

Comparison of Long-term Mid-infrared Variability between Broad-line and Narrow-line Seyfert 1 Galaxies: Postprint

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Abstract

The long-term mid-infrared variability amplitudes of Broad-line Seyfert 1 (BLSy1) galaxies and Narrow-line Seyfert 1 (NLSy1) galaxies were compared using archival data from the Wide-field Infrared Survey Explorer (WISE). Additionally, the correlations between long-term mid-infrared variability amplitude and common active galactic nucleus parameters were analyzed, using samples of BLSy1 galaxies, NLSy1 galaxies, and a combined sample of BLSy1 and NLSy1 galaxies. The main results are as follows: (1) The long-term mid-infrared variability amplitude of BLSy1 galaxies is greater than that of NLSy1 galaxies, possibly due to differences in the accretion disk structure between BLSy1 and NLSy1 galaxies. Based on the correlation analysis results between long-term mid-infrared variability amplitude and common active galactic nucleus parameters, the greater long-term mid-infrared variability amplitude of BLSy1 galaxies compared to NLSy1 galaxies may also be primarily due to differences in the Eddington ratio between BLSy1 and NLSy1 galaxies. (2) The long-term mid-infrared variability amplitudes of BLSy1 galaxies, NLSy1 galaxies, and the combined sample all show significant negative correlations with 5100 Å luminosity, Eddington ratio, and FeII emission line strength. The long-term mid-infrared variability amplitude of NLSy1 galaxies shows a significant positive correlation with [OIII] λ 5007 emission line strength.

Full Text

Preamble

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The Comparison of Long-term Mid-infrared Variability between Broad-line and Narrow-line Seyfert 1 Galaxies

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Abstract

Using archival data from the Wide-field Infrared Survey Explorer (WISE), we compared the long-term mid-infrared variability amplitudes of Broad-line Seyfert 1 (BLSy1) galaxies and Narrow-line Seyfert 1 (NLSy1) galaxies. Additionally, we analyzed the correlations between long-term mid-infrared variability amplitude and common active galactic nucleus (AGN) parameters, utilizing samples of BLSy1 galaxies, NLSy1 galaxies, and a combined sample of both types. The main results are as follows: (1) The long-term mid-infrared variability amplitude of BLSy1 galaxies is greater than that of NLSy1 galaxies, possibly due to differences in accretion disk structure between the two types. Correlation analysis suggests that the larger variability amplitude in BLSy1 galaxies may also be primarily attributed to differences in Eddington ratio between BLSy1 and NLSy1 galaxies. (2) The long-term mid-infrared variability amplitudes of BLSy1 galaxies, NLSy1 galaxies, and the combined sample all show significant negative correlations with 5100 Å luminosity, Eddington ratio, and FeII emission line strength. The long-term mid-infrared variability amplitude of NLSy1 galaxies shows a significant positive correlation with [OIII] 5007 emission line strength.

Keywords: galaxies: Seyfert, infrared: variability, radiation mechanisms: thermal radiation, methods: statistical

1 Introduction

Active Galactic Nuclei (AGN) are extragalactic sources with highly active central regions, powered by accretion onto supermassive black holes (SMBHs) located at galaxy centers. Their observational characteristics include compact morphology, high luminosity, broad continuum radiation, and strong emission lines. Seyfert galaxies represent a lower-luminosity class of AGN with prominent emission lines in their spectra, such as hydrogen Balmer lines, [OIII] emission lines, and MgII emission lines. Based on spectral features, Seyfert galaxies are primarily divided into two subclasses: Seyfert 1 and Seyfert 2. The former exhibit broad lines including permitted lines (e.g., H I, He I, or He II) and narrower forbidden lines (e.g., [OIII]), along with some narrow permitted lines, while the latter show only narrow permitted and forbidden lines.

Seyfert 1 galaxies are further classified into Broad-line Seyfert 1 (BLSy1) and Narrow-line Seyfert 1 (NLSy1) galaxies based on emission line properties. The original classification criteria for NLSy1 galaxies include: relatively narrow Full Width at Half Maximum (FWHM) of the $H\beta$ emission line ($\text{FWHM} < 2000 \text{ km s}^{-1}$), weak [OIII] emission lines (flux ratio of [OIII] to $H\beta < 3$), and high black hole accretion rates. Compared to BLSy1 galaxies, NLSy1 galaxies exhibit

stronger FeII radiation, more pronounced soft X-ray excess, rapid X-ray flux variations, lower black hole masses, and higher Eddington ratios. However, the relationship between BLSy1 and NLSy1 galaxies remains unclear. NLSy1 galaxies may represent an early evolutionary stage of AGN, preceding BLSy1 galaxies, though some studies find similar black hole masses and Eddington ratios between the two types, suggesting their differences arise from geometric structure rather than evolutionary stage.

Non-periodic variability is ubiquitous in AGN across wavelengths from radio to high-energy bands, with timescales ranging from minutes to years. Variability provides valuable insights into AGN physics, enabling estimation of black hole masses and probing the structural characteristics of accretion disks, broad-line regions, and dust tori. It is also widely used for AGN identification and confirmation. Various physical processes have been proposed to explain AGN variability, including accretion disk instabilities, Poisson processes, and starburst models. Therefore, studying the variability of BLSy1 and NLSy1 galaxies can help understand the physical properties of their central black holes and surrounding structures.

Previous studies have extensively compared the long-term UV and optical variability amplitudes of BLSy1 and NLSy1 galaxies, consistently finding that BLSy1 galaxies show greater variability amplitudes than NLSy1 galaxies in these bands. Since UV and optical radiation in AGN primarily originates from the accretion disk, different variability amplitudes may indicate distinct physical processes occurring in the accretion disks of BLSy1 and NLSy1 galaxies. Furthermore, long-term UV and optical variability amplitudes have been found to correlate with common AGN parameters, particularly showing negative correlations with 5100 Å luminosity, Eddington ratio, and FeII emission line strength, suggesting that different variability amplitudes may reflect different observational characteristics between BLSy1 and NLSy1 galaxies.

AGN infrared radiation primarily arises from thermal re-emission by dust tori heated by UV and optical photons produced in the central accretion process. While the long-term variability behavior of BLSy1 and NLSy1 galaxies has been extensively studied in the UV and optical bands, less attention has been paid to their infrared variability. This paper compares the long-term mid-infrared variability amplitudes of these two galaxy types. According to the standard AGN model, infrared variability amplitude depends on both the amplitude of UV/optical variability and the dust covering factor. Studying mid-infrared variability in these galaxies not only allows comparison with UV/optical results and provides indirect clues about accretion processes, but also enables analysis of dust torus properties.

Correlation analysis between variability and AGN parameters is an effective method for exploring AGN physics. Previous work found negative correlations between long-term mid-infrared variability amplitude and 5100 Å luminosity, Eddington ratio, and FeII emission line strength, but only for NLSy1 galaxies. This paper analyzes correlations between long-term mid-infrared variability am-

plitude and common AGN parameters for both BLSy1 and NLSy1 galaxies, as well as for a combined sample, to investigate the overall relationship for Seyfert 1 galaxies. Infrared observations offer unique advantages: in low-redshift AGN, the infrared continuum is less affected by strong emission lines and dust extinction compared to UV/optical bands.

2.1 Sample

For this study, we utilized the latest Seyfert 1 galaxy catalog provided by the literature, which includes 52,273 BLSy1 galaxies and 22,656 NLSy1 galaxies. This catalog was obtained through detailed decomposition of quasar and galaxy spectra from the Sloan Digital Sky Survey Data Release 17 (SDSS DR17) using the publicly available Bayesian AGN Decomposition Analysis software. The catalog contains sources detected by FIRST (Faint Images of the Radio Sky at Twenty-Centimeters), including 2,568 BLSy1 galaxies and 730 NLSy1 galaxies. These radio-detected sources represent a small fraction (4.91% and 3.22%, respectively) of the total BLSy1 and NLSy1 populations. Since synchrotron radiation from jets in radio-loud AGN can significantly contribute to infrared variability, we excluded these radio-detected sources, leaving 49,705 BLSy1 galaxies and 21,926 NLSy1 galaxies for our analysis.

2.2 WISE Long-term Variability Data

The Wide-field Infrared Survey Explorer (WISE) features a 40 cm infrared telescope that completed its first all-sky survey in mid-infrared bands in July 2010. Operating at wavelengths of 3.4 μ m, 4.6 μ m, 12 μ m, and 22 μ m (W1, W2, W3, and W4 bands) with spatial resolutions of 6.1', 6.4', 6.5', and 12.0' respectively, WISE achieved significantly higher sensitivity than previous infrared missions such as IRAS. With NASA support, the WISE data processing system was improved and renamed NEOWISE (Near-Earth Object Wide-field Infrared Survey Explorer). NEOWISE conducted surveys only in W1 and W2 bands, entering hibernation in February 2011. It was reactivated in December 2013, maintaining original performance and continuing W1 and W2 surveys as NEOWISE-R until July 2024.

To calculate long-term mid-infrared variability, we used all NEOWISE-R data from December 2013 to July 2024, spanning approximately 10.6 years. Due to higher signal-to-noise ratio in W1 band, we retrieved W1 photometric data for 49,705 BLSy1 galaxies and 21,926 NLSy1 galaxies from the NASA Infrared Science Archive (IRSA) using a search radius of 3'. We applied quality screening criteria to remove bad data points:

1. **w1rchi2 < 5**: Reduced chi-squared value for profile-fit photometry in W1 band must be less than 5
2. **nb < 3**: Number of Point Spread Functions (PSFs) used in multi-frame pipeline profile fitting must be less than 3

3. **cc_{flags} = 0**: No contamination or confusion from known image artifacts in W1 band
4. **qual_{frame} > 0**: Frame quality score must be positive, indicating good image quality and reliable data
5. **qi_{fact} > 0**: Single-frame image quality factor must be positive
6. **saa_{sep} > 0**: Angular separation from the South Atlantic Anomaly (SAA) boundary must be positive, indicating minimal SAA impact
7. **moon_{masked} = 0**: No contamination from lunar scattered light during photometric or positional measurements in W1 band

We also removed data points where W1 magnitudes were upper limits only (84,143 points for BLSy1 galaxies, representing 0.55% of total; 59,571 points for NLSy1 galaxies, representing 0.99%). After quality screening, we segmented observations into epochs with approximately 180-day intervals (one full sky coverage period for NEOWISE-R), yielding epochs of about 1-day duration each. Following data cleaning and epoch segmentation, 2,040 BLSy1 galaxies (4.10%) and 1,624 NLSy1 galaxies (7.41%) had ≥ 17 observation epochs. To ensure robust analysis of long-term mid-infrared variability, we retained only sources with >17 epochs, resulting in final samples of 47,665 BLSy1 galaxies and 20,302 NLSy1 galaxies.

3.1 Weighted Average

To study long-term mid-infrared variability, we performed weighted averaging for each observation epoch of the 47,665 BLSy1 and 20,302 NLSy1 galaxies. For each epoch with N photometric measurements m_1, m_2, \dots, m_N and corresponding errors $\sigma_1, \sigma_2, \dots, \sigma_N$, the weighted average magnitude and its error are given by:

$$m_{\text{wtd}} = \frac{\sum_{i=1}^N w_i m_i}{\sum_{i=1}^N w_i}$$

where weights $w_i = 1/\sigma_i^2$. The standard error of the weighted mean is:

$$\sigma_{m_{\text{wtd}}} = \sqrt{\frac{1}{\sum_{i=1}^N w_i}}$$

The total variance for each source's light curve is calculated as:

$$\sigma_m^2 = \frac{1}{N_{\text{ep}} - 1} \sum_{i=1}^{N_{\text{ep}}} (m_i - m_{\text{wtd}})^2$$

where N_{ep} is the number of epochs. The total uncertainty is defined as:

$$\epsilon^2 = \frac{1}{N_{\text{ep}}} \sum_{i=1}^{N_{\text{ep}}} \epsilon_i^2 + \epsilon_s^2$$

with ϵ_i representing individual epoch uncertainties and $\epsilon_s = 0.024$ mag being the systematic uncertainty for W1 band. The intrinsic variability amplitude is then:

$$\sigma_m = \sqrt{\sigma_m^2 - \epsilon^2} \quad \text{if } \sigma_m > \epsilon, \text{ otherwise } 0$$

Figure 1 [Figure 1: see original paper] shows example long-term mid-infrared light curves for a BLSy1 galaxy (SDSS J000115.88+051902.0) and an NLSy1 galaxy (SDSS J144619.29+005317.9) in W1 band.

3.2 Long-term Variability Amplitude

To characterize long-term mid-infrared variability, we calculated the variability amplitude σ for each source using variance analysis with observational uncertainties subtracted:

$$\sigma_m = \sqrt{\frac{1}{N_{\text{ep}}} \sum_{i=1}^{N_{\text{ep}}} (m_i - \bar{m})^2 - \epsilon^2}$$

where m_i is the magnitude in each epoch, \bar{m} is the weighted mean magnitude across all epochs, and ϵ^2 is the total uncertainty defined above. This approach follows standard methods for quantifying variability amplitudes in large AGN samples.

4.1 Mid-infrared Variability of BLSy1 and NLSy1 Galaxies

Applying this method, we calculated long-term mid-infrared variability amplitudes for 47,665 BLSy1 galaxies and 20,302 NLSy1 galaxies. In the BLSy1 sample, 3,059 sources (6.42%) had $\sigma = 0$, while 44,606 showed non-zero variability. In the NLSy1 sample, 2,274 sources (11.20%) had $\sigma = 0$, with 18,028 showing detectable variability. Sources with $\sigma = 0$ likely exhibit very small amplitude variations.

Figure 2 [Figure 2: see original paper] presents the cumulative probability distribution functions (CPDFs) of σ for both samples, clearly showing that BLSy1 galaxies have larger long-term mid-infrared variability amplitudes than NLSy1 galaxies. The mean σ values are 0.088 mag for BLSy1 galaxies and 0.086 mag for NLSy1 galaxies. Median values with uncertainties are $0.074^{+0.053}_{-0.040}$ mag for BLSy1 and $0.069^{+0.053}_{-0.045}$ mag for NLSy1 galaxies, confirming the greater variability in BLSy1 systems.

Statistical tests support this conclusion: Kolmogorov-Smirnov (K-S) test yields $D = 0.057$ with $P = 4.262 \times 10^{-40}$, while Mann-Whitney U test gives $U = 5.198 \times 10^8$ with $P = 2.384 \times 10^{-53}$. The K-S test statistic D represents the maximum vertical difference between cumulative distribution functions, with small P -values indicating significantly different distributions. The large U statistic and small P -value from the rank-sum test further confirm that the two samples have distinctly different variability amplitude distributions. This result mirrors findings in UV and optical bands, where BLSy1 galaxies also show greater variability amplitudes than NLSy1 galaxies.

4.2 Mid-infrared Variability of Matched Subsamples

Brighter AGN are more likely to have detectable small-amplitude variability. To avoid biases from differences in infrared brightness distributions, we performed redshift-W1 luminosity 2D matching between 47,665 BLSy1 and 20,302 NLSy1 galaxies. This matching ensures similar luminosity distributions in the final samples.

We calculated W1 luminosities by first converting magnitudes to flux densities using:

$$F_\nu = F_{\nu 0} \times 10^{-m_{\text{vega}}/2.5}$$

where F is flux density, $F_0 = 309.54$ Jy is the zero-point flux density, and m is Vega magnitude. After averaging flux densities across all epochs for each source, we computed luminosities using:

$$L_{W1} = 4\pi d_L^2 F_\nu \frac{c}{\lambda}$$

where d is luminosity distance, c is vacuum light speed, and λ is wavelength, adopting cosmological parameters consistent with the literature.

Table 1 and Table 2 list basic information and variability results for BLSy1 and NLSy1 galaxies respectively. Using redshift intervals of 0.002 and W1 luminosity intervals of 0.01 dex, we performed nearest-neighbor matching in the redshift-luminosity plane, obtaining 9,323 BLSy1 and 9,323 NLSy1 galaxies. Figure 3 [Figure 3: see original paper] shows the distribution of matched subsamples, with histograms of redshift and W1 luminosity. A 2D K-S test yields $D = 0.00091$ with $P = 1$, confirming no significant differences in the 2D distributions of redshift and W1 luminosity between the matched subsamples.

Figure 4 [Figure 4: see original paper] presents the CPDFs of σ for these matched subsamples (including 733 BLSy1 and 1,068 NLSy1 galaxies with $\sigma = 0$). BLSy1 galaxies clearly show larger variability amplitudes, with mean σ values of 0.090 mag versus 0.083 mag for NLSy1 galaxies. Median values are $0.075^{+0.054}_{-0.042}$ mag for BLSy1 and $0.066^{+0.050}_{-0.043}$ mag for NLSy1 galaxies.

