NITARP Proposal 2010 –
Color Magnitude Relationships in Nearby Active Galactic Nuclei

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Abstract:

Archival data from the Spitzer and GALEX Space Telescopes will be used in an attempt to determine the inherent luminosity of nearby Active Galactic Nuclei (AGN) by plotting a UV-IR color-magnitude diagram. The previous difficulty in determining the luminosity of AGN using this technique has been that AGN are variable and observations were often taken at widely different times. As a result color-magnitude diagrams were constructed using UV and IR data points acquired decades apart. Also there is usually an unknown amount of obscuration towards the AGN emission region. This study attempts to mitigate both of those issues: i) by using data that were collected much closer in time to each other, since both GALEX and Spitzer were launched and carried out most of their observations within the same 5 year period; and ii) by choosing Type I AGN, which show the least amount of obscuration.

Scientific Goals

The basic structure of an AGN is a super-massive black hole (SMBH) surrounded by an accretion disk. This structure is further surrounded by dust. The material in the accretion disk heats to temperatures that cause emission in the UV. This emission warms the dust hovering around the accretion disk of the SMBH and the dust reemits the energy as infrared light. Our project will exploit this interaction between the accretion disk and the dust of an AGN. Similar to the observation that blue (hot) stars are more luminous than red stars, we hope to show that a hotter accretion disk in the AGN will yield corresponding increases in the temperature of the dust surrounding these accretion disks.

Most galaxies are collections of stars that exhibit absorption lines arising from the stars in the galaxy. Some galaxies have Active Galactic Nuclei (AGN) that emit light when gas is heated in the accretion disk around a SMBH and so have emission lines, as opposed to absorption lines.

AGN are classified by the width of their hydrogen emission lines: Type I AGN have broader hydrogen emission lines (Doppler motion broadened to speeds equivalent to at least 10,000 km/sec), and Type II AGN have narrower emission lines (equivalent to speeds of less than 10,000 km/sec). AGN are further classified by the accretion rate of their SMBH; Seyfert galaxies accrete material less quickly than do quasars.

A unified model attempts to describe Type I and Type II AGN as the same objects being viewed from different angles. In the unified model a dust and gas torus is postulated to surround the accretion disk surrounding the black hole. When an AGN is observed edge-on, the view of the fast-moving gas near the accretion disk is obscured by the torus (the broad emission lines are obscured leaving just narrow emission lines). Conversely, when an AGN is observed nearly face-on or at least at an angle sufficient to see beyond the torus, the fast-moving gas near the accretion disk is visible and the AGN exhibits broad emission lines. This proposed study will analyze AGN with face-on/nearly face-on views where the fast-moving gas is visible (Seyfert Type I). These face-on views provide the most useful views of the AGN since they exhibit the least absorption.

The fundamental goal of this AGN study is to search for a correlation between color and magnitude for AGN and to use the color-magnitude relationship to gauge the inherent luminosity of the AGN (similar to the way that we use color-magnitude correlations to determine the luminosity of stars). Although this correlation has been investigated previously, the current study will optimize the AGN targets and emission data to:
(i) focus on a narrow range of AGN types so that absorption effects can be minimized;
(ii) use emission data obtained at relatively simultaneous times for the different wavelengths of interest (within approximately a 5 year period); and
(iii) use data from GALEX and Spitzer which both provide higher resolution measurements than data previously available in the UV and IR wavelengths.

The specific output of this study is to create a Color-Magnitude graph of the type:
(i) Magnitude at 5.8µm vs Color (measured as the difference in magnitudes at 227.5 nm (near ultraviolet) and 155 nm - far ultraviolet)
OR
(ii) Magnitude at 4.5µm vs Color (measured as the difference in magnitudes at 227.5 nm (near ultraviolet) and 155 nm - far ultraviolet)

Photometric measurements from the IRAC images will be made using the Aperture Photometry Tool (APT) software developed at the Spitzer Science Center. This tool allows the user to load in the IRAC images and then select individual sources for photometry. Count values are then converted to magnitudes. APT also determines an uncertainty for each measurement allowing for proper error bars to be displayed in data plots.
Since we have chosen wavelengths where the AGN emission is dominant in the UV and in the IR, the resolution of the two observatories (4.5" and 6" for the FUV and NUV bands and 2.4" for both IRAC bands) will be dominated by AGN emission. So although the resolutions are a bit different, the dominant source of emission in each case will be the AGN emission allowing for comparison across the two telescopes.

The Value of Spitzer and GALEX Data

Emission from the AGN disk occurs when matter accretes (peaking at UV wavelengths) or when energy from the accretion heats the dust around the disk (peaking at IR wavelengths). Since the peak emission from the AGN is in the UV, the GALEX data will provide access to this peak emission.

GALEX has imaged many of the host galaxies of the AGN relevant to this study. GALEX's data archive provides the far and near UV flux values for many of the targets in this study and will be used to estimate the color (temperature) of the AGN. The color will be compared to the IR energy emitted primarily by each AGN's dust-laden torus. This IR flux will be quantified by the Spitzer tool: APT, Aperture Photometry Tool. GALEX and Spitzer each imaged the same targets within 5 years of each other and thus provide contemporaneous, multiwavelength data, although some limited variability may be possible within this 5 year time span. Since the accretion UV emission requires time to heat the dust and then re-emit the energy in the IR, small time delays in collecting the IR data may be acceptable.

In addition the emissions are thermal processes in AGN, and as a result one might expect their characteristics to follow a Color-Magnitude relationship similar to that of a Hertzsprung-Russell Diagram. More specifically, if higher energy UV light is emitted by the AGN, the resulting IR from the heated dust should also exist at higher energy. This relationship has not yet been observed, either because it does not exist or because the precision in the datawas lacking. For example, perhaps the difficulty in handling extinction corrections for the continuum (in the ultraviolet and infrared) leads to difficulties in knowing magnitudes accurately and, leads to inaccurate estimates of the AGN luminosity.

This proposed study is especially unique due to:
(i) the excellent sensitivity and resolution of the data from both GALEX (UV) and Spitzer (IR), which are much higher than the sensitivity and resolution in previous studies; and
(ii). the unprecedented simultaneity of this data collection, as the data from Spitzer and GALEX were collected within the same 5-year period.

Target Galaxies

A narrow range of AGN will be investigated, that adhere to the following criteria:

i. **Seyfert Type I** : Hydrogen emission lines are Doppler broadened in Type I AGN due to the rapid motion of the gas near the accretion disk. Since the rapidly moving gas is visible, and this gas is near to the black hole, these broad lines suggest that the view of the accretion disk is not blocked. The view is near to face-on and not obscured by the torus surrounding the accretion disk.

ii. $z < 0.1$: The small redshift values ensure that the AGN are local (nearby). The location is important since light from more distant objects has a lower signal-to-noise ratio and tends to be contaminated by host galaxy light. The AGN light becomes more difficult to interpret at larger distances as host galaxy contamination becomes larger. The resolution that can be obtained for Spitzer and GALEX data—the Spitzer IRAC camera has a resolution of 2.4 arcseconds, and the GALEX camera has a maximum resolution of ~5 arcseconds—limits our study to nearby AGN. The Spitzer and GALEX beam sizes determine how well light from the nucleus can then be resolved and separated from host galaxy light.

iii. **Elliptical Shape** : Elliptical galaxies are older and thus contain older stars and exhibit little star formation. This greater age and lack of star formation means that elliptