OIRMA : Optical-Infrared Reverberation Mapping of AGN

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Abstract

Continuum reverberation mapping (CRM) can be used to measure physical distances in AGN accretion disks. CRM uses changes in short wavelength flux traveling away from the central region of an AGN's accretion disk. Time delays, proportional to the physical distance, occur when the flux from the central region is absorbed and re-emitted by the outer regions. Limited number of studies have been conducted to measure the continuum reverberation of Type 1 Seyfert galaxies due to a finite number of continuous observations in both the optical and infrared (IR). The goal of this project is to mine data from the Near Earth Objects Wide-field Infrared Survey Explorer (NEOWISE) and the Transiting Exoplanet Survey Satellite (TESS) which have spatial and temporal overlap. Once the areas with high temporal coverage are identified, we will use the CATWISE Catalog to identify potential AGN by infrared color selection and analyze their light curves at multiple wavelengths. The light curves will then be utilized to find the time delay between the reprocessed emission in the optical and in the infrared. The end goal is determining the distance between the optical emitting region and the infrared emitting region.

Background

Using the CatWISE2020 and NEOWISE-R catalogs, we identified potential AGN for continuum reverberation mapping.

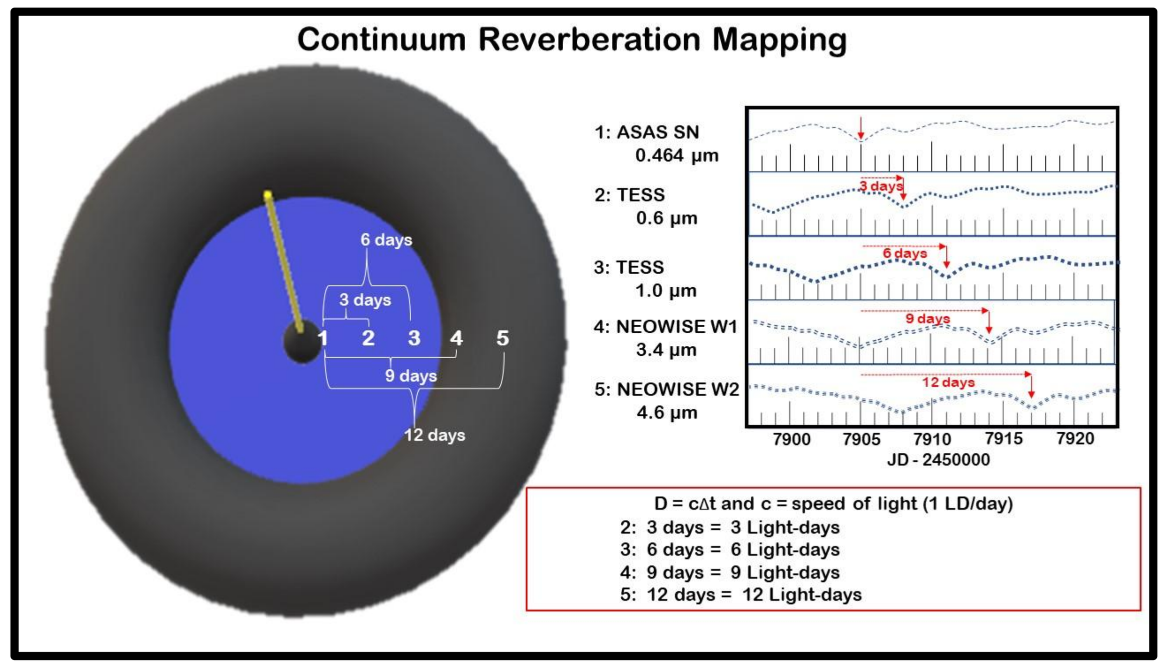


Figure 1: Continuum Reverberation Mapping (face on view) (N. Boys NITARP) -- Energy from very close to the black hole propagates outward and irradiates the accretion disc. As the energy is absorbed by the material in the disc and reradiated outward it traces the varying temperature profile of the accretion disc where the closer/hotter emission is re-emitted at shorter wavelengths and the further/cooler region reradiates at longer wavelengths. Ultraviolet wavelengths originate from positions near the center and IR wavelength from distant parts of the disk, or from the torus. Based on the delay (Δt) from a measured 0.464 µm wavelength to the 4.6 µm wavelength, we may determine the distance from the optical emitting region in the accretion disc to the infrared emitting region in the torus structure.