Statistical tests confirm this difference: K-S test gives $D = 0.085$ with $P = 1.322 \times 10^{-29}$, while Mann-Whitney test yields $U = 4.849 \times 10^7$ with $P = 9.380 \times 10^{-43}$. Thus, even after controlling for redshift and W1 luminosity, BLSy1 galaxies exhibit greater long-term mid-infrared variability amplitudes than NLSy1 galaxies.

4.3 Influence of Dust Covering Factor on Mid-infrared Variability

Since mid-infrared variability amplitude may be affected by dust covering factor (CF), with larger CFs tending to produce greater mid-infrared variability, we calculated W1 band CFs for 47,665 BLSy1 and 20,302 NLSy1 galaxies as the ratio of W1 luminosity to bolometric luminosity. Bolometric luminosities from the literature were computed using $L_6 = 9.26 \times L(5100 \text{ \AA})$. We find average W1 CFs of 0.462 for BLSy1 and 0.526 for NLSy1 galaxies, with median values of $0.433^{+0.467}_{-0.175}$ and $0.351^{+0.484}_{-0.154}$ respectively, indicating larger CFs in NLSy1 galaxies. K-S and Mann-Whitney tests confirm significantly different CF distributions ($D = 0.055$, $P = 2.067 \times 10^{-37}$; $U = 4.546 \times 10^8$, $P = 1.005 \times 10^{-35}$).

Since W2 band may be closer to the peak of the dust torus spectral energy distribution, we also analyzed W2 data for 52,273 BLSy1 and 22,656 NLSy1 galaxies using identical quality criteria, retaining 46,782 BLSy1 and 18,965 NLSy1 sources with >17 epochs. W2 CF averages are 0.599 for BLSy1 and 0.675 for NLSy1 galaxies, with medians of $0.454^{+0.591}_{-0.197}$ and $0.356^{+0.435}_{-0.152}$ respectively, again showing larger CFs in NLSy1 galaxies. Statistical tests confirm significantly different W2 CF distributions ($D = 0.049$, $P = 9.807 \times 10^{-29}$; $U = 4.237 \times 10^8$, $P = 1.971 \times 10^{-19}$).

For the redshift-W1 luminosity matched subsamples, BLSy1 galaxies have average and median W1 CFs of 0.495 and $0.356^{+0.435}_{-0.152}$, while NLSy1 galaxies have 0.527 and $0.346^{+0.464}_{-0.147}$, showing no significant difference. Statistical tests support this: $D = 0.021$ ($P = 0.032$) and $U = 4.380 \times 10^7$ ($P = 0.349$). These results suggest that dust covering factor is not the primary cause of the greater mid-infrared variability in BLSy1 galaxies. The difference likely originates from the accretion disk, though our CF estimates are approximate and require more systematic future investigation.

4.4 Correlations with AGN Parameters

We investigated correlations between W1 band long-term variability amplitude (σ) and six AGN parameters for 44,606 BLSy1 and 18,028 NLSy1 galaxies: 5100 Å luminosity, black hole mass, Eddington ratio, FWHM of H β emission line, FeII emission line strength (R_{4570}), and [OIII] 5007 emission line strength (R_{5007}). The 5100 Å luminosity represents continuum emission at that wavelength. Eddington ratio, describing accretion rate, is defined as $R_{\text{dd}} = L_6 / L_{\text{dd}}$, where $L_{\text{dd}} = 1.3 \times 10^{38} (M_6 / M_{\odot}) \text{ erg s}^{-1}$. FeII strength is defined as the flux ratio

of FeII (4434–4684 Å) to broad H β , while [OIII] strength is the ratio of [OIII] 5007 to narrow H β .

We performed linear regression in log-space and calculated Spearman correlation coefficients with chance probability P-values for BLSy1, NLSy1, and combined samples. Table 3 summarizes all correlation results.

4.4.1 Correlations with 5100 Å Luminosity, Black Hole Mass, and Eddington Ratio

Figure 5 [Figure 5: see original paper] shows σ versus 5100 Å luminosity and black hole mass. Both BLSy1 and NLSy1 galaxies exhibit significant negative correlations between σ and 5100 Å luminosity, confirmed by Spearman coefficients (Table 3). This matches UV/optical studies and extends to other AGN types. No significant correlation appears between σ and black hole mass, consistent with findings that the mass dependence disappears when accounting for Eddington ratio dependence.

