A Color-Magnitude Diagram for Active Galactic Nuclei

Educator Team: Thomas Doyle, Dodd Middle School, Freeport, NY
Wendy Curtis, Waynflete School, Portland, ME
Pamela Thompson, Monrovia High School, Monrovia, CA
Mentor Teacher: John Blackwell, Phillips Exeter Academy, Exeter, NH
IPAC Staff: Jacob Llamas, Spitzer Science Center, Caltech, Pasadena, CA
IPAC Staff, Jean-Christophe Mauduit, Spitzer Science Center, Caltech, Pasadena, CA
Science Mentor: Varoujan Gorjian, Spitzer Science Center, Caltech, Pasadena, CA

Abstract

Archived data from GALEX, WISE and SDSS will be used to construct a UV-IR color magnitude diagram for Type I quasars at redshift values of $0.1<z<0.5$. This study will attempt to demonstrate a correlation between the IR luminosity and the temperature of the accretion disk in Active Galactic Nuclei. Previous studies (NITARP 2010) have been unsuccessful in showing a correlation. To increase the probability that this study will be successful in finding a correlation we intend to: (1) Have a large number of sources, by focusing on Type I quasars at similar local redshifts. (2) Use Type I AGN, which should provide a clear view of the accretion disk with minimal interference from the surrounding dust of the torus, (3) Use data at longer IR wavelengths which should help limit variability, (4) Use GALEX, SDSS, and WISE, which have all operated within a similar time frame providing us observations that are reasonably close in time together.

Background

The term Active Galactic Nucleus (AGN) refers to phenomena in the nuclei, or central regions, of some galaxies, which causes substantial energy release beyond what can be attributed directly to stellar processes. AGN are theoretically caused by supermassive black holes actively drawing material into an accretion disk. Thermal processes in the accretion disk produce continuum emission that peaks in the ultraviolet region of the spectrum. Near the accretion disk there is a separate region of fast moving hydrogen gas that, being heated by emission from the accretion disk, produces Doppler broadened emission lines (the motion is broadened due to particle speeds equivalent to at least 10,000 km/sec.) This area of gas although not resolved, is known to be separate from the disk due to its lag time in emissions during brightening events. Further from this Broad Line Region (BLR) is a gas and dust region that absorbs the short wavelength emission from the accretion disk, and re-emits it in the infrared. Finally, much further still, clouds of cooler gas illuminated by the accretion disk have characteristic narrow emission lines (For review see "An Introduction to Active Galactic Nuclei")[i].

The two largest subclasses of AGNs are Seyfert galaxies and quasars, and the distinction between them is to some degree a matter of semantics. The fundamental difference between these two subclasses is their luminosity; in the case of a typical Seyfert galaxy, the total energy emitted by the nuclear source at visible wavelengths is comparable to all of the stars in the galaxy (i.e. about 10^{11} times the luminosity of the sun), but in a typical quasar the nuclear source is brighter than the stars by a factor of 100 or more. Additionally, there are two types of AGN that according to the Unified Model are thought to be the same objects but viewed from different perspectives. Both types of

AGN are theorized to have a torus of dense dust surrounding the accretion disk. In Type I AGN, the view is face on, looking up/down on the ring of the torus, enough to detect the fast moving gas near the accretion disk, so that both the narrow and broad emission lines are apparent. In Type II AGN, the view is thought to be looking through the torus, edge on, so that the broad emission lines from the fast moving gas are obscured by the dust, leaving only the narrow emission lines visible in the spectra. Since most quasars have been discovered visually, and are extraordinarily bright, they tend to be Type I, where there is no interference from the dust of the torus. Type II quasars are relatively rare, since they are harder to identify because the dust of the torus obscures our view.

In theory, just as hotter stars are more luminous, hotter AGN (those with hotter, more efficiently accreting disks) should also be more luminous. Also, there should be a correlation between the ultraviolet emissions of the accretion disk and the infrared emissions of the gas and dust that is heated by the accretion disk. This would be a function of the temperature of the accretion disk. The greater the temperature then the greater its luminosity and hence the larger the volume of dust that will be heated. With a larger amount of dust that is heated, then the surface area of the heated dust will be larger, resulting in a higher IR luminosity from the dust. Taking the emitting region to be roughly a ring, then the increase in emitting surface area should be proportional to the size of the ring, and hence proportional to $\pi(R_{\text{Outer radius}})^2 - \pi(R_{\text{Inner radius}})^2$. If a correlation could be found between the temperature of the accretion disk (as represented by its UV color) and the IR luminosity, that would allow us to calculate distances to some of the farthest objects in the universe by using the AGN as standard candles.

Scientific Goals

The goal of this research is to produce a color magnitude diagram showing the theorized correlation between luminosity and color of Type 1 AGN. This correlation has been investigated previously, notably in 2010 by a NITARP team. This current study will continue the work of the 2010 NITARP team, additionally broadening the base number of targets by using data from quasars instead of Seyfert galaxies, as well as recently released data from WISE. Though local Type 1 AGN whose radiation is not redshifted would be more convenient to study, but, as shown by the 2010 team (Gorjian et al. 2010)[ii], the number of sources available is insufficient to gain a statistically large sample size (Figure 1).

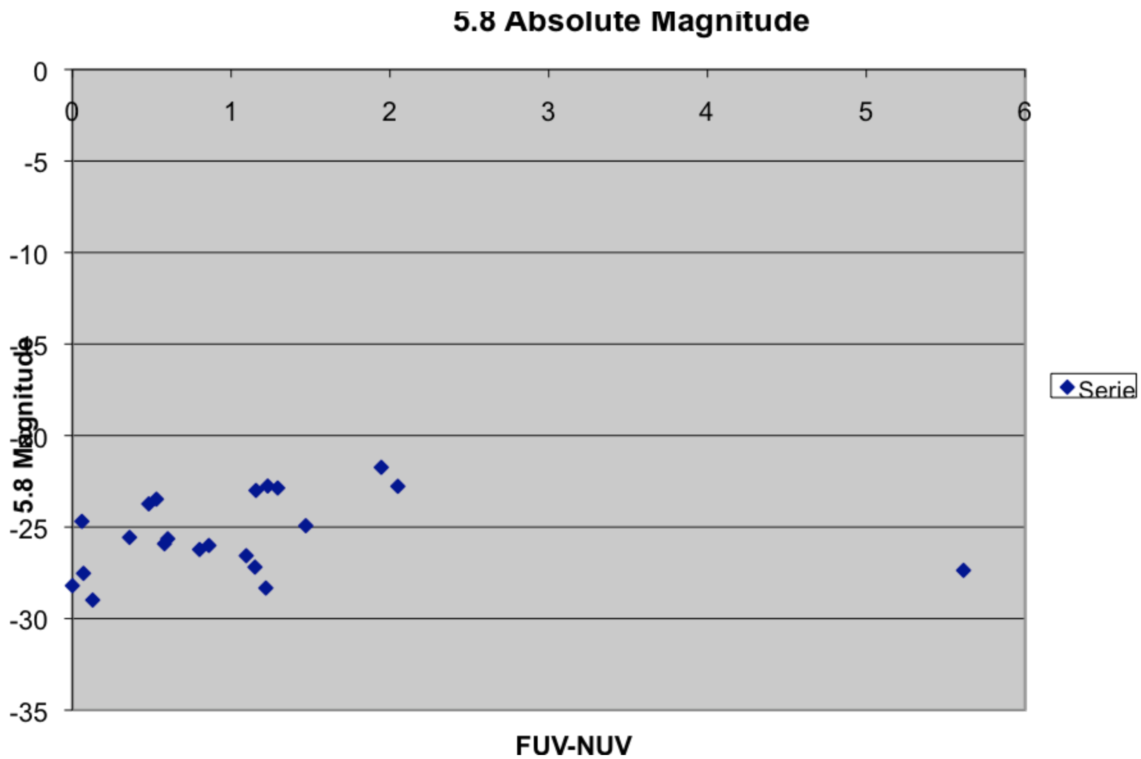

Figure 1. Color-magnitude diagram from Gorjian et al (2010) using Spitzer data at 5.8 microns and the FUV and NUV filters from GALEX. Note the small number of sources preventing a statistically significant result to be gained.

