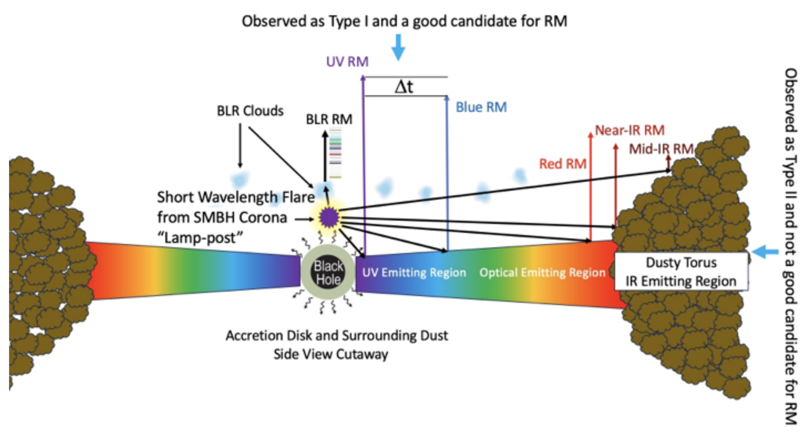
Using Spitzer Space Telescope data to catalog short-term variable AGN for determining the size of accretion disks.

Meredith Cullen[1], Varoujan Gorjian[2], Benjamin Senson[3], Lauren Albin[4], Kevin Molohon[5], Cooper Buchman[1], Khandro Butler[1], Emma Marmande[1], Allen Moore[1], Samuel Williams[1], Asyn Su[6]
[1] UMS-Wright Preparatory School, Mobile, Alabama
[2] JPL/Caltech, Pasadena, California
[3] Madison College and MMSD Planetarium, Madison, Wisconsin
[4] Young Harris College and O. Wayne Rollins Planetarium, Young Harris, Georgia
[5] Champlin Park High School, Champlin, Minnesota
[6] Asheville School, Asheville, North Carolina

ABSTRACT

Current theoretical modelling of the accretion disks around the supermassive black holes (SMBH) at the center of galaxies, known as active galactic nuclei (AGN), does not match well to that determined by observations. A way to measure the unresolved accretion disk size is through reverberation mapping (RM) of short timeframe variable AGN. Unfortunately, there is a very small sample size of candidate AGN with known short-term variability. These objects have short period emission events where variations in high energy light close to the SMBH travel outward and are absorbed at larger radii of the accretion disk and re-emitted at longer wavelengths. The time delay between initial detection of these short wavelength variations and their later detections at longer wavelengths provide a way to measure the span of the accretion disk. Measuring the size of the accretion disk can be used to derive its luminosity so the AGN can then be used as a standard candle. This in turn can be used to determine the Hubble constant over the vast distances over which the AGN can be observed. This project looked for short-term variable AGN that exist as background sources in the Young Stellar Object VARiability survey (YSOVAR) conducted by the Spitzer Space Telescope of multiple star forming regions. Potential AGN from multiple fields of YSOVAR data were first selected by color ([3.6]-[4.5]>0.4) and then by magnitude ($m_{3.6}$>14). 85 potential short-term variable AGN were identified. These sources have the potential to provide reliable candidates for the follow-up reverberation mapping to help determine the physical dimensions of the accretion region around a SMBH.

Figure 1: Using RM to map the accretion disc. Energy is emitted by a central source and absorbed by the accretion disc at varying radii. The wavelength of the light making its way to the observer represents the temperature profile of the disc: photons absorbed by nearby, hotter material are re-emitted at shorter wavelengths, and photons absorbed by more distant, cooler material are re-emitted at longer wavelengths. Re-emission from the dust occurs at IR wavelengths.



BACKGROUND

What are AGN?

Active Galactic Nuclei (AGN) are supermassive black holes (SMBH) found at the center of galaxies that can give off light from large amounts of in-falling gas that forms the accretion disk and loses gravitational potential energy. For the purposes of this research, we are interested in **short-term variable AGN** where short period flare events originating above the SMBH result in emission spikes detectable in the IR portion of the spectrum are re-emitted, resulting in six sigma variability in magnitude.

What is Reverberation Mapping?

Reverberation Mapping (RM) is a technique for determining the unresolved accretion disk size of variable AGN (e.g. Cackett, Bentz, Kara 2021). Following a flare event, spikes in the emission spectrum of an AGN can first be detected in the UV followed by longer wavelength, progressively time delayed signals from the optical to the IR as the signal travels from the hot inner region of the accretion disk to the edge of the dusty torus. Thus the reverberation of the flare event can be used to map the accretion region of the SMBH.