Figure 6 [Figure 6: see original paper] shows σ versus Eddington ratio and H β FWHM. All three samples show clear negative correlations between σ and Eddington ratio, quantified by linear regression and Spearman coefficients (Table 3). This agrees with previous NLSy1 mid-infrared studies and UV/optical results for both galaxy types. The negative correlation may reflect the standard thin accretion disk model, where the emission radius at a given wavelength increases with Eddington ratio, reducing variability amplitude.

4.4.2 Correlations with Emission Line Parameters

Figure 6(b) and Table 3 show no significant correlation between σ and H β FWHM for any sample. Figure 7 [Figure 7: see original paper] presents σ versus FeII and [OIII] 5007 strengths. All samples show significant negative correlations between σ and FeII strength. NLSy1 galaxies uniquely show a significant positive correlation between σ and [OIII] 5007 strength, while BLSy1 and combined samples show none. These mid-infrared correlations mirror those in UV/optical bands but are weaker, possibly because UV/optical radiation is partially obscured by the dust torus, damping the mid-infrared response.

4.4.3 Impact of AGN Parameters on Variability Differences

The correlation analysis suggests that differences in σ between BLSy1 and NLSy1 galaxies may stem from different parameter distributions, but the dominant parameter remains unclear. Based on parameter distributions and Spearman coefficients, Eddington ratio appears most influential. We therefore controlled for Eddington ratio and FeII strength to examine their impact on the σ differences.

Table 4 shows correlations under specific constraints. When fixing Eddington ratio, the negative correlation between σ and FeII strength weakens for BLSy1

galaxies but remains significant for NLSy1 galaxies. When fixing FeII strength, both types show significant negative correlations between σ and Eddington ratio, though the correlation coefficients are smaller than when Eddington ratio is allowed to vary. These results suggest that Eddington ratio is the parameter most likely responsible for the observed differences in long-term mid-infrared variability amplitudes between BLSy1 and NLSy1 galaxies.

5 Summary and Discussion

We compared long-term mid-infrared variability amplitudes of 47,665 BLSy1 galaxies and 20,302 NLSy1 galaxies using WISE archival data, and analyzed matched subsamples controlling for redshift and W1 luminosity. In all cases, BLSy1 galaxies exhibit greater long-term mid-infrared variability amplitudes than NLSy1 galaxies, confirmed by K-S and Mann-Whitney tests. The lower variability amplitude in NLSy1 galaxies may be attributed to their narrower H β line widths, lower black hole masses, higher Eddington ratios, and stronger FeII emission. The possibility that NLSy1 galaxies represent an earlier evolutionary stage may contribute to these parameter differences.

Previous UV/optical studies attributed variability differences to distinct physical processes in accretion disks, likely resulting from different disk structures. Since mid-infrared radiation originates from dust tori heated by UV/optical photons, accretion disk differences may be reflected in the dust emission, producing the observed mid-infrared variability differences. Although jet synchrotron radiation could contribute to mid-infrared emission, we excluded radio-detected sources to minimize this effect. Dust covering factor does not appear to drive the observed differences, as NLSy1 galaxies actually have larger CFs in both W1 and W2 bands, yet show smaller variability amplitudes. Therefore, the variability differences likely originate primarily from the accretion disk.

Correlation analysis reveals significant relationships between long-term mid-infrared variability amplitude and AGN parameters, particularly negative correlations with 5100 Å luminosity, Eddington ratio, and FeII strength. These correlations, also found in previous work, are consistent with UV/optical studies but weaker in the mid-infrared, possibly due to dust obscuration damping the variability signal. The standard thin accretion disk model provides a framework for understanding the Eddington ratio dependence, as the emission radius at a given wavelength increases with accretion rate, reducing variability amplitude. The correlation between variability amplitude and FeII strength appears to be influenced by Eddington ratio, with our controlled analysis indicating that Eddington ratio is the most likely parameter driving the differences between BLSy1 and NLSy1 galaxy variability.

Overall, our mid-infrared results are consistent with UV/optical studies in terms of both the greater variability amplitude in BLSy1 galaxies and the identified correlations with AGN parameters, supporting the scenario where mid-infrared emission arises from thermal reprocessing of UV/optical radiation by dust tori.

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