In the unified model of AGN, a central black hole is surrounded by a rotating accretion disc. The accretion disc is then surrounded by a thick, dusty doughnut-shaped torus, see Figure 1. (Peterson, 1997) The dust that constitutes the torus can only occur where temperatures are below the sublimation temperature of the dust. The inner radius of the torus thus depends on the temperature of the accretion disk.

Active galaxies are too distant for their central regions to be resolved, so determining their structures is a matter of inference. One approach to determining the scale of the disc and torus is Reverberation Mapping (RM), the process of examining time-domain data from the AGN at multiple wavelengths. The technique hinges on the following process: for reasons that are poorly understood, there is significant energy generated from a position directly above the black hole. This energy propagates outward and irradiates the accretion disc and the torus. As the energy is absorbed by the accretion disc and re-radiated outward, the re-emissions map out the temperature profile of the accretion disc. The closer/hotter emission occurs at shorter wavelengths and the further/cooler emissions occurs at longer wavelengths. (Figure 3)

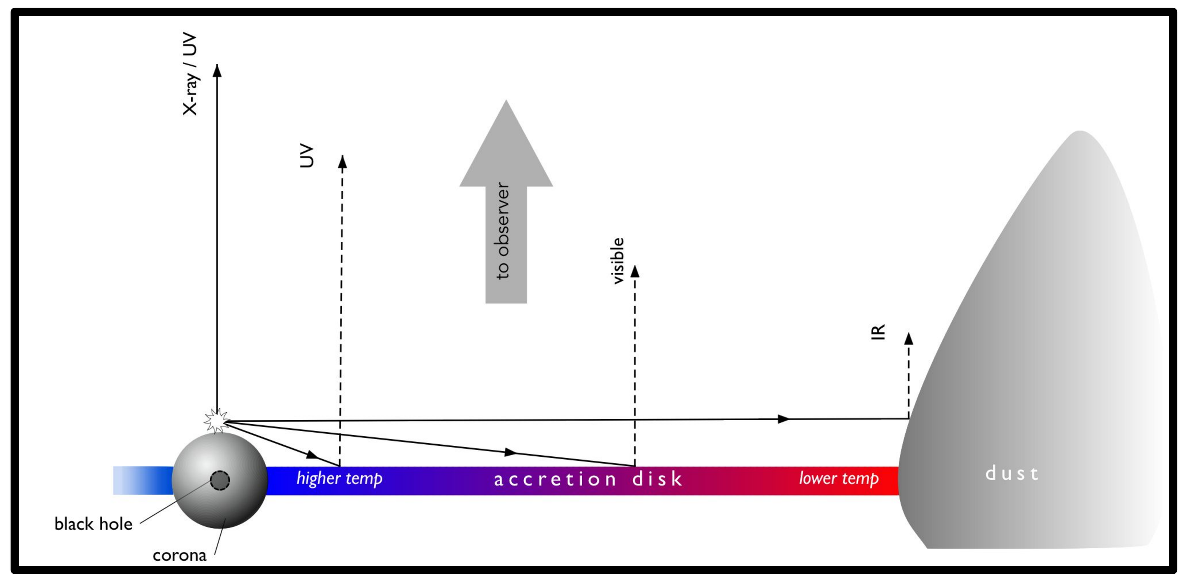


Figure 2: Using RM to map the accretion disc (edge on view) (D. Strasburger NITARP). Energy is emitted by a central source and absorbed by the accretion disc at varying radii. The wavelength of the light making its way to the observer represents the temperature profile of the disc: photons absorbed by 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.

The central source of radiation exhibits significant variability, and this causes variability in the resulting UV, optical and IR re-emissions. Because of the physical separation between the central source and absorbing regions, there is a transmission-time delay between the primary signal from the central source and the secondary signal from the site of absorption and re-emission. The physical separation from the accretion disc to the torus structure may be determined from the time delay (Δt) between the UV or optical re-emission from the accretion disc and the infrared re-emission from the torus (See Figure 1 in Overview). The delay is reminiscent of acoustic reverberation, hence the term RM. For recent examples of continuum RM see Edelson et al (2015), Lyu et al (2019), and Yang et al. (2020).

