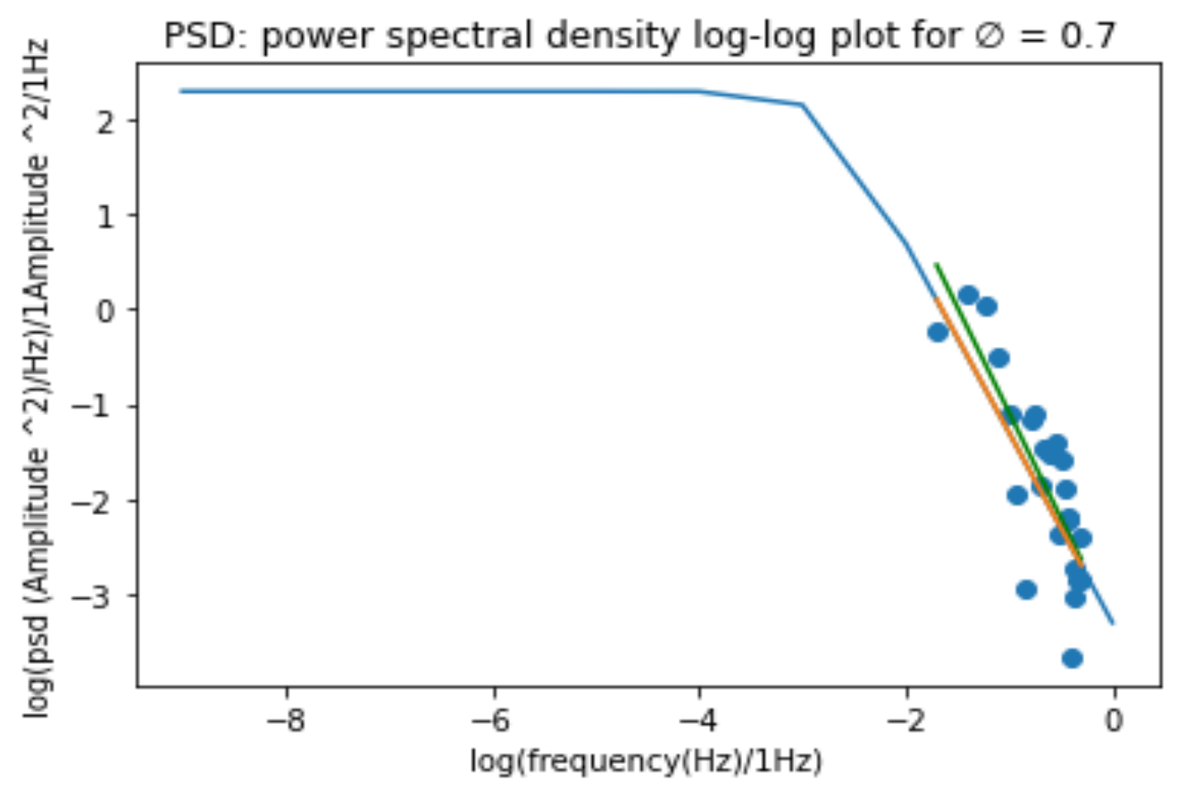


Figure 7: Plot of the expected PSD and the PSD for a quasar observed 50 times over a 3 year period given a tau of 104 days.

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