NITARP Proposal 2015

Determining distances for active galactic nuclei using an optical and near-infrared color-magnitude diagram

Education team:

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Abstract:

Type I active galactic nuclei (AGN) selected from the NASA/IPAC Extragalactic Database (NED) will be used in an attempt to establish a correlation between the ratio of the dust emission and the accretion disk emission (color) to the AGN luminosity. If successful, this work could yield a mechanism for using AGN as a standard candle. This work builds on previous NITARP team attempts to establish such a relationship, but is novel in that it uses near-infrared (NIR) wavelengths as a better discriminator of the transition between accretion-dominated and dust/torus-dominated emission. Type I Seyferts and quasars with redshifts less than 0.1, and with photometry available from the Sloan Digital Sky Survey (SDSS) and the Two Micron All Sky Survey (2MASS) will be used. We will make a color-magnitude diagram analogous to a Hertzsprung-Russell (HR) diagram for the area where the dust vaporizes. The expectation is that the more luminous the AGN, then the more extended the dust sublimation radius, causing a larger hot dust emitting surface area which corresponds to a greater NIR luminosity. Hence the transition between the accretion disk emission to the dust emission will be studied at 1 micron in an effort to show different colors for different luminosity AGN, leading to a predictive color-magnitude diagram which may result in a mechanism for using AGN as a standard for cosmic distances.

Background:

Active Galactic Nuclei (AGN) arise from accretion onto supermassive black holes at the centers of galaxies. They emit an excess of light from their nuclei beyond the sum total of light that should be coming from their central stars. No other mechanism besides accretion onto a supermassive black hole is able to explain the vast amount of energy emanating from the centers of these galaxies. The accretion disk is formed by gas around the black hole and is heated by frictional force from the accreting gas. The distribution of light that is emitted by an accretion disk peaks in the UV but has significant amounts of emission that is in the optical range. There is a second region of fast moving hydrogen gas just above the accretion disk that is being heated by the UV light; this shows itself as Doppler broadened emission lines (the broadness is due to the velocity of the gas). (Figure 1) Any matter (namely dust) that surrounds this accretion disk is warmed by the light from the accretion disk and, absorbs it and re-emits it as blackbody radiation at infrared (IR) wavelengths. (Figure2)

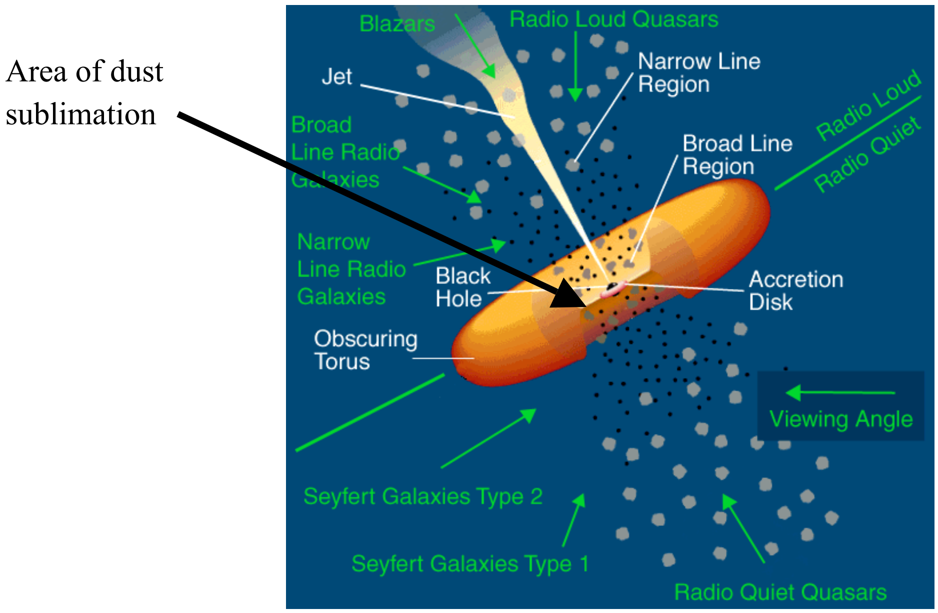

Figure 1. Schematic of a black hole, an accretion disk and surrounding dust (Urry and Padovani, 1995)

