The Varying Light of AGNs in Dwarf Galaxies

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Scientific Justification *Be sure to include overall significance to astronomy. Limit text to three pages with figures, captions and references on no more than two additional pages.*

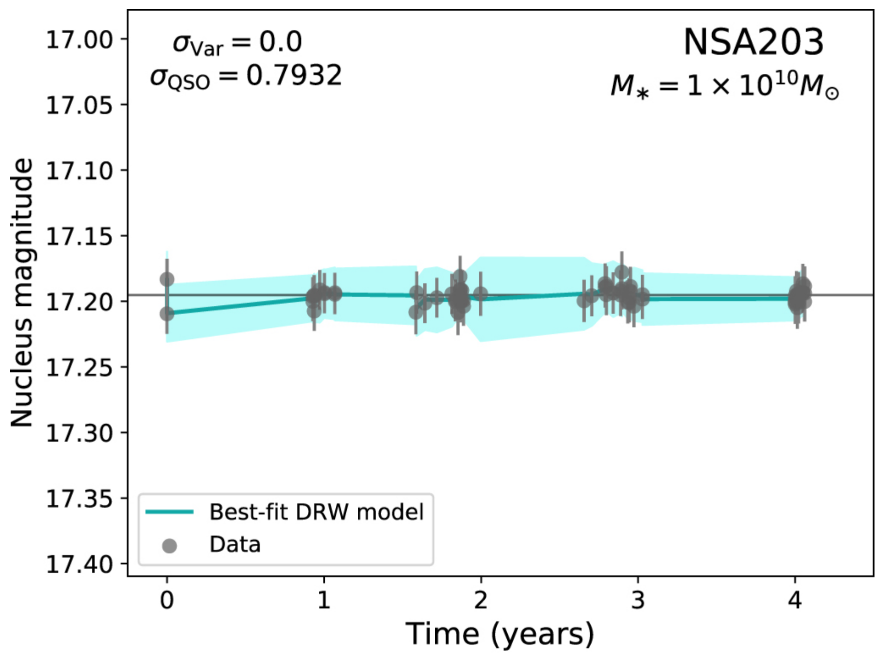
Most massive galaxies host supermassive black holes (BHs; Kormendy & Ho 2013), but their origins remain unknown. While the first generation of BHs, or BH "seeds", at high redshifts are difficult to observe, the massive BH population in nearby dwarf galaxies are within observational reach and can constrain BH seed properties, as their masses are close to their initial seed masses (Volonteri 2010). Therefore, the dwarf galaxy BH population can help constrain the masses and thus the formation paths of BH seeds (Greene et al. 2020).

However, detecting BHs in dwarf galaxies is difficult due to their lower masses and luminosities. Traditionally, optical searches often rely on narrow-line diagnostic diagrams (e.g., BPT diagrams; Baldwin et al. 1981), which are limited by the low metallicity, actively star-forming environments typical of dwarfs. Therefore, we must identify systems typically missed by other techniques. Previous work has shown that active galactic nuclei (AGN) vary at all wavelengths, and identifying quasars via optical variability has been a useful tool (e.g. Geha et al. 2003). Thus, optical variability may be the most viable option to identify BHs in dwarfs with average to high star formation rates (SFRs).

Despite the extensive work on AGN variability, the origin of the variability remains uncertain. It is potentially due to the accretion disk experiencing thermal instabilities (Kelly et al. 2009). These variations tend to be aperiodic and irregular, with timescales ranging from hours to years. Based on their variable properties, AGN variability is distinguishable from other variable objects. To accurately characterize variability, multivisit surveys have been used (MacLeod et al. 2011). The observed variability depends on several parameters, including the baseline, cadence, and photometric accuracy. Figure 1 shows observed light curves that illustrate a non-variable galaxy and a variable galaxy (Baldassare, Geha & Greene 2020).

Fifteen nearby starburst dwarf galaxies are proposed for observations with GMOS on Gemini-N. Although SDSS spectra already exists for these dwarfs, there has yet to be confirmation of an AGN in any of these BH candidates. An analysis of SDSS spectra shows that eight out of the fifteen dwarfs exhibits [Fe X] and/or Si II, six with no [Fe X] and/or Si II, and one with only [Fe X]. Molina et al. (2021b) showed that coronal line [Fe X] can be used as a selection method to identify BHs in dwarf galaxies. However, recent analysis on one of their sources raised doubts about the [Fe X] selection method due to the presence of a Si II doublet, which can blend with [Fe X]. Determining the presence of a BH via optical variability can help support or refute the [Fe X] selection method. Additionally, AGN confirmation will allow us to correlate the properties of galaxies with and without the presence of an AGN. Observing the variability can also help put constraints on the occupation fraction (i.e., the fraction of galaxies with BHs) for dwarfs. These observations will shed light on the nature of dwarf galaxies and the black holes that reside within them.

