# Searching for Short-Term Variable Active Galactic Nuclei: A Vital Step Towards Using AGN as Standard Candles

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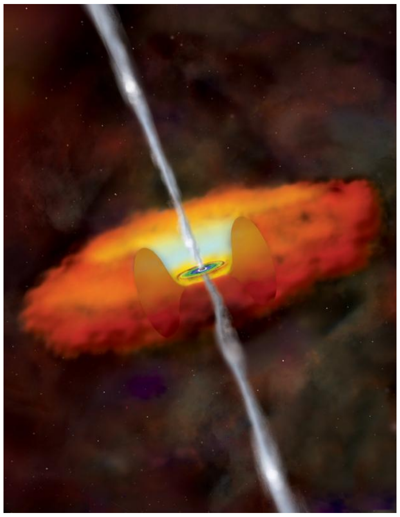
## 1. Abstract:

Current models for active galactic nuclei (AGN) accretion and physical size do not match the limited observational data available, so there is an active need from the modeling community for many more reverberation mapping campaigns with which to better calibrate models. Since short-term variable AGN can be more easily monitored for reverberation mapping than long-term variable AGN, they can begin to provide data more quickly. The goal of this project will be to find short-term variable AGN from the Young Stellar Object Variability (YSOVAR) survey conducted using the *Spitzer Space Telescope*. Potential AGN from the YSOVAR data will be selected first by color and then by magnitude. Since AGN share some similar color characteristics with young stars, images of each object will then be visually assessed for galaxy-like structure to further reduce the chance that the object is a foreground star. Then the spectral energy distribution (SED) for each potential AGN will be examined for AGN-like characteristics. By going through this process, the expectation is to find tens of previously unidentified AGN and isolate several that vary in brightness over time-scales of roughly less than a few weeks after inspecting their light curves.

## 2. Background:

Nearly every galaxy harbors a supermassive black hole at its center (Ferrarese and Merritt 2000, Gebhardt et al. 2000). Matter falling into the central supermassive black hole forms into a super-heated accretion disk, which gives off large amounts of radiation across the electromagnetic spectrum. Galaxies which have significant black hole accretion are called active galactic nuclei (AGN) and will show excess radiation compared to the radiation expected from a galaxy due to only stars and regions of dust and gas (Peterson, 1997). Of interest for this proposal, all AGN show an infrared excess as the UV/optical light from the accretion disk is absorbed and re-radiated by a lower temperature dust and gas torus surrounding the accretion disk.

AGN classification depends on how much material is actively accreting onto the black hole and on the angle from which it is viewed from Earth (see Figure 1). There are two main categories of AGN: quasars and Seyfert galaxies. Of these, the cores of quasars have the greatest energy output, outshining all of the stars in their host galaxies by two orders of magnitude. The cores of Seyfert galaxies are less luminous with an output that is roughly equal to all of the stars in the host galaxy. Both Seyferts and quasars are divided into two classes, Type I and Type II, according to the angle at which they are being viewed from the Earth. In a Type I AGN (quasar or Seyfert), the central black hole region with velocity-broadened emission lines can be seen, while a Type II AGN is tilted relative to the Earth and the central black hole with its accretion disk and broad lines is obscured by the dusty torus and so only narrow emission lines can be seen.



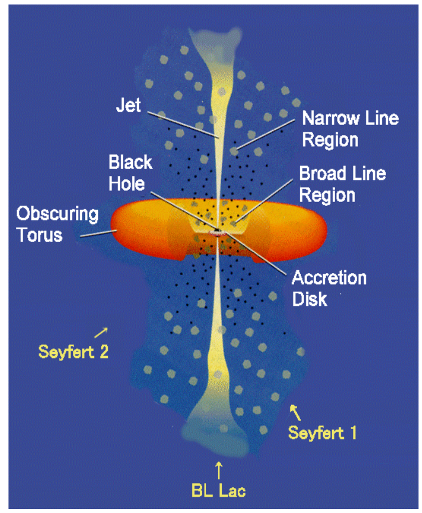



*Figure 1. (Left image) Artist's depiction of the region surrounding a supermassive black hole which is actively accreting. (Right image) Whether an AGN is classified as a Seyfert or quasar depends upon the amount of infalling material. The Type I or Type II designation is based on the angle from which the galaxy is viewed from the Earth.* (Urry & Padovani, 1995)