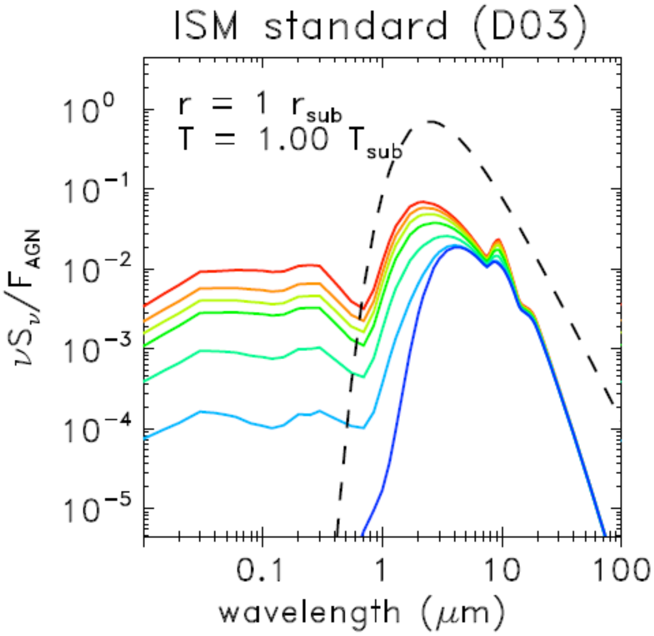

Figure 2. This model shows the ratio of cloud emission to total AGN flux. The various lines represent a specific phase angle, φ, of the cloud in steps of 30° (with red = 0° and purple = 180°). The dashed line is the corresponding black-body emission B_ν (T) with the same temperature as the hot side of the cloud at the same distance from the AGN (Hönig and Kishimoto, 2010).

Seyfert galaxies and quasars are two subcategories of AGN that we will be studying. The difference between the two is the amount of radiation that is emitted from the central source. Seyfert galaxies emit energy from the nuclear source (at visible wavelengths) that is equal to all the energy from the stars in the host galaxy; quasars emit energy from the central source that is >100 times the luminosity of the host galaxy stars. Luminous quasars are rare and are only found at great distances. The great distance means only the very bright nuclear source is seen, not the stars in the host galaxy.

There are two types of AGN, type I and type II. In type I AGN, the view of the accretion disk is face-on or nearly face-on. In this orientation, the dust torus does not block our view of the fast moving hydrogen gas near the accretion disc so that both narrow and broad emission lines are apparent. In type II AGN, the view is thought to be looking edge-on at the dust torus, so the viewer does not see the broad emission lines and the UV light from the accretion disk is also blocked (Figure 3). This is because the broad emission lines from the fast moving hydrogen gas and the accretion disk itself are hidden by the dust (Figure 1). Most quasars that we detect are visually bright and show both types spectral lines and so are type I. Type II quasars are rare (Djorgovski et al. 2001, Zakamska et al. 2003), mainly because it is difficult to detect them although the accepted thought is they, like other AGN, are one and the same (type I and type II) and the only difference is the orientation..

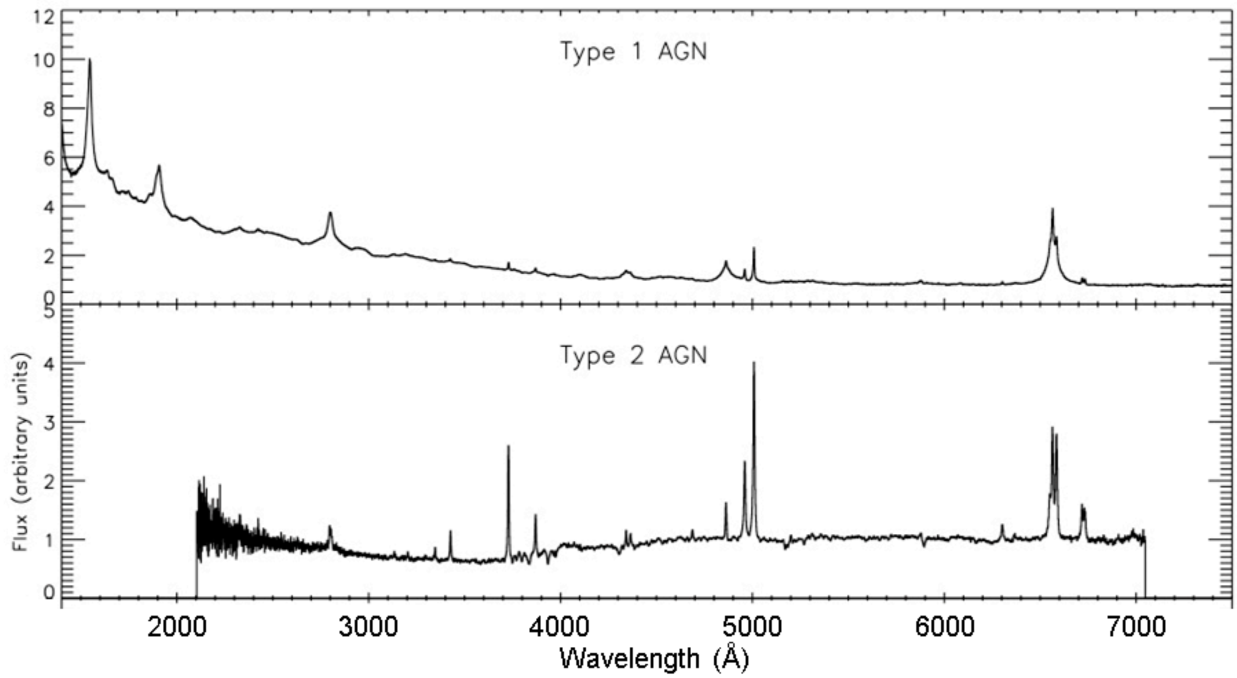

Figure 3. Spectra of type I and type II AGN. Note the difference in broad spectral lines between type I and type II AGN and the excess of UV light short-ward of 3500 Angstroms (Steinhardt and Silverman, 2013).

For stars on the main sequence of the Hertzsprung-Russell (H-R) diagram, the hotter stars are more luminous. We draw an analogy from the H-R diagram to the thermal emission of AGN such that hotter AGN (with higher temperatures and efficiently radiating accretion disks) should also be more luminous. This would also imply that the dust sublimation radius, which is the transitional region between the accretion disk and the dust-containing region, should also be pushed out. As the dust sublimation radius increases, the surface area of the emitting dust also increases, making the AGN more luminous in the IR. Therefore, there should be a relationship between the optical emission from the accretion disk and the start of the IR emission from the inner edge of the dust cloud (Figure 2). Previous studies by NITARP projects have shown a limited correlation between the accretions disk color (in optical and UV) and the dust luminosity at wavelengths greater than 3.6 microns. The limited correlation is most likely because AGN luminosities tend to be averages of blackbody emission from the differing accretion disk radii instead of a single blackbody emission from a single temperature region. However, we propose that there could be broader correlation between the luminosity of the accretion disk and the region where the accretion disk transitions to the dust-containing region. This transition is located on the Rayleigh-Jeans side of the spectral curve for the accretion disk and the Wien side of the curve of the dust cloud. If a correlation can be found between the energy emitted by the accretion disk in the optical and the energy emitted by the dust in the NIR, it would allow us to calculate distances to some of the farthest objects in the universe by using the AGN as standard candles.

Scientific Goals:

Though the broad mechanisms of AGN emission are understood, there is currently no good way to measure the luminosity, and therefore the distance, to these galactic centers. The Hertzsprung-Russell Diagram established a strongly predictive relationship between the temperature (color) and luminosity of stars, thereby providing a method to find stellar distances. A similar color-magnitude diagram for AGN would be useful for determining intergalactic distances. Our goal is to establish a similarly predictive relationship by plotting the ratio of optical/IR wavelengths from the accretion disk/dust to the luminosity of the AGN. If average accretion disk temperature is known, then a comparison can be done between absolute and apparent luminosity.

The goal of this research is to produce a color magnitude diagram characterizing the theorized correlation between the luminosity and color of type I AGN. This correlation has been investigated by previous NITARP teams in 2010, 2012 and 2013. These teams have been able to find correlations between UV and optical luminosities; however none have been predictive as significantly different colors predict similar luminosities (see Figure 4).

