PI Information

Paulina Lira, plira@das.uchile.cl, Universidad de Chile, Faculty member

co-Is Information

Paula Sanchez-Saez, pasanchezsaez@gmail.com, PUC, Chile
Shai Kaspi, shaik@tauex.tau.ac.il, Wise Observatory, Israel
Franz Bauer, fbauer@astro.puc.cl, PUC, Chile
Igor Chilingarian, Igor.Chilingarian@cfa.harvard.edu, Harvard, USA
Xiao-Bo Dong, xbdong@ynao.ac.cn, YNAO, China
Paula Caceres, paula.caceres.burgos@gmail.com, UChile, Chile

Title

Establishing the ubiquitousness of short-time scale variability in dwarf accreting Black Holes

Abstract

We propose to obtain high cadence nuclear light curves for a sample of eight galaxies which host AGN with bona-fide dwarf BHs. These observations will determine the ubiquitousness of short-time scale variability in this type of source and help to constrain the completeness of the current searches for dwarf BHs, and potentially the seeds of Super Massive BHs, through variability.

Telescope, Instrument

SMARTS 1.0m, Apogge F42 Camera

Time requested, Preferred dates, Moon

total = 6 nights (50 hours); min = 2 nights (16 hours); preferred date = early Nov; moon = gray-dark

SCIENTIFIC AIM AND RATIONALE

Small mass Black Holes (BHs) are expected to reside in small galaxies that have not suffered a significant history of interactions and stellar growth, leaving their central black holes in a state close to that of their formation. Since there is great uncertainty about what constituted the seeds of the Supermassive BHs observed in giant galaxies, it is therefore of great importance to determine the demographics of these dwarf BHs, as this can help to distinguish between the competitive scenarios for SMBH seed formation (see Figure 5 in Greene et al. 2019).

Variability is a ubiquitous characteristic of accreting BHs. Although it is still not clear what drives this variability, plenty of cases show that flux variations observed at optical wavelengths are driven by the reprocessing of much faster variations produced in the far UV or X-rays (Arevalo et al. 2008, Breedt et al. 2009, Lira et al. 2011, 2015, Shappee et al. 2014, McHardy et al. 2014, Edelson et al. 2015, Fausnaugh et al. 2016, 2018, Troyer et al. 2016, Gallo et al. 2018). Hence, the fastest time-scale of optical variability is given by those variations that are not smeared out by the light-travel time that takes for the central variable signal to reach those regions where the reprocessing takes place. Hence, smaller BHs, with their smaller disks, are characterized by shorter time scale variations than their more massive peers.

NGC4395, regarded as a prototype dwarf AGN, was first discovered to vary by Lira et al. (1999), and later monitored throughout the electromagnetic spectrum (Iwasawa et al. 2000, Shih et al. 2003, Vaughan et al. 2005, Skelton et al. 2005, Minezaki et al., 2006, Desroches et al. 2006, Cameron et al. 2011, King et al. 2013, den Brok et al. 2015, McHardy et al. 2016). Figure 1, left, shows the optical monitoring by Edri et al. (2012) obtained with the 1m Wise telescope in Israel. The monitoring lasted nine nights and shows persisting variability on time scales of hours. Short time scales are indeed expected given the small size of the accretion disk in this source. For example, assuming a Shakura-Sunyaev accretion disk structure a relation between the accretion disk temperature T at a certain radius R is given by $T^4 = 1.6 \times 10^{23} \frac{\dot{m}}{M_8} \frac{1}{r^3}$ K^4, where $\dot{m}$ is the accretion rate in Eddington units, M_8 is the BH mass in units of $10^8 M_\odot$, and $r = R/R_{\rm Sch}$ is the reduced radius, with $R_{\rm Sch}$ the Schwarzschild radius. We can relate T to a characteristic wavelength using the Wien displacement law. For NGC4395 we have that $\dot{m} \sim M_8 \sim 10^{-3}$ and $R_{\rm Sch} \sim 3 \times 10^5$ km. Observing at 5000Å corresponds to a temperature of 6000 K in the accretion disk, and we find that $R \sim 5 \times 10^2$ light-seconds. This back of the envelope calculation shows that variability faster that $2 \times R \sim 0.3$ hours should not be observed, which matches well the observations (see Figure 1). On the other hand, for a very massive ($10^9 M_\odot$) BH accreting at 10% its Eddington limit, the shortest time scale for variability is ~ 10 days!