How are high confidence AGN identified for Infrared RM?

All AGN exhibit an IR excess as short wavelength light from the inner accretion disk is absorbed and re-emitted by dust in the torus. We can separate AGN from other objects in images by plotting them on a color-color diagram using the Vega magnitude system. Most AGN are found where [3.6] - [4.5] > 0.4, indicating an IR excess (Stern et al., 2005). Our goal to identify high-confidence short-term variable AGN for RM builds on the search conducted by Kilts et. al (2017) where a total of 26 short-term variable AGN were identified across the regions of GGD 12-15, IRAS 20050+2720, L1688, and NGC 1333. Similarly, looking in the background of archival images taken by the Spitzer Space Telescope for the Young Stellar Object Variability (YSOVAR) survey (Rebull et. al, 2015), our team searched for AGN in the regions of IC 1396, NGC 1333, GGD 12-15, L1688, IRAS 20050+2720, AFGL490, Cephc, Monr2, and Serpens Main.

METHODS

Potential AGN from multiple fields of YSOVAR data were first selected by color with well-defined magnitudes in 3.6 and 4.5 µm. Using this color-color plot as a guide, objects with [3.6]-[4.5]>0.4 were considered.

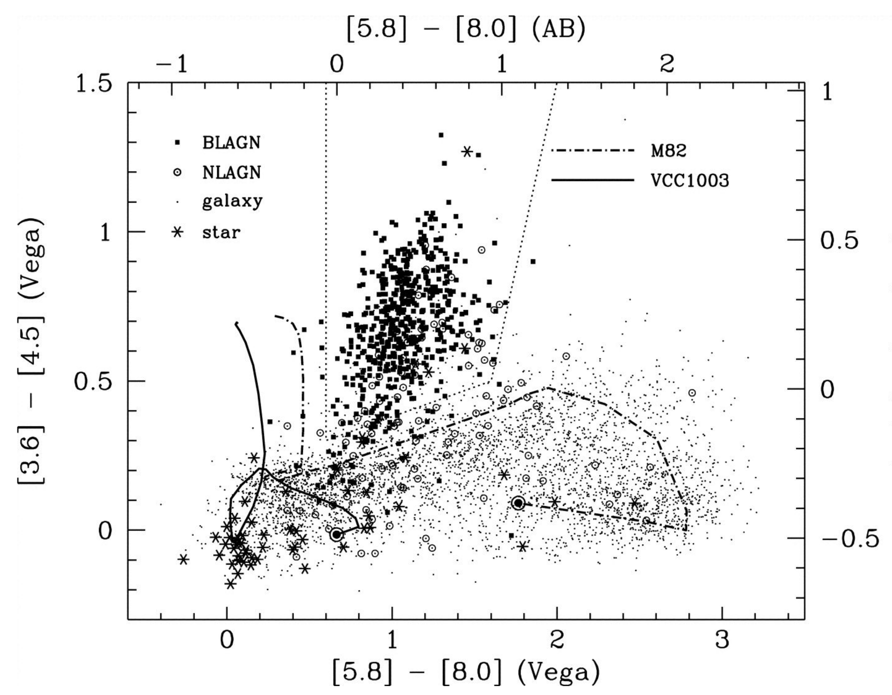
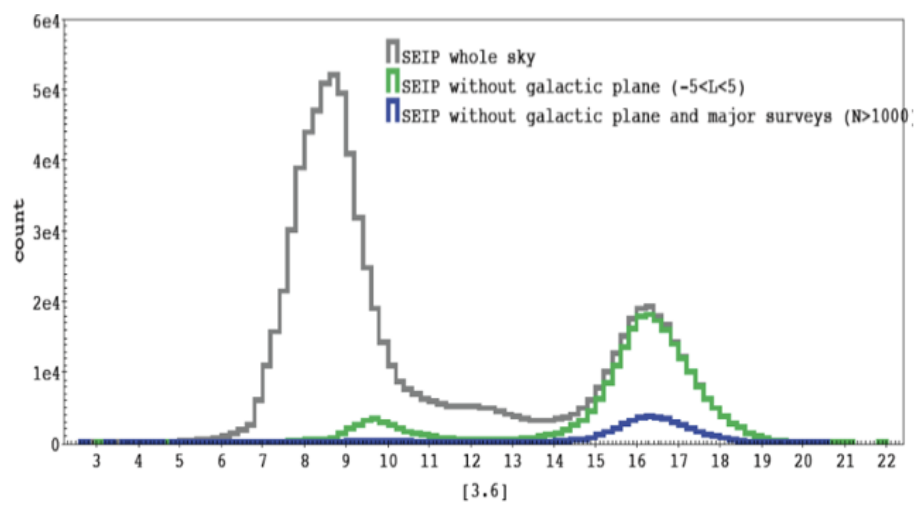


Figure 2: Color-color plot of objects in the IRAC Shallow Survey, a wide-field survey in the Bootes Field. The trapezoidal area defined by the dotted line in the upper center shows a region with a high concentration of broad line AGN. Both AB and Vega magnitudes shown (Stern, et al., 2005)

Figure 3: Using this bi-modal distribution of galactic and extra-galactic sources as a guide, objects with $m_{3.6}$>14, which are primarily extra-galactic, were considered. (Stasburger, et al.,2015)



RESULTS

Applying the AGN identification methods of Stern et al (2005) and Strasburger et al (2015) to the YSOVar catalog identified 692 high confidence AGN with multiple observations for each object within a 30 day period.

Analyzing the ratio of variation in magnitude to the standard deviation of the observations at both 3.6 and 4.5 microns produces our catalog of 20 high confidence, short-term variable Active Galactic Nuclei with variability at greater or equal to 6 sigma variability in both the 3.6 and 4.5 micron channels.

An additional 65 AGN were found to have greater or equal to 6 sigma variability in either the 3.6 or 4.5 micron channel.

A total of 85 high-confidence AGN with six sigma variability were identified.

Summary of High Confidence Short Period Variable AGN

YSOVar Region	Number of HC AGN with LC	Variability ≥ 2.000 6 σ Number in either 3.6 or 4.5 µ (both)
IC 1396	47	8(2)
NGC 1333	79	8(0)
GGD12-15	68	7(4)
L1688	71	8(0)
IRAS20050+2720	8	1(0)
AFGL490	159	5(1)
Cephc	101	36(13)
Monr2	47	1(0)
Serpens Main	112	11(0)
TOTALS	692	85(20)

References:

Cackett, Edward M.; Bentz, Misty C.; Kara, Erin, 2021, iScience, vol. 24, issue 6, p. 102557

Kilts, Kelly; Gorjian, Varoujan; Rutherford, Thomas; Kohrs, Russell; Urbanowski, Vincent; Bellusci, Nina; Horton, Savannah; Jones, Dana; Jones, Kaytlyn; Pawelski, Peter; Tranum, Haley; Zhang, Emily, 2017, American Astronomical Society, AAS Meeting #229, id.250.37

Rebull, L. M.; Cody, A. M.; Covey, K. R.; Günther, H. M.; Hillenbrand, L. A.; Plavchan, P.; Poppenhaeger, K.; Stauffer, J. R.; Wolk, S. J.; Gutermuth, R.; Morales-Calderón, M.; Song, I.; Barrado, D.; Bayo, A.; James, D.; Hora, J. L.; Vrba, F. J.; Alves de Oliveira, C.; Bouvier, J.; Carey, S. J.; Carpenter, J. M.; Favata, F.; Flaherty, K.; Forbrich, J.; Hernandez, J.; McCaughrean, M. J.; Megeath, S. T.; Micela, G.; Smith, H. A.; Terebey, S.; Turner, N.; Allen, L.; Ardila, D.; Bouy, H.; Guieu, S., 2014, AJ, 148, 92

Stern, Daniel; Eisenhardt, Peter; Gorjian, Varoujan; Kochanek, Christopher S.; Caldwell, Nelson; Eisenstein, Daniel; Brodwin, Mark; Brown, Michael J. I.; Cool, Richard; Dey, Arjun; Green, Paul; Jannuzi, Buell T.; Murray, Stephen S.; Pahre, Michael A.; Willner, S. P., 2005, ApJ, 631,163

Strasburger, David; Gorjian, Varoujan; Burke, Todd; Childs, Linda; Odden, Caroline; Tambara, Kevin; Abate, Antoinette; Akhtar, Nadir; Beach, Skyler; Bhojwani, Ishaan; Brown, Caden; Dear, AnnaMaria; Dumont, Theodore; Harden, Olivia; Joli-Coeur, Laurent; Nahirny, Rachel; Nakahira, Andie; Nix, Sabine; Orgul, Sarp; Parry, Johnny; Picken, John; Taylor, Isabel; Toner, Emre; Turner, Aspen; Xu, Jessica; Zhu, Emily, American Astronomical Society, AAS Meeting #225, id.336.26

We gratefully acknowledge funding via NASA Astrophysics Data Program funds and NASA/IPAC Archive Outreach funds.