This study will vary from the previous projects by focusing on the area between the gas and dust cloud in type I AGN by using the NIR (SDSS i and z and 2MASS J, H and K_s) values to a color magnitude diagram since the longer wavelengths (3.5 and 4 microns) did not exhibit strong, predictive correlations. For this color magnitude diagram, we will look for a good ratio (where a change in the color would result in a significant change in the luminosity) of NIR to optical wavelengths to see which color best represents the changing ratio of the optical to the near IR for different luminosities of the accretion disk and the dust.

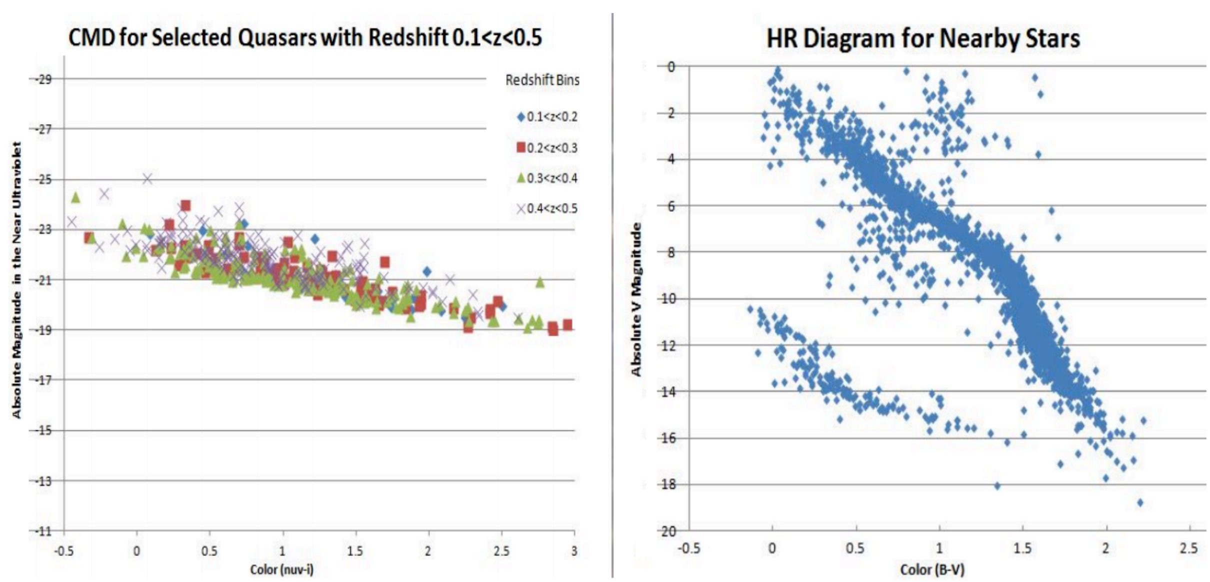

Figure 4. ***(Left)*** Color Magnitude Diagram for Quasars: Color is the ratio of fluxes in the near ultraviolet (GALEX) to the z band (SDSS) and is plotted against absolute magnitude in the near

UV (GALEX) and ***(Right)*** Color Magnitude Diagram for Stars: This plot shows the correlation between color (B-V) and absolute magnitude of nearby stars. Data was taken from the HEARSARC catalog of nearby starts (3^{rd} edition) (Curtis et al., 2013).

We intend to:

- Focus on type I quasars and Seyferts. This provides a large number of sources for which obscuration by dust is minimized so that observed optical radiation can be directly attributed to thermal emission by the accretion disk. The NASA/IPAC Extragalactic Database (NED) lists ~89,000 type I quasars and ~10,000 type I Seyferts from which we will choose those that have both Sloan Digital Sky Survey (SDSS) and Two Micron All Sky Survey (2MASS) data.

- Measuring in the 2MASS (1.2, 1.7 and 2.2μm) and SDSS i and z range will allow us to focus on the spectral energy distribution between the accretion disk and the dust cloud.

- We will choose a low redshift range ($z < \sim 0.1$) so that all of the chosen filters cover similar emitted wavelengths.

- By having a large sample, it is our goal to statistically average out over the inherent variability of these AGN. By doing this we will be dealing with most systems in their median states and not their highest or lowest emitting states.