Of particular interest, AGN vary in their outputs across much of the electromagnetic spectrum. Since matter accretion onto a black hole does not occur at a steady rate, spikes in the amount of radiation observed from an AGN will occur as large clumps of matter fall into the accretion disk. These variations occur over spans of months down to a few days and that variability appears to follow no predictable pattern (Peterson, 1997). This radiation spike will first be observed primarily in the ultraviolet from the inner accretion disk itself. The resulting wave of radiation travels outward into the surrounding regions (outer accretion disk, broad-line region (BLR), dusty torus) where it is absorbed and re-emitted at longer wavelengths. By observing the time delay ($\Delta t$) between the initial and secondary spikes, and by calculating the distance that light traveled in that time, ($c\Delta t$ where c is the speed of light), reverberation mapping can give the physical separation of features around the supermassive black hole (Blandford & McKee, 1982)

Making reverberation measurements (beyond the scope of this project) requires fast cadence observations to ensure that changes in the light curves are not missed between observing epochs. AGN which exhibit variations over shorter than average time scales would make the required observations easier to obtain. Currently, only a few AGN have been sufficiently observed to allow for reverberation mapping to be done on them, in particular to get the scale of separation between the accretion disk and the dusty torus (Koshida, et al., 2014). The handful of well-mapped AGN do not allow for significant calibration of models of the inner region of AGN. However, with better models, it may be possible to find a correlation between the size of the AGN and its luminosity, thus making it suitable as a standard candle even at extreme distances. Having a list of AGN targets for short-duration reverberation mapping measurements would be a significant step towards furthering the field's understanding of AGN and the eventual goal of using AGN as well-calibrated distance indicators.

Currently, the best calibrated method for obtaining distance measurements to the furthest objects comes from observations of Type Ia supernovae (SNe Ia). This method has a significant distance limitation however since SNe Ia can only be observed to a redshift of roughly z=0.3 (Branch & Tammann, 1992). It has already been shown that reverberation mapping holds some promise for using AGN for measuring distances up to redshifts of roughly z∼4 (Watson, Denney, Vestergaard, & Davis, 2011) based on the time delay between the light from the accretion disk and the subsequent absorption and re-emission of the light from the BLR where the distance of the BLR changes based on the luminosity of the source. Additionally, a distance measure that makes use of AGN has the potential to be used to redshifts of about z∼9 as certain types of AGN are some of the farthest observable objects in the universe (Zitrin, et al., 2015). The new proposed work will provide many new targets that can, after monitoring, be used to provide a better calibration of the time-delay/BLR/luminosity relationship noted above as well as further input into models of accretion which could lead to greatly improving the distance measures to the farthest objects in the universe. These new distance measurements could ultimately lead to significant improvements on the best known value for the Hubble constant and our understanding of the rate of acceleration of the universe.

**3. Selection Steps and Methodology**

AGN can be identified from data collected in narrow or broadband IR space-based surveys based on their IR excess, but these surveys have not been designed to monitor for variability. On the other hand, there are surveys that concentrate on the variability of other objects in the IR, such as young stars (e.g. the YSOVAR survey). While the YSOVAR observations were focused on galactic sources, they also pick up extra-galactic sources in the background.

Although analysis of an object's spectrum is the ideal way to distinguish AGN from other objects with infrared excess, such as starburst galaxies and young stars with dusty disks, color-color plots in the mid-infrared have shown regions of AGN concentration, allowing for preliminary AGN distinction without spectra. For this effort, objects will be selected from the YSOVAR survey that fall within the trapezoidal area on a color-color plot of [3.6]-[4.5] versus [5.8]-[8.0] (all wavelengths in µm) that Stern et al. (2005) found to be dominated by broad line (Type I) AGN (see Figure 2). Only objects with a reliable measurement in all four of the relevant wavelength bands will be used. The YSOVAR survey has a slightly shallower depth than the survey that the Stern et al. (2005) results are based on (known as the IRAC Shallow Survey (Eisenhardt et al. 2004)). The IRAC Shallow Survey had 90 sec exposures and YSOVAR had 54 sec exposures, however they are sufficiently comparable to use for this selection technique.

