Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

An active galactic nucleus (AGN) resides in the center of most massive galaxies. These central engines, most likely supermassive black holes (SMBHs), attribute their luminosity to the accretion of material from the surrounding accretion disk onto themselves. A nearby region of gas, the broad line region (BLR), resides above and below the accretion disk. This region is named from the broad emission lines that are produced in this area due to Doppler broadening. While recent research is beginning to unravel the shape and size of the BLR, there is much more to learn about the layout of the region near the accreting SMBH. The aim of this proposed project is to further unravel the environment surrounding AGNs via reverberation mapping of the BLR, specifically with the broad Hα emission line.

The target for this project is the quasar 3C 273. This quasar is particularly unique in that it is the brightest quasar in the sky thus far [6]. Recent work done by the Sloan Digital Sky Survey Reverberation Mapping team noted that this quasar has the largest calculated mass, as well [10]. A candidate such as 3C 273 pushes the limits of the observable quasars in both luminosity and mass, suggesting that the extremes of physics may be at play within this space. Rather than focus on too many targets and sacrifice accuracy, this project will focus all time into gaining the most precise measurements possible of this unique and extreme source.

The aim of this project is to constrain the size of the BLR surrounding 3C 273. Reverberation mapping is a manner of observing the continuum of a quasar along with a broad emission line over an extended period of time. The continuum light comes from that of the accretion disk, which is significantly closer to the central engine than the BLR is. Flares within the continuum may correspond to an increase in accretion onto the SMBH but assuredly point to some behavior happening close to the AGN. When any amount of light is emitted by the AGN, the continuum will see an increase in magnitude before the BLR does, and the time difference between these peaks in luminosity correspond to the light travel time between the central engine and the BLR. Observing the time difference between a peak in the light coming from the continuum and the light coming from a broad emission line thus constrains the distance of the BLR with respect to the center of the system.

In order to witness the correlated rise and fall of luminosity in the continuum and broad Hα emission line, this target will need to be observed with both high frequency, high precision, and long project duration. The frequency of measurements must be high enough that there are several data points along a peak of emission; a clear peak must be available in order to match the shape and size of peaks between the two areas of measurement. The error bars within these measurements must be small enough that true flux variations will not be confused for noise. Finally, the overall length of the project will need to span at minimum the approximate light travel time from the SMBH to the BLR, which is on the order of a lightmonth [5]. One should expect that the random peaks will not appear immediately upon observation, and several peaks should be observed in order to constrain the range of distances to the BLR. Once began, this observation period should span several months at a minimum. Hence, this proposal requests long-term status for collecting its data.

One of the less expensive ways to gather reverberation mapping measurements is through photometry. Photometric measurements allow for shorter exposure times while maintaining an equivalent signal to noise ratio (S/N). One filter is necessary to view the continuum in an area rid of any emission lines. This will provide the benchmark that will later be used as a comparison to the data of the BLR. Another filter must be used that fully encapsulates the broad Hα emission line; the entirety of its flux must be collected in order to ensure proper alignment of peaks after data collection. Hα is a promising option for this observation as it typically has a large flux in quasars and falls in the center of the i band of GMOS-N at its point of highest transmission [12, 13]. This should keep S/N high and exposures times low, allowing for efficient and timely data collection.

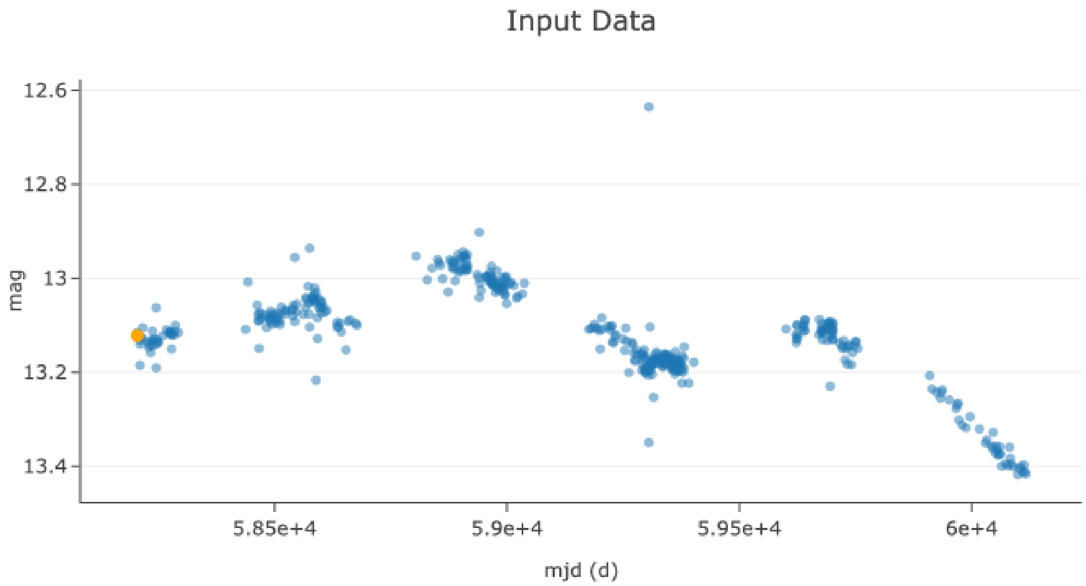

Figure 1: This plot of magnitude versus date shows the variability expected from 3C 273. The light curve shows peaks with height of approximately 0.2 magnitudes [15].

References

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Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification?*

The quasar 3C 273 has an angular width of approximately 30 arcseconds [1]. GMOS-N has spatial sampling of 0.0807"/pixel on its imager, which gives $pixel/0.0807" \cdot 30" = 2.421\ pixels$ across the target [2]. This sampling size of roughly 2 pixels across the source will Nyquist sample the data, which is proper to avoid over or under-sampling.

The target has a right ascension of 12h 29m 7s = 187.2792°and a declination of 2°3'9" = 2.0525°[6, 11]. Gemini North, located at a latitude of +19:49:25.7016 = 19.8236°, provides a minimum airmass of $1/cos(19.8236° - 2.0525°) = 1.05$. This will occur when 3C 273 crosses the meridian; with a tentative and approximate March 21 observation date, an object with 3C 273's right ascension of 12h 29m 7s would cross the meridian 29 minutes and 7 seconds before local midnight, at 23:30:53. This airmass will provide relatively high S/N data, and this quasar will be observable for a large majority of the night at this time of year.

Figure 1 illustrates what appears to be 3C 273's minimum variability in magnitude of approximately 0.2 magnitudes [15]. In order to be able to distinguish the variability as true peaks from noise, error bars less than or equal to one fifth of the smallest variation expected are necessary. For a uncertainty this small, a fractional uncertainty of $0.2 \cdot 0.2mag = 0.04mag$ is equal to the desired uncertainty in magnitude. A S/N of $1/(fractional\ uncertainty) = 1/0.04 = 25$ is the desired ratio in order to differentiate all essential data fluctuations [7]. This ratio should be achieved in both continuum and Hα measurements.

This project will observe the continuum and broad Hα emission line. With a redshift of 0.158 [6], the redshifted Hα centroid will be at $\lambda_{obs} = z \cdot \lambda_0 + \lambda_0 = 0.158 \cdot 6564.614$Å+6564.614Å= 7601.823Å[14]. This wavelength falls in the region of maximum transmission of the GMOS-N i filter [12, 13]. 3C 273 has an i magnitude of 12.47524 [9]. With the input of z=0.158, i=12.47524, a QSO background from 800-8550Å, a Hamamatsu CCD array, no binning, full frame region of interest, low amp gain, slow amp read mode, and rather pessimistic observing conditions (85% image quality, 70% cloud cover, 80% sky background, any amount of water vapor in the air, and an airmass < 1.2), the S/N for an observation of 0.0005 seconds is 26.30 [8], falling above the necessary threshold.

A good selection for the continuum is rest wavelengths of 5855Å-5955Å, which have no emission line features within that range. These values correspond to redshifted wavelengths of 6780.55Åand 6895.89Å, which align with the range of the GMOS-N OVI filter [12, 13]. For the same observing conditions previously stated for the Hα measurement, replacing the i filter with the OVI filter, the S/N for an observation is 25.00 [8]. Thus, both the Hα sampling and the continuum sampling fall above the proper S/N ratio to identify and align peaks for reverberation mapping. These exposure times are extremely short, and with a total program time of 19 minutes and 9 seconds (overhead of setup = 360.0 s, telescope offset = 7 x 7.0 s assuming ABAB dithering pattern, exposure = 8 x 0.0 s, readout = 8 x 82.5 s, DHS Write = 8 x 10.0 s) per observing session, this is a feasible project to propose; measurements can be placed in short time slots with ease.

Local minima in the continuum and BLR can be separated by a few hundreds of days. With several samples desired along each peak, this proposal suggests a sampling frequency of approximately 4 days, as followed by other reverberation mapping projects such as Shen et. al 2023, Kinemuchi et. al 2020, and Peterson 1993 [3, 5, 10]. Nuñez et. al 2015 calculated a light travel time of 45.7 days to the edge of the dusty torus [4]. While this proposal does not suggest measurement intervals of more than a few days, this sets a hard upper limit on measurement cadence; if the light has reached the dusty torus, reverberation mapping information can no longer be collected from the BLR for that specific peak in the continuum. Therefore, all measurements should remain as close to a 4-day cadence as possible. These experimental choices will provide the best possible data to answer the proposed research question.