We have used the prediction that small BHs should show fast variability to search for such objects. In Martinez-Palomera et al. (2020) we found candidate dwarf BHs by obtaining high cadence light-curves of the nuclei of galaxies and looked for variable sources. We showed that this method is about 40 times more efficient selecting low mass BHs than spectroscopic searches like those conducted by Dong et al. (2012) and Chilingarian et al. (2018) using the SDSS database. Still, only 1/25 galaxies showed such variability. Are these all the accreting dwarf BHs found in this sample? This question is of great significance if we want to constrain the occupation numbers of BH seeds. A significant fraction of the non-variable nuclei could be explained because they host massive BHs, which do not show variability in time-scale of hours, and/or because their BHs are not active, but we can factor in these scenarios using models and observational constraints. But the lack of detected variability could be real, meaning not all small accreting BHs vary, or that our observations were not sensitive enough to detect their variability.

We want to determine whether fast variability is a ubiquotous characteristic of low mass BHs by

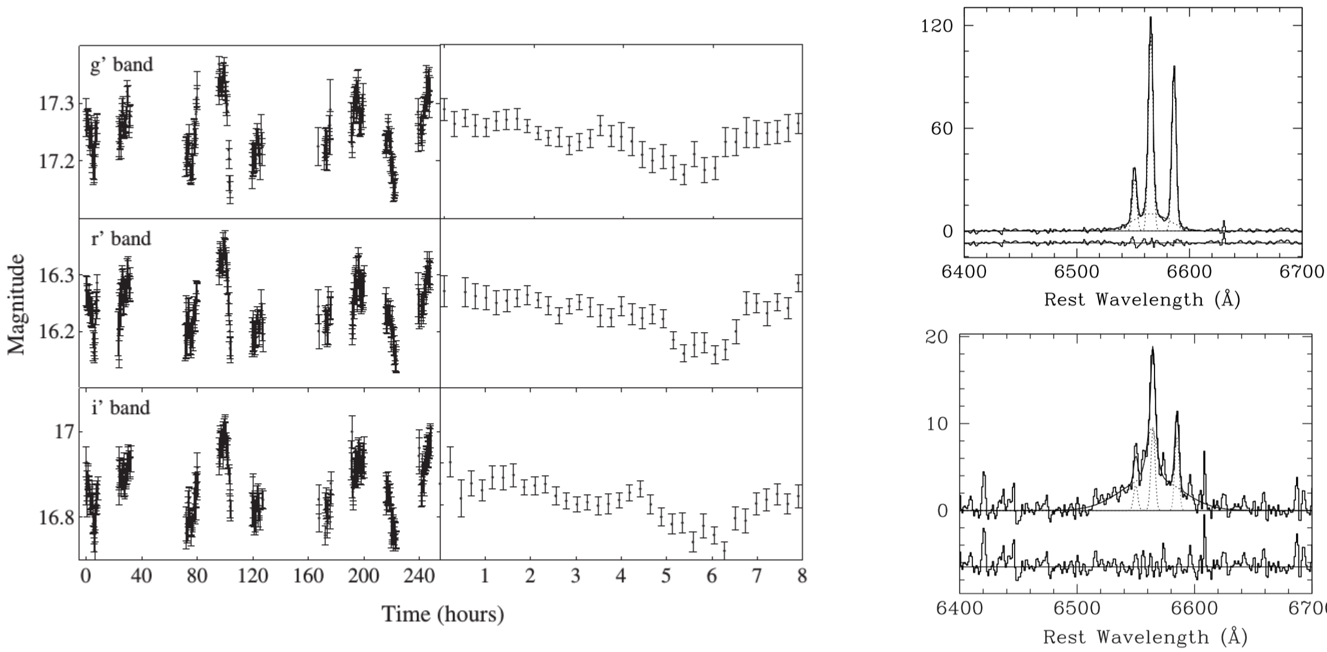

Figure 1: **Left:** light curves of the prototype dwarf AGN NGC4395 obtained with a 1m telescope by Edri et al. (2012). The left panel shows all nine nights of monitoring while the right panel shows the detail light curve corresponding to the first night. **Right:** two example of the secure detection of broad components in the Hα emission line of galaxies reported by Green & Ho (2007).

conducting a new controlled study. We have selected bona-fide accreting BHs with masses below $\sim 10^6 M_\odot$ (the limit between the so called Super Massive and Intermediate Mass regimes) from the samples of Greene & Ho (2007), Dong et al. (2012) and Chilingarian et al. (2018). These works searched for broad but weak components to Balmer lines, a trademark of AGN activity – see Figure 1, right. The presence of broad components in objects drawn from the Chilingarian sample was carefully assesed by eye since this survey aims at the detection of particularly low mass systems, whose signature is particularly difficult to detect at high significance. Our selection of bright southern sources selected from these 3 works gave a total sample of 23 objects, most of them observable during an A semestre, with eight with good observability in a semestre B.

As a pilot program, we obtained nuclear photometry for two objects from the Greene & Ho (2007) using the Wise 1m telescope under bad weather conditions. The results are encouraging. Both of them showed episodes of variability during the observations of ~ 4.5 hours (Figure 3). 2/2 seems like a confirmation that all accreting low-mass BHs show short-term variability. However, this could be a fortuitous result. Moreover, while one of the objects shows variability throughout the observations, the second one seems to have a quiet period. Is this real or just a result of the poor data quality? Is the presence of variability dependent on BH mass or accretion rate? We might be able to put some constraints on this.

In summary, using a total sample of ~ 20 galaxies (2 observed already, eight proposed here, another ~ 10 for semester A) hosting BHs in the $M_{BH} \sim 10^{5-6} M_\odot$ range we would like to test whether all these sources present variability in a time scale of few hours, expected for BHs of this mass. The results will help us to greatly constrain the completness in variability selected dwarf AGN, and therefore the occupation numbers of dwarf BHs. Our selection of bright sources will ensure that our choice of telescope will be suitable to obtain enough S/N and cadence to probe these objects with great detail. It is importante to notice that no current time domain survey images the sky at the cadence required by our study and hence we need to obtain our own custom observations.

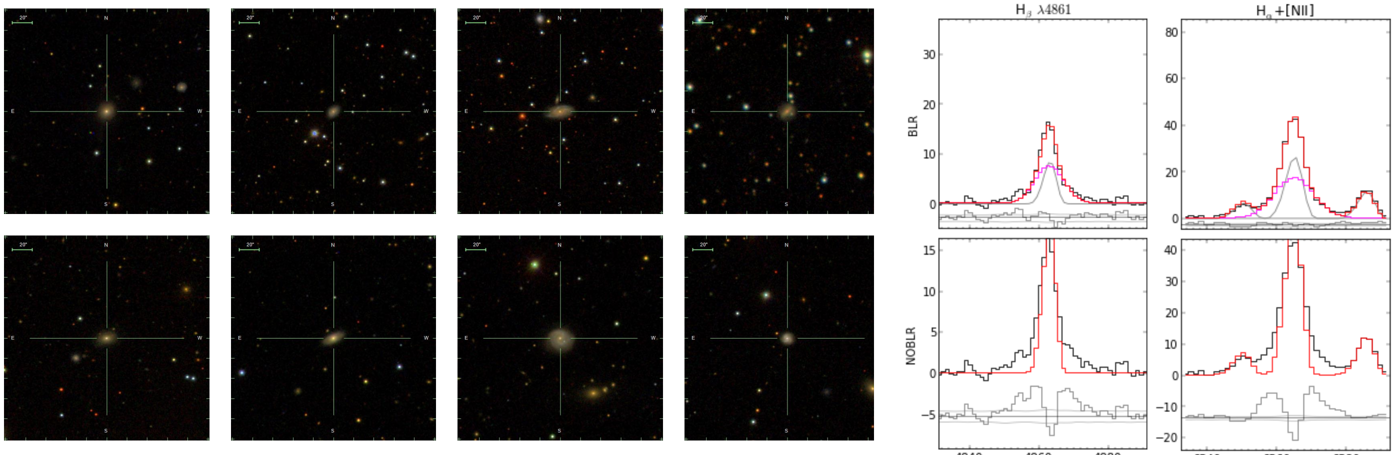

Figure 2: **Left:** RGB composite SDSS images of some of our proposed targets and **Right:** detail of the fits to the Hα and Hβ emission lines for our source J022849 (top panels with a broad component and bottom panel without a broad component). The fits suggest a BH of mass $2 \times 10^5 M_\odot$ in this nucleus (Chilingarian, private communication).

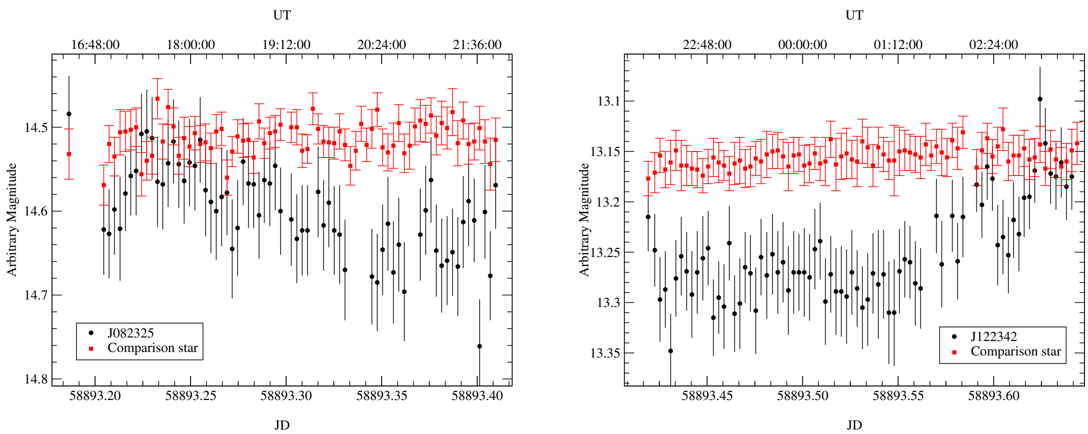

Figure 3: Nuclear light curves for J082325 and J122342 from the Greene & Ho (2007) sample, as observed with the 1m Wise telescope.

REFERENCES: Arevalo, P., et al., 2008, MNRAS, 389, 1479 • Cameron et al., 2012, MNRAS, 422, 902 • Cann et al., 2018, arXiv:1805.09351 • Chilingarian et al., 2018, ApJ, 863, 1 • den Brok et al., 2015, ApJ, 809, 101 • Desroches et al,2006, ApJ, 650, 88 • Dong et al., 2012, ApJ, 755, 167 • Edelson, R. et al., 2015, ApJ, 806, 129 • Edri et al., 2012, ApJ, 756, 73 • Fausnaugh, M. et al., 2016, ApJ, 821, 56 • Fausnaugh,2018, ApJ, 854, 107 • Forster et al., 2016, ApJ, 832, 155 • Gallo et al., 2018, MNRAS tmp • Giuricin et al., 2000, ApJ, 543, 178 • Green & Ho, 2007, ApJ, 670, 92 • Greene, Strader & Ho, 2019, ARA&A, 2019arXiv191109678G • Iwasawa et al., 2000, MNRAS, 318, 879 • Koliopanos, et al., 2017, A&A, 601A, 20 • Koliopanos, 2018, PoS-SISSA, arXiv:1801.01095 • King et al., 2013, ApJ, 774, L25 • Lira et al., 1999, MNRAS, 305, 109 • Lira, P., et al., 2011, MNRAS 415 1290 • Lira, P., et al., 2015, MNRAS 454 368 • Martinez-Palomera, J., et al., 2020, ApJ, 889, 113 • McHardy et al., 2016, AN, 337, 500 • McHardy, I. et al., 2014, MNRAS, 444, 1469 • Minezaki et al.2006, ApJ, 643, L5 • O'Neill, et al., 2006, ApJ, 645, 160 • Peterson et al., 2005, ApJ, 632, 799 • Sanchez et al., 2017, ApJ, 849, 110 • Shappee, B.J., et al., 2014, ApJ, 788, 48 • Shih, et al., 2003, MNRAS, 341, 973 • Skelton, et al., 2005, MNRAS, 358, 781 • Troyer, J., et al., 2016, MNRAS, 456, 4040 • Vaughan, 2005, MNRAS, 356, 524

CURRENT STATUS OF THE PROJECT

In recent semesters we have had three successful proposals on the subject of variability in dwarf AGN.

CN2020A-78 was awarded with 1 night on the Baade Magellan telescope to follow up variability selected dwarf AGN. The goal was to determine whether they present broad components to their Balmer lines. However, most of the night was lost to telescope failure.

CN2019B-69 was awarded 2 nights on the Blanco telescope to obtain fast cadence observations of the galaxies in the Eridanus field in order to find nearby dwarf AGN selected by variability. The run was conducted in October 2019 with one night lost to weather. We are currently processing the good data using the LSST pipeline installed in the Leftraru machine at the NLHPC.

2018B-2019A: we were awarded a total of 18 nights with the 0.9m telescope to obtain better sampled light curves for candidate dwarf AGNs selected from Martinez-Palomera et al. (2020). None of the data were useful because of the a string of bad seeing conditions which varied between $\sim 2-3$ arcseconds.

TECHNICAL DESCRIPTION

Figure 3 demonstrates the feasibility of our observations. We will use an identical size telescope located in a far superior site (CTIO vs Wise Observatory in Israel). Using the most efficient filter available will maximize light collection, so that integration times will be kept as short as possible, to obtain a cadence of at most 20 minutes between observations, depending on the presence of clouds, moon and the quality of the seeing. All targets selected from the Green & Ho and Dong samples have $m_g < 17$, while sources from the Chilingarian sample are fainter, at $m_g \sim 18 - 19$ and will require longer time integrations. Only one such target will be inluded this semester and its spectrum is shown in Figure 2. The camera mounted on 1.0 SMARTS telescope, with its fast readout, is perfectly suited for our goals.

We want to observe each target for most of a whole night. This will be possible if our run is scheduled at the beginning of November. Six of our sources are well suited for this observational strategy. If we are allocated a single run of six full nights (uncertain at this time), we have two sources that will be observable at the beginning and at the end of the night to avoid waisting telescope time. If we are allocated partial nights, those two sources are better suited for a more continous monitoring earlier and later in the semestre, respectively.

A long stare of $\sim$5 hours will give us the definite proof of variability as this is several times the expected time-scale for variability for this mass range. In the case of J082325 and J122342 it proved to be the correct strategy. Hence, we request a total of six nights with 1.0m SMARTS telescope, or 50 hours. Our minimum request is two nights or 16 hours.

We will calibrate our nuclear measurements against local stars available in the FoV. The size of the detector secures many comparison stars. To take into account the seeing variations, all images will be taken to a common PSF before using aperture photometry to isolate the nuclear flux, as it has been proven to be a robust and straight forward strategy (Arevalo et al. 2008, Lira et al. 2011, 2015). We do not require dark time, but bright conditions are not optimal to measure the low amplitude variability expected for our sources. Hence, gray or dark time is preferred.