References: Baldassare V. F., Geha M., Greene J., 2018, ApJ, 868, 152 • Baldassare, Geha & Greene 2020, ApJ, 896, 10 • Baldwin et al. 1981, PASP, 93, 5 • Butler, N. R., & Bloom, J. S. 2011, AJ, 141, 93 • Geha et al. 2003, AJ, 125, 1 • Greene et al. 2020, ARA&A, 58, 257 • Kelly et al. 2009, ApJ, 698, 895 • Kormendy & Ho 2013, ARA&A, 33, 581 • MacLeod et al. 2011, ApJ, 728, 26 • Magorrian, J., Tremaine, S., Richstone, D., et al. 1998, AJ, 115, 2285 • Molina et al. 2021a, ApJ, 910, 5 • Molina et al. 2021b, ApJ, 922, 155 • Reefe et al. 2023, ApJ, 946, 38 • Volonteri 2010, A&ARev., 18, 279



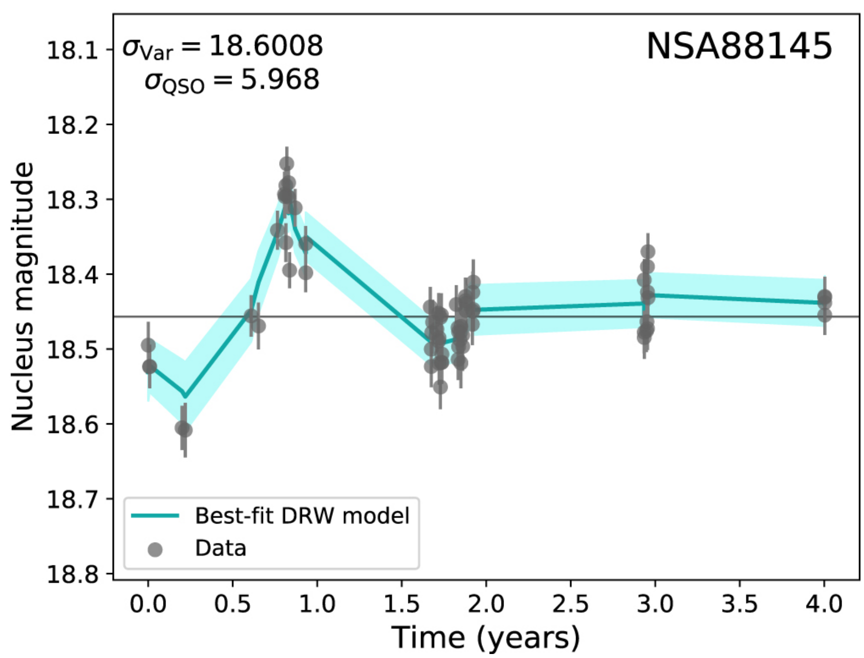


Figure 1: Light curves for a non-variable galaxy and a variable galaxy from Baldassare, Geha & Greene (2020). The measured value of the nucleus magnitude is in gray. Both curves contain 70 data points and span 4 years.

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

The proposed dwarf galaxies have been selected because of their locations on the sky, g-band magnitude, and whether or not they have [Fe X] and/or Si II. This information is compiled in Table 1. With GMOS-N observations, we aim to answer:

1. Do these galaxies host BHs?

While some BH detection methods have been used on this data set (e.g., Molina et al. 2021a, Reefe et al. 2023), we will perform a complete, systematic search for AGNs in these dwarf galaxies. This will be done by obtaining g-band imaging data once every 6 months over the course of 4 years to construct light curves for each of the 15 galaxies. To identify a dwarf AGN, we expect to see a median 1σ variability of 0.05 mag (e.g. Baldassare et al. 2018). We will also calculate the signficance that the source is variable and the significance the source variability is not AGN-like to determine if the variability is characteristic of an AGN and not another variable object using the software QSO_fit (Butler and Bloom 2011).

2. How does an AGN affect the properties of it's host galaxy?

Building from (1), we will study the host galaxy's stellar mass and SFR for dwarfs with and without AGNs. By studying the distribution of stellar mass for each galaxy, we can determine if galaxies with AGN tend to have higher stellar mass or not. Additionally, we will use a narrow-line diagnostic diagram ([O III]/Hβ vs. [N II]/Hα), which will allow us to see if our galaxies live in the AGN region or star-forming region of the diagram, adding reliability to our results. To determine how the presence of an AGN affects SFR, we will correlate which objects have a variability-selected AGN to dwarfs with potential Si II emission, since Si II is likely a result of star formation. Furthermore, using the sample of variable-selected AGN, we will identify which galaxies host an AGN and exhibit a potential [Fe X] emission line, which will help future [Fe X] searches.

3. What is the occupation fraction of dwarf galaxies?

To study the fraction of galaxies that host BHs, we will plot the variable AGN fraction of our sample vs. stellar mass to see if there is any relationship. If a decline in the fraction of variable AGNs with decreasing stellar mass is observed, then a potential explanation of this could be that there is a lower BH occupation fraction for low-mass galaxies. This could be significant as massive galaxies have an occupation of essentially 100% (Magorrian et al. 1998), while the occupation fraction for low-mass galaxies is still unclear. This test would help put constraints on the occupation fraction for dwarf galaxies.

Table 1: Target Dwarf Galaxy Properties

RA	Dec	m_g	[Fe X]/Si II
196.13445	-3.5561452	17.31	Either or both
137.15227	5.2908196	18.14	Neither
161.2408	3.886987	17.51	Either or both
177.88725	-2.372798	16.82	Either or both
214.71303	21.044373	17.53	Either or both
146.0078	-0.64227164	15.84	Either or both
158.07864	27.664661	15.60	Neither
147.47559	0.61629295	15.83	Either or both
178.15698	-2.468442	15.63	Either or both
193.71278	2.6541026	14.99	Neither
147.81995	7.83001	14.57	Neither
149.19186	28.828827	14.64	Neither
194.6675	14.216886	16.19	Neither
251.79443	21.087364	17.05	Either or both
193.27489	-3.21634	15.23	[Fe X] Only

Technical Description *The Management plan should describe the overall plan for conducting the proposed survey. Be sure to include: 1) Approach: Discuss the organizational plan to execute the tasks required to complete the research goals and delivery of the data products. Include plans to support the observing runs, the pipeline processing plan, data reduction and analysis, archiving plan, data dissemination plan, and coordination of the survey with non-NOIRLab facilities or data sources. 2) Personnel requirements: Discuss the roles of the survey team members in an anonymized way. Anticipated levels of participation for individuals should be discussed in the Team Information and Relevant Background attachment. 3) You may include an anonymized description of institutional/other support Additional information can be presented in the Team Information and Relevant Background attachment. Limit text to one page.*

The goal of this proposed observing run is to accurately measure the variability in the nuclei of 15 nearby dwarf galaxies. Since we are measuring optical variability, images will be taken in the g-band. The apparent g-band magnitudes range from 14.57 to 18.14, with an average magnitude of m_g=16.26. Given that, and the minimum noise needed to observe a 1σ variability of 0.05 mag, this indicates an SNR of 325.2 for each object. This allows us to obtain an exposure time of 18 sec. With the setup time for the imaging instrument being 360 sec, the readout time being 35.4 sec, and the write time being 10 sec, this translates to an average 7 minutes per target, and 105 minutes total for 1 exposure of each target. However, to detect variability, we plan to take an image of each object once every 6 months, for 4 years. Previous work has shown that the fraction of AGN detected is highly dependent on the measurement baseline, with fractions for baselines less than two years being $\sim$ 0.25%, while the fraction for baselines longer than two years is $\sim$ 1%. Additionally, previous samples used to study AGN variability span 4 years (Baldassare, Geha & Greene 2020). The 6 month cadence is chosen as a minimal requirement necessary to obtain enough data points to measure the AGN variability, as well as providing flexibility. Therefore, it will take 8 nights over the course of 4 years to construct a light curves for our BH candidates. This totals to a request time of 14 hours. This project only requires quick optical imaging, making Gemini-N the ideal telescope.

Release of Data *Describe the data products (reduced observations, single or stacked images, spectra, object catalogs, and so on) to be released, as well as the timeline and mechanism of their release to the community. Please differentiate between intermediate products developed during the execution of the survey versus the final products likely to be produced after the full observations have been obtained. Limit text to one page*

— Enter your release of data information