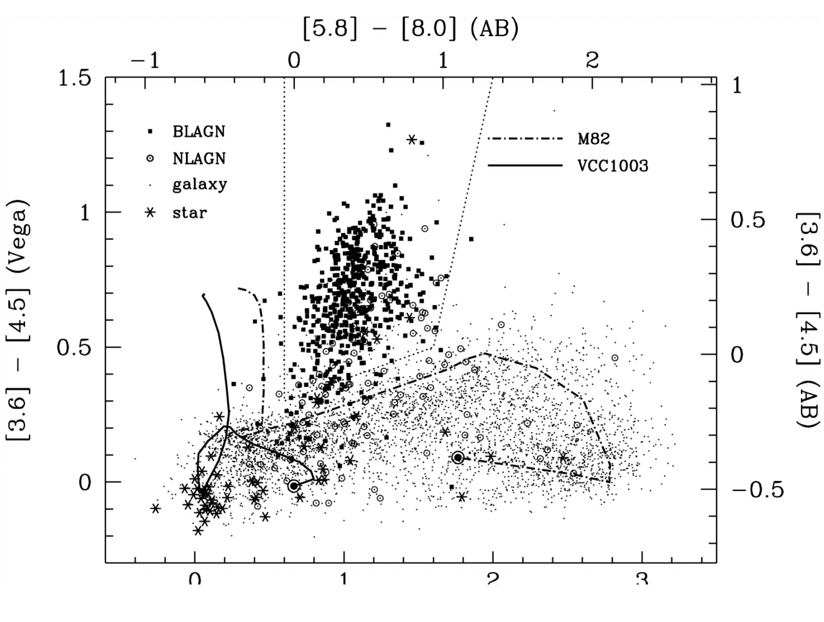



*Figure 2. Color-color plot of objects in the IRAC Shallow Survey , a wide-field survey in the Boötes field. The trapezoidal area defined by the dotted line in the upper center shows a region with a high concentration of broad line AGN. (Stern, et al., 2005) Both AB and Vega*

*magnitude calibrations are provided.*

After selection based on color, objects will be further culled by magnitude in the 3.6 µm band. Based on the objects in the Spitzer Enhanced Imaging Products (SEIP) catalog[1] with reliable 3.6 µm band magnitudes a bimodal distribution was found for object magnitudes (Strasburger, et al., 2015) (Figure 3). Objects in the brighter part of the distribution are almost entirely of Galactic origin while those in the dimmer part of the distribution are extragalactic. The region between the two lobes includes substantial overlap of the tails of both modes and possibly a unique lobe peaking near a magnitude of 12. In the interest of being conservative, only objects with magnitudes higher than (dimmer than) 13 will be examined further. The four YSOVAR survey regions (GGD 12-15 (Wolk, et al., 2015) IRAS 20050+2720 (Poppenhaeger, et al., 2015) L1688 (Gunther, et al., 2014), and NGC 1333 (Rebull, et al., 2015) contain 8,942 unique objects. Preliminary analysis shows that after cuts based on color and magnitude, as described above, there are 170 potential AGN within these fields which warrant further investigation.