Expected Outcomes:

The majority of the ~99,000 quasar & Seyferts initially pulled from NED will be removed due to redshifts of $z>0.1$ or missing SDSS or 2MASS data. Our goal is to identify hundreds of AGN over multiple colors and luminosities for use in this study. If the remaining sample of close proximity ($z<0.1$) AGN is too small (less than 200), the maximum redshift may need to be increased. If this is the case, care will be taken to make sure the emission wavelengths used in this study have not shifted beyond the 2MASS and SDSS bandwidths. With a sufficient sample size we expect to find a predictive correlation between AGN color and luminosity based on optical (accretion disk) and NIR (dust) wavelengths.

Archived Data:

NED will be used to search for objects that fit the above search criteria. The resulting sources will then be extracted from the SDSS and 2MASS archival data sets.

Education/Outreach:

Diedre Young:

- Two three hour workshops will be given to the teachers at Ridgway Christian School and Ridgway Christian High School showing the advantages of using archived data in the classroom and also pushing STEM projects in other areas; English, Math, etc. The workshops will also be offered to other high schools in the surrounding area.
- Students will be encouraged to do 'spin-offs' on this project or a new project from archived data that can be entered into the SE Arkansas regional science fair.
- A workshop will be offered at the Arkansas Science Teachers' Curriculum Conference in November 2016 showing the advantages of using archived data in the classroom and also pushing STEM projects in other areas; English, Math, etc. (This ties into our Common Core and Next Generation Science Standards).
- Students' poster from this 2015 program will be entered in the February 2016 STEM posters at the state capital. This is for undergraduate level STEM posters which this poster will qualify.
- Students will present their findings at the RCHS 'Astronomy Night' in the spring of 2016 where parents and students from not just our school but other local schools will come to participate.

Lee Pruett:

- I will present our summer work and my involvement with NITARP at a school board meeting in the fall.
- I will host a one hour professional development session at Notre Dame HS on the use of data in the classroom and collaborate with department colleagues to use the NITARP experience as the foundation for a science research course.
- I will propose a session on the use of archival data for student research at a 2016 Computer Using Educator (CUE) conference in San Jose.
- I will propose a session at an upcoming NSTA meeting (either local or national) on the use of archival databases in student research.
- I will work with students to present our poster at the American Geophysical Union (AGU) Bright Stars session in San Francisco (December 2015).

Robert Palmer:

- I will share my experiences on several levels. The astronomical research skills I learn from this project will be incorporated into the astronomy course I currently teach. I will share my NITARP experiences with my colleagues at Willmar Senior High School during staff in-services. All participating students and I will present our NITARP research experience to students, staff, and school board members throughout the year. The students and I will be hosting community wide presentations at regional libraries, Girl/Boy scout, and 4H club meetings. Our astronomy class hosts weekly star parties that are open to the public. I shall include presentations about our NITARP research during these community star parties.

- I will also submit proposals for presentations to share my NITARP experiences at our regional, state, and national science teacher conferences. Manuscripts of those presentations will be posted on my website and submitted to science and education journals.

- I will develop a new research based course to offer through Willmar Community Education for students in grades 6-12 and their parents. This class will meet for about 1 hour a week throughout the year.

John Gibbs:

- Seventeen students at Glencoe High School have expressed interest in participating in this research project. Most of these students are currently enrolled in my physics and/or astronomy classes. Additional students from other classes will also be invited to participate. During the spring we will meet for one to two hours after school each week to study and discuss much of the background for this project. Topics will include the electromagnetic spectrum, blackbody radiation and Wien's law, quasars and Active Galactic Nuclei (AGN), as well as extensive practice manipulating data in Excel. In addition to this we will also read selective sections from relevant literature sources.

- In addition to presenting the results of our work at the 2016 AAS meeting in Kissimmee, Florida, students will also present our work to the Glencoe High School faculty and possibly the Hillsboro School Board.

- I will continue to promote the NITARP experience with educators whenever the opportunity arises. Specifically, I will contact two recent Oregon NITARP educators to team up and present a session at the Oregon Science Teachers Association fall meeting in October, 2015 and I will contact the Rose City Astronomers to see if they would be interested in having us share our NITARP results and experiences with them.

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