The data from WISE includes measurements at wavelengths of 12 and 22 microns in addition to the 3.4 and 4.6 micron measurements used in previous studies. Using these longer wavelengths should avoid issues of contamination by starlight that have peak emission around 1micron, and again should give a better measure of the temperature of the dust with less variability, as these cooler regions are more distant from the variable source and should average over short term variations. The color of the AGN will be determined by comparing the intensity of two wavelengths in the ultraviolet region, using archived data from the Sloan Digital Sky Survey (SDSS) and from the Galaxy Evolution Explorer (GALEX) reported in "The UV Properties of SDSS-Selected Quasars"[iii]. For the initial comparison, wavelengths of 277.5 nm (obtained from the near UV GALEX filter) and 355.1 nm (obtained from the u-band SDSS filter) will be used to determine color. This color is a tracer of the temperature of the AGN accretion disk (Figure 2). Several additional comparisons may be explored using another SDSS filter if no correlation is apparent using this particular comparison.

We intend to;

(i) Focus on Type I quasars. This provides a large number of sources (479) for which obscuration by dust is minimized so that the radiation observed can be directly attributed to thermal emissions by the accretion disk.

(ii) Sources will be selected at similar redshift values of $0.1<z<0.5$. Consistent measurements can then be taken at each desired wavelength without needing to correct for the redshift. The wavelengths studied will be selected in order to avoid contamination from emission lines (specifically the strong Lyman alpha

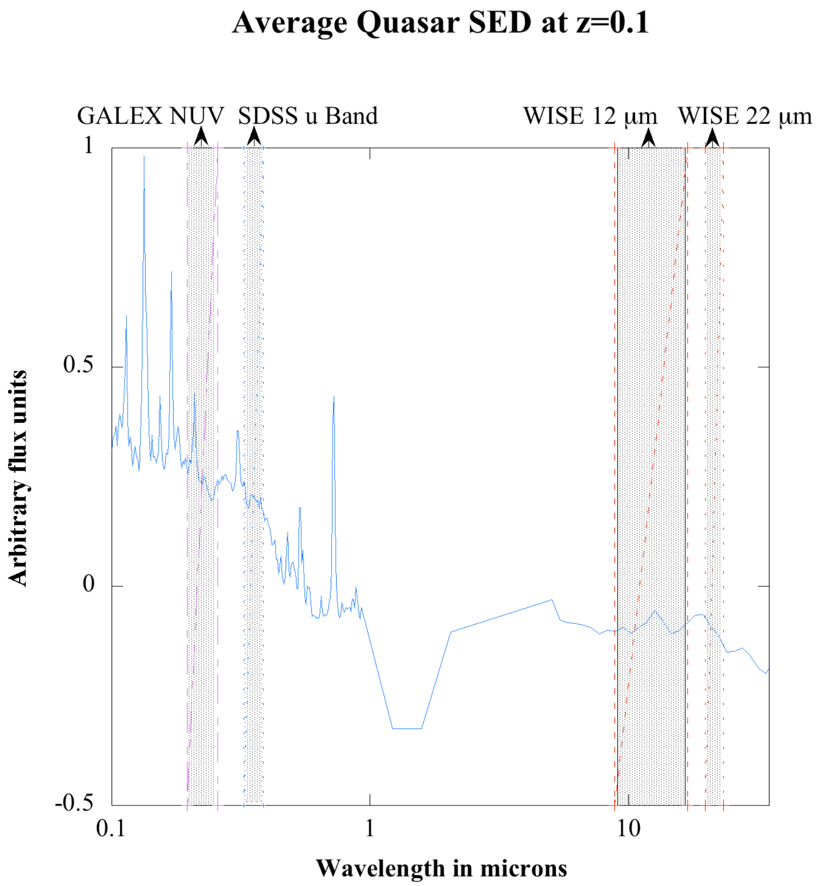

Figure 2. An average quasar Spectral Energy Distribution (SED) from the UV to the IR based on Sheng et al (2012)[iii], redshifted to z= 0.1. Filters from GALEX, SDSS, and WISE are noted. The GALEX NUV and SDSS u band filters are well placed to measure the slope of the UV emission which indicates the temperature of the accretion disk. The WISE 12 and 22μm bands are well placed to measure the emission of the dust heated by the UV from the accretion disk. The FUV GALEX band is not used since the very powerful Lyman Alpha line (strongest in the above image at 0.13 μm) would have contaminated the measurement. Although there are still contaminating emission lines in the NUV filter, they are not as strong as the Lyman Alpha line.

line) that have been redshifted into the region measured by UV filters on the instruments used in this study. (Figure 2)

(iii) Use data obtained at relatively simultaneous times for different wavelengths of interest (within approximately a 5 year period). Both the larger number in the sample and observations obtained closely in time should minimize (though not eliminate) the effects of variability.

(iv) Use data from GALEX, SDSS, and WISE, allowing for an increased number of sources, at an increased number of wavelengths. Due to the redshift of these sources, which is unavoidable because of the number of sources required, GALEX data alone cannot be used. Redshifted Lyα lines are a strong contaminant at the wavelength measured by the far UV GALEX filter, so only the GALEX near UV filter can be used. (The flux collected by the near UV filter is redshifted from the far UV region.) For a second UV wavelength, SDSS u-band measurements will be used.

Expected Outcomes

(i) Color magnitude diagram plotting IR magnitude at 12 μm against color, determined by the ratio of UV magnitudes at 277.5 nm and 355.1 nm

(ii) Color magnitude diagram plotting IR magnitude at 22 μm against color, determined by the ratio of UV magnitudes at 277.5 nm and 355.1 nm

(iii) Additional color magnitude diagrams may be explored using combinations of IR magnitudes of 3.4, 4.6, 12, or 22 μm against color, determined by ratios of UV magnitudes at 277.5 nm, 355.1 nm

(iv) The statistical significance of all generated color-magnitude diagrams will be estimated by a least squares fit.

Archived Data

The Sloan Digital Sky Survey was used to search for objects that fit the above search criteria, while cross-referencing for compatibility with GALEX. In all, 3037 targets were identified that were observed by both the SDSS and GALEX missions (Trammel et al. 2007)[iv], of which 479 lie in between redshifts of 0.1 and 0.5. Since the entire WISE sky catalog became available in March, we have done a comparison with the GALEX/SDSS sources, and all 479 sources have counterparts in all 4 WISE channels.

There will be three sets of archival data extraction for this project. GALEX data will use extracted magnitudes from the 3rd public release of data (Trammel et al)[iv]. These magnitudes will be in the Near UV (175-280 nm). The SDSS data used to correlate with the GALEX data (Trammel et al)[iv] will provide our u-band (355.1 nm) magnitudes. Both GALEX and SDSS are available through a web interface, and can be easily downloaded. The infrared data will be extracted from the newly released (March 2012) WISE database. The WISE magnitudes are at 3.4, 4.6, 12, and 22 μm. They are also available through a web interface, and can be easily downloaded.

Instruments

The Galaxy Explorer (GALEX) instrument is a 50 cm Ritchey-Chretien telescope, with a large field of view in four different optical paths, two UV simultaneous channels. The NUV resolution of 6 arcseconds is degraded about 20% compared to the resolution of the FUV of 4.5 arcseconds due to the proximity focusing[v]. The GALEX survey has imaged all of the galaxies that are relevant to our study. Their data archive will provide our near UV flux values for the targets, and with the u-band flux value from SDSS will be used to estimate the color (temperature) of the AGN. The color will then be compared to the IR energy emitted by the surrounding dust in the torus. As the temperature increases in the accretion disk at both the NUV and the u-band, we expect that there will be a corresponding increase in the temperature of the surrounding dust in the IR.

The Sloan Digital Sky Survey (SDSS) uses a ground-based 2.5-m wide-angle optical telescope, and takes images using a photometric system of five filters; u (ultraviolet), g (green), r (red), i (infrared) and z (900 nm) SDSS has a resolution of 1 arcseconds FWHM with a pixel size of 0.4 arcseconds[vi]. Although this is considerably narrower than the GALEX resolution it should not affect our photometry because we are looking at point sources. The SDSS filters are primarily in the visual part of the spectrum, and so may be contaminated with varying degrees of host galaxy star-light. However, the u-band flux values should be clean enough for us to use for our study without any corrections since the AGN peaks in the UV, and main sequence stars are not very bright in the UV.

The Wide-field Infrared Survey Explorer (WISE) instrument is a four-channel imager which operates in a single mode. It includes a 40-cm telescope with 47 arcminute field of view, and has detector arrays at 3.4, 4.6, 12, and 22 μm. It has a resolution of 6 arcseconds (12 arcseconds at 22 μm). At 3.4 μm the data is contaminated with starlight. Since most galaxies have a large number of stars that emit at this wavelength, as do the AGN, there could be confusion as to the source of the flux. At 4.6 μm, there could still be some interference from starlight, but this channel may provide some useful information. The 12 and 22 μm filters track cooler dust and are in a region which should have little host galaxy starlight contamination.

By combining the data from all the above instruments we hope to arrive at a tight UV-IR color magnitude diagram.

Education and Outreach Goals

John Blackwell

John intends to use this project in several ways to educate the public, students, and other teachers:

- Public outreach will be achieved by lectures at the McAuliffe-Shepherd Discovery Center, Concord, NH. The Discovery Center is a combined museum/planetarium/education center for both teachers and students to learn more about space, space flight, astronomy and astrophysics. They host lecture programs (Super-Stellar Fridays) to the public and professional development programs for teachers. John has spoken at this venue regularly for over ten years with groups ranging in size from 50 to over 100 and at age levels from kindergartners to adult. John is planning to do both talks and professional development workshops for teachers within this year.
- Teacher workshops: John is planning the next Phillips Exeter Academy Astronomy Education Conference for June of 2013. Attending this conference will be 14 high school astronomy teachers. Among the many topics covered in this week-long conference will be this NITARP project and the use of publically available data sets which can be used in the classroom for science education.
- The Local Astronomy Clubs: The New Hampshire Astronomical Society (NHAS) and the Academy's student-run astronomy club both have opportunities for speakers to present interesting research and opportunities for others. This

NITARP project would be presented to the 200+ members of the NHAS and the 60+ students in the astronomy club.

- Training Videos: John will develop and record a series of online training videos to be made available to the public. These videos will assist those interested in accessing the data sources from SDSS, WISE and GALEX. The hope is to then use these for public access and for classroom training. Assessment of their use and utility can be made by monitoring the #-of-views metric provided online, and by viewer feedback.
- Classroom activity: John will use this project in his Advanced Astronomy and Observational Methods in Astronomy courses allowing the students to get the feel of astronomical research using modern data-mining techniques. An outcome of this activity will be lesson plans, videos and assessment material aimed at advanced high school and introductory college level astronomy students.

Wendy Curtis

In conducting this research, Wendy plans to meet the following educational and outreach goals:

1. Introduce an Astronomy Research Activity open to any Upper School Student at Waynflete School in Portland, ME. The purpose of this activity will be to involve students in real and current scientific research in the field of astronomy. The students who attend the NITARP program at Caltech in July of 2012 will lead the activity. Students in this activity will participate in the research that is being conducted, learn to use photometry tools, analyze archived data, and increase their general understanding of what scientists do. The activity will meet for 40 minutes once a week throughout the school year and include as many as 20 students.

2. Incorporate digital imaging and use of archived data into a senior elective Astrophysics course. While at Caltech this summer, we will use the Aperture Photometry Tool (APT) to analyze images from the WISE All-sky Data Release. Wendy will bring this knowledge to the Astrophysics class to increase the technical depth of the course. Additionally, Wendy will generate projects throughout the year, which make use of archived data. Students will learn to use data catalogues such as GALEX, SDSS, and WISE and will be supported as they plan, conduct, and present their own research on a topic of their choice.

3. Present at the Maine Science Teacher Association (MSTA) yearly conference in the fall of 2012 and/or the fall of 2013 on the work that was done in connection with this program. In presenting, Wendy hopes to encourage other area astronomy teachers to better incorporate current scientific data into class activities.

4. Assess the impact of this program on students. Wendy will conduct pre- and post-tests on students in different groupings and assess the changes in their perceptions about what scientists do, how scientists think, and how they feel about themselves as scientists. Students entering Astrophysics and participating in the research group will be one sample

group, students entering Astrophysics but not participating in the research group will be a second sample group, and students of the same age range taking a different, unrelated science class will be a third group sampled. Pre- and post-test responses from each group will be compared in order to gage the progress of students who participate in these programs compared to the progress of those who do not.

Tom Doyle

- Freeport Schools is in the process of creating research curriculum spanning grades 5 through 12. To date, Tom's NITARP experience has provided a wealth of material that will be incorporated into this curriculum. Students are currently conducting research using GALEX, NED, SDSS, and WISE databases. Research activities these students are involved in include the use of APT analyzing photometry, creating HR diagrams of open and globular clusters, measuring the jets from M 87, and calculating the luminosity of Seyfert galaxies. The students will present their posters at our science fair March 26, 2012.

- Students on our team who will attend the NITARP program at Caltech this summer will speak and present their findings to other students and teachers and at a future Board of Education meeting. These students will become mentors in the future for other students conducting astronomy research.

- Our school district has a partnership with The Cradle of Aviation Museum in Uniondale, New York, which has implemented a multi-disciplinary approach to teaching that incorporates Astronomy. We have been part of a number of professional development meetings and students have taken part in museum activities. Tom's NITARP experience will now be included in these kinds of activities.

- As part of the Cradle of Aviation museum outreach Tom has been partnered with an astronomer from the Amateur Observers Society of New York (AOSNY). The astronomer will visit our class on a number of occasions. (More on this later). Tom will speak at a future meeting of this organization describing his involvement with NITARP.

  Tom will give a presentation of his experience with NITARP at a future NSTA meeting.

Pamela Thompson

Pamela's goals of the NITARP program at Monrovia High School and surrounding community;

1. Curriculum Development

Curriculum for informal study will be developed using the guidelines of, "A Framework for K-12 Science Education: 2012, Practices, Crosscutting Concepts, and Core Ideas"

(Committee on Conceptual Framework for the New K-12 Science Education Standards; National Research Council, 2012). Included activities will incorporate the use of the Aperture Photometry Tool (APT) and data from Spitzer, GALEX, SDSS, & WISE. The activities will be intended for use by small groups in earth science and astronomy classes, and by the Math and Science Academy as part of independent research projects. The intention is to encourage the use of data to inspire original research. The curriculum will be made public and shared with other local science teachers in the San Gabriel Valley, Pasadena, and other small local districts.

2. Professional Development

Pamela plans on visiting other local schools during their professional development days to present the curriculum and encourage application and participation in the NITARP program. This would include the San Gabriel Valley, Pasadena, and other small local districts, impacting 100+ math and science teachers, helping to pool resources and build relationships between small districts like Monrovia.

3. Astronomy Outreach

Pamela intends to write an article about her NITARP experience to be published in the Los Angeles Astronomical Society newsletter, and to present the project and the NITARP program to the general meeting at Griffith Observatory. The LAAS membership currently stands at ~450 persons. This will deepen the understanding within the amateur community of how space based astronomical research is conducted, and encourage members who are doing outreach and who are interested in research to apply to NITARP.

4. Math and Science Academy

Students that are involved in the 2012 NITARP will write their own proposal and present it as a poster project to their peers and to the community as part of their Math and Science junior project in May of 2012, and again with their results in May of 2013. In addition students involved in the 2012 group will be expected to;

- Commit to meet one a week for 90 minutes for the duration of the project
- Create a presentation of their NITARP experience and be willing to present it to other schools and audiences
- Mentor the next group of juniors seeking a research option for their project.

References

[i] An Introduction to Active Galactic Nuclei by B. Peterson, Cambridge U Press, 1997

[ii] Bulletin of the American Astronomical Society, V. Gorjian, Vol. 43, 2011

[iii] The New Generation Atlas of Quasar Spectral Energy Distributions from Radio to X-rays by Sheng et al, 2011 ApJS, 196, 2

[iv] The UV Properties of SDSS-Selected Quasars by Trammel et al., 2007, AJ, 133, 1780

[v] A GALEX Instrument Overview and Lessons Learned by P. Morrissey, 2006, SPIE, 6266, 26

[vi] The 2.5 meter Telescope of the Sloan Digital Sky Survey by James E. Gunn et al, 2006, AJ, 131, 2332