Method of Selection

CRM requires time-domain data for at least two different wavelengths.

This condition can be met by the NEOWISE and TESS data sets. The two missions have overlapping continuous viewing zones (CVZ) at or near the ecliptic poles. The CVZ for NEOWISE has a diameter of roughly one degree. TESS has a significantly larger CVZ, so targets in the NEOWISE CVZ are assumed to be also visible by TESS.

Criterion 1-- spatial selection:

Objects in the CatWISE2020 catalog within 30 arcminutes of either the north or south ecliptic pole

We used mid-IR color to identify candidate AGN within the spatially selected population. Stern et al 2005 identified AGN via a source's color in the first four IRAC channels on the Spitzer Space Telescope. We note that on the Stern et al plot, the great majority of AGN may be identified on the diagram by a single color cut: [I1] - [I2] ≥ 0.5, the blue dotted line

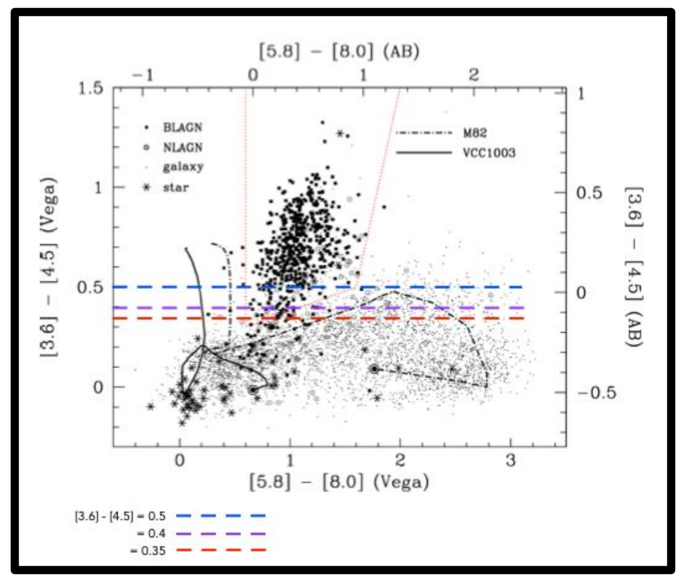


Figure 3: Identification of AGN from mid-IR colors (Stern et al 2005) Note that AGN may be selected on the basis of one color alone

The first two WISE bands (3.4µ and 4.6µ) are nearly identical to the IRAC bands I1 and I2 (3.6µ and 4.5µ), so we use [W1] - [W2] as a proxy for [3.6] - [4.5]. This yields our second selection criterion.

Criterion 2 -- color:

$$[W1] - [W2] \geq 0.4$$

(Note that we shifted the threshold down to 0.4 to expand the selection.) Sources with high SNR and relatively faint sources have light curves where the noise swamps the low level of variability, giving us further constraints.

Criterion 3 -- reliable light curve:

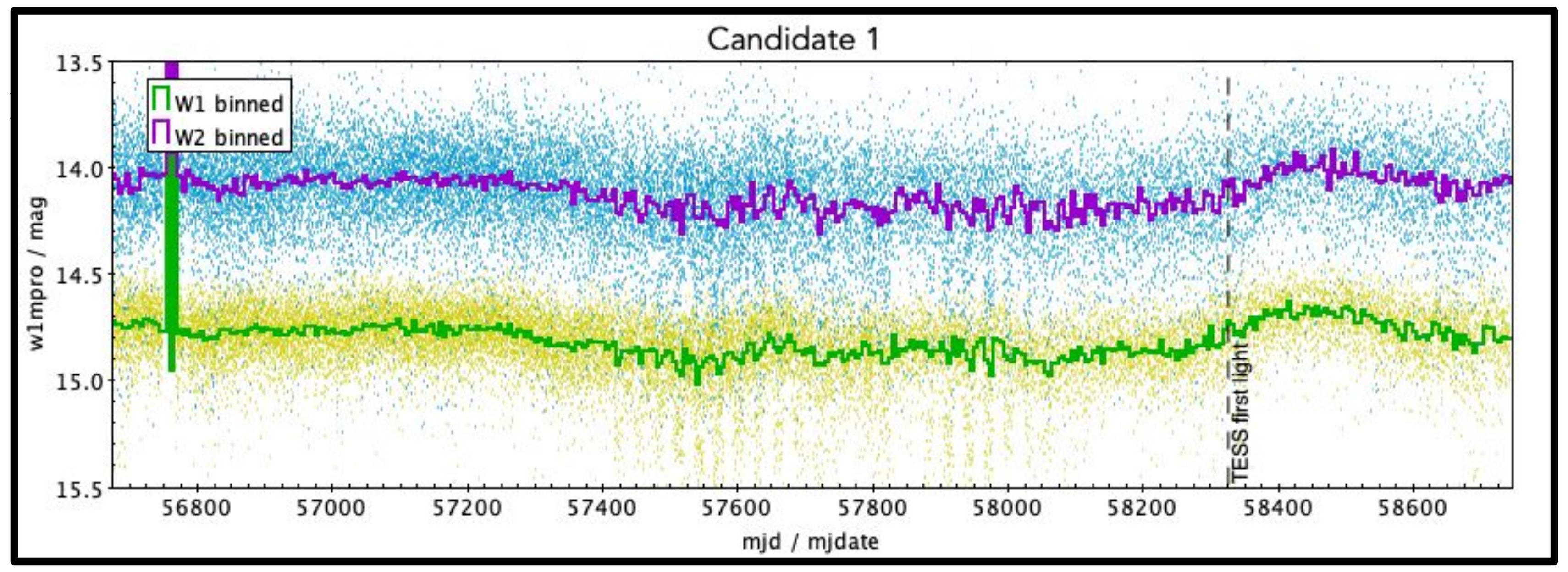
W1 and W2 SNR > 10
[W1] < 15.5

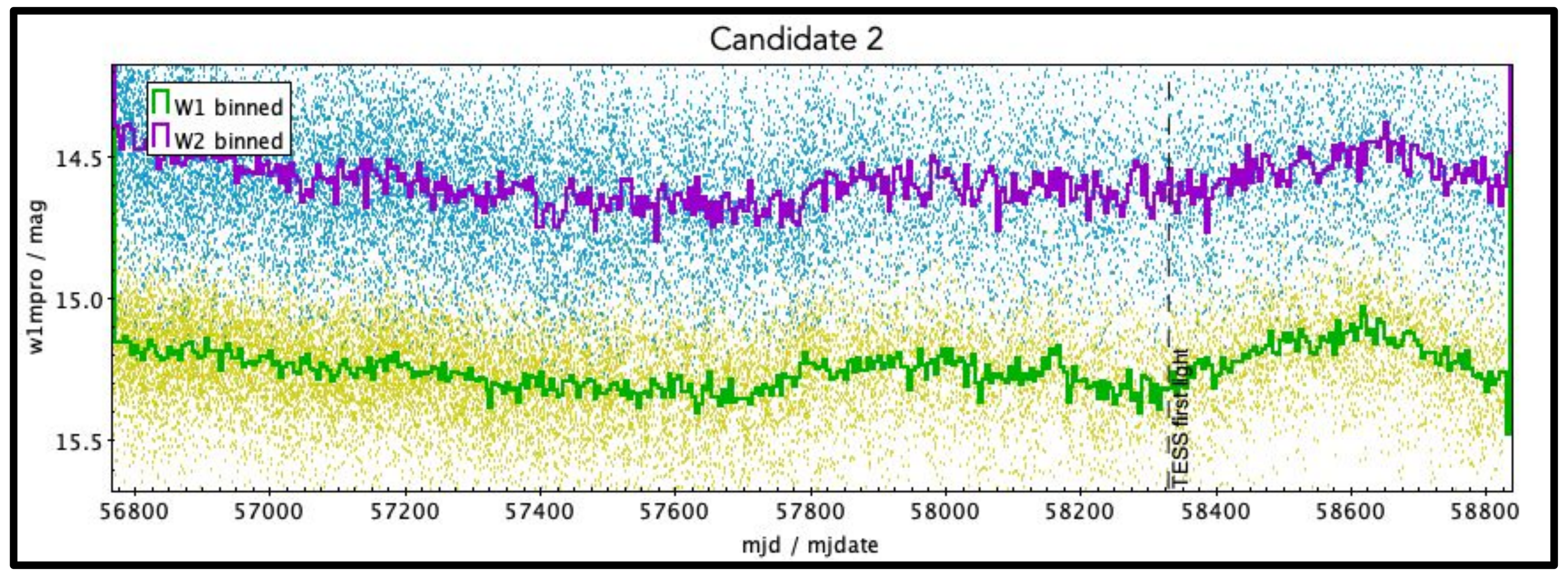
We constructed light curves of the remaining sources from single-exposure data in the NEOWISE-R archive. We manually screened the remaining sources for aperiodic variability. (Bright sources with obvious periodicity were assumed to be foreground stars captured by shifting the color cut from 0.5 to 0.4.)

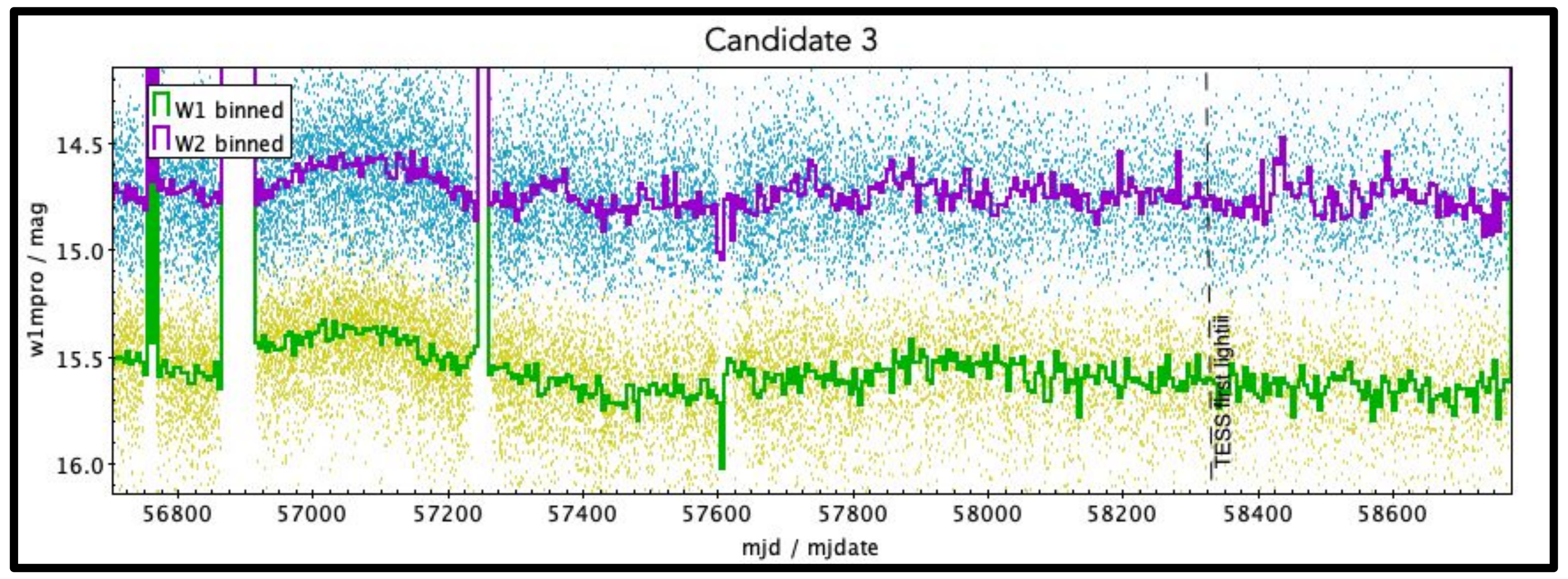
Results

Our selection criteria yield roughly 500 sources, of which three showed variability greater than 0.20 magnitudes and are good candidates for continuum reverberation mapping.

Below are light curves of our candidates.







Future Work

- Acquire TESS data for CRM candidates
- Recheck sources that have shown variation prior to TESS collection
- Check possible sources to other optical databases (such as the Catalina Sky Survey and ASAS-SN)
- Expand search radius around the NEP and SEP
- Lower the [W1]-[W2] threshold for identification of AGN (See Figure 3, horizontal dashed lines)
- Perform continuum reverberation mapping on the sources based on the optical and infrared data collected

References

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Edelson et al 2015, ApJ 806, 129
Stern et al 2005, ApJ 631, 163
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We gratefully acknowledge funding via NASA Astrophysics Data Analysis Program