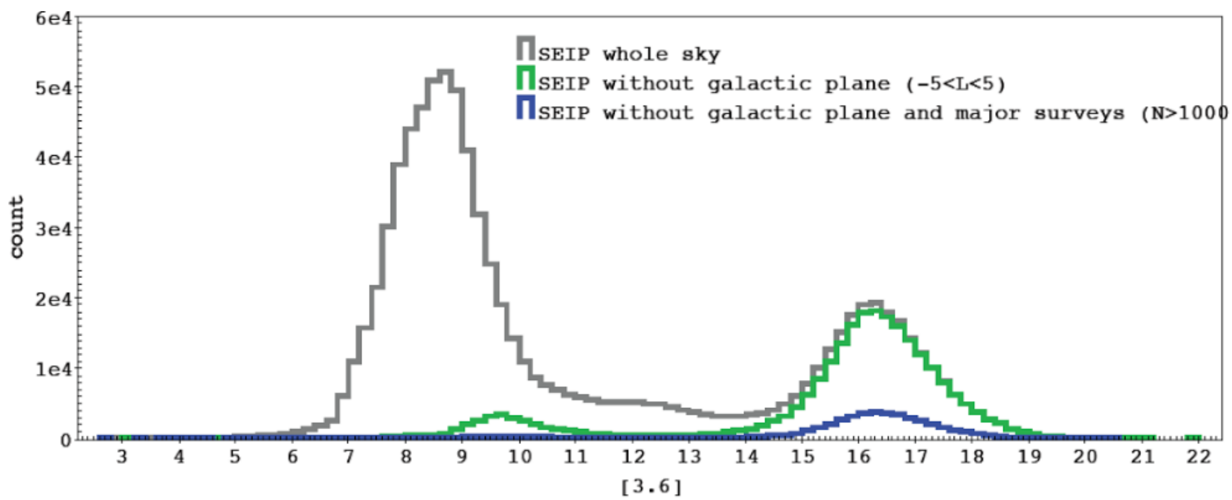



*Figure 3. The 3.6-micron magnitudes of objects in the SEIP which exhibits a bimodal distribution. Objects in the larger mode at left are primarily galactic while those in the smaller mode at right (magnitudes greater than about 13) are mostly extragalactic.* (Strasburger, et al., 2015)

Once objects are selected as potential AGN based on color and magnitude, images of each object will be examined at 2 µm from the 2-Micron All Sky Survey (2MASS). Objects should display visual characteristics of galaxy-like structure as opposed to appearing as point sources or point sources with some nebulosity, either of which would likely indicate that the object is a star. Also each object's SED (Spectral Energy Distribution) will be analyzed to look for characteristic AGN qualities such as a shorter wavelength peak in the infrared. If both the images and SED indicate that the object is in fact a galaxy, we will then look at the [3.6] and [4.5] wavelength light curves for the object. Since the YSOVAR survey was looking for young stars, which typically vary over much shorter time scales than AGN, the observational cadence was faster (4 – 16 hours) and was conducted over a shorter amount of time (35 – 40 days) than would typically be employed for measuring AGN variability. Therefore, this project will be biased in favor of finding Type I AGN that show variability over the time scale of a few weeks.

[1] The SEIP is a catalog of all point sources detected during the *Spitzer Space Telescope* cold mission which lasted 5.75 years

**4. Expected Outcomes:**

Using the culling methods described above, we expect to find tens of AGN within the YSOVAR survey. From these, we hope to find several AGN which vary on time-scales of roughly less than 40 days (the typical span of the YSOVAR survey). These would be ideal candidates for the follow-up observations required for reverberation mapping.

**5. Archived Data:**

We will be searching for short-term variable AGN within the Young Stellar Object Variability (YSOVAR) survey conducted by the *Spitzer Space Telescope*. We will be making use of the measured magnitudes in the [3.6], [4.5], [5.8], and [8.0] wavelength bands, light curve data in the [3.6] and [4.5] bands, and SEDs. We will also use 2.0 µm band images from 2MASS.

**6. Education/Outreach:**

Thomas Rutherford:

- Presentation at the National NSTA meeting in Nashville, Tennessee in March 2016 about science research in the classroom. It will not be exclusively about NITARP, but the NITARP program will be a centerpiece of the talk.
- Presentation of a talk at the 2017 NSTA meeting in Los Angeles about the NITARP program.
- Presentation at the 2017 NSTA meeting in Los Angeles about science research in high school—once again, though not the focus, the NITARP program will be discussed.
- Poster presentation at the 2017 AAS meeting in Dallas, Texas
- Talks at two local astronomy clubs about the NITARP program and about the current AGN project.
- Presentation before the students at two local universities. At East Tennessee State University, the talk will be given before the students at the weekly Physics seminar. At King University, a talk will be given to the astronomy class.
- Presentations to the staff at district-wide staff development sessions. An invitation will be extended to the local school systems to see if there is any interest in a presentation about the project before their staff and/or students.
- The students will present the project before the school board at one of the monthly board meetings.
- Interviews with local media outlets, such as newspapers and television stations about science research in general and the NITARP program in particular.

Kelly Kilts:

- Be an advisor for students interested in astronomy projects for the science fair by helping them pursue projects using archival data.
- Offer two workshops in district: one with a content focus aimed at teachers in younger grades, and a second to talk about my experiences in the program and opportunities arising primarily aimed at secondary teachers.

- Present at the local astronomy / telescope makers club about working with archival data, being a mentor for students, and opportunities to share that work.
- Contribute to poster presentation at the 2017 AAS meeting in Dallas, Texas
- Presentation at department meeting about involving students in higher level research through the use of archival data.
- Will seek out presentation opportunities at local universities on how to be a mentor to high school students using previously acquired in the lab or publicly available archival data.

Russell Kohrs:

- **NITARP Education Poster:** Using my NITARP experience, I plan on creating and implementing a lesson, or unit, in my environmental science curriculum this fall that incorporates the color theory utilized to study AGN with environmental data. Specifically, I would like to have students gather NASA Earth Observation data from some instrument, or set of instruments, and help them learn to interpret the data in ways similar to how electromagnetic data is used in Astronomy. LANDSAT may provide a good place to start, particularly with the use of band color math, but other instruments may have raw data in a variety of wavelengths that could provide useful insights. In addition, the students whom I involved in NITARP will be using this experience for their research class at school. It will be interesting to compare their experiences and learning with that of other students using some set of variables.
- **NITARP Ambassador Plans:** This spring, I will have a chance to speak to one of our local Rotary Clubs about the NITARP program. Once our work is completed in January and I have local students involved, I anticipate even more interest from such groups. Thus, I expect that at least in part, I will be sharing about the NITARP experience with local civic and interest groups. In addition, I hope to provide some professional development to teachers in local school districts. Some unique opportunities exist for this, particularly because most of our local schools offer Astronomy courses. Encouraging teachers to involved their students in research in the classes, showing them where they can find archived data with which to work, and in providing starting points for that work, perhaps more students will become involved and inspired by the program.

Vincent Urbanowski:

- *Contextualization of mathematics.* Mathematics instruction suffers from the abstract presentation of concepts and problem solving algorithms. Simple “word problems” can provide context, but are often contrived and unsatisfying in an effort to connect the math with everyday experience. Authentic applications of math, even when not directly relevant to everyday experience, are vastly preferable because 1) students experience using math to do things that are not possible in any other way and 2) students are often interested in new topics. I am personally trying to develop project-based curriculum that hits all the math standards without “feeling” like a math course. This astronomy project deals with big and interesting questions, and provides solid applications of algebra, geometry, algebra 2 and supporting technologies such as advanced spreadsheet functionality and collaborative platforms.
- *Opportunities for students’ personal growth.* Students taking part in research have a rare opportunity to indulge interest, apply skills and challenge themselves to grow intellectually. Participating students can participate in AAS conferences and/or local science fairs with the same project.

- *Presentation/Professional Development with peers.* As a frequent presenter, I look forward to sharing the science and methodology at National Science Teachers Association (NSTA) conferences, and the math applications at National Council of Teachers of Mathematics (NCTM) conferences.
- *Lesson/activity development.* The big science we're learning here can be scaled down to hands-on activities with mathematical follow-on. For example, we can simulate color shifted imaging by acquiring images through arbitrarily-selected color filters and combining in RGB. We can simulate a spectral energy distribution by photographing a source through various color filters representing the bands of an astronomical SED, and making color-color plots.
- *Connecting with local astronomers.* There is a community of astronomers in my district. This project will provide opportunity for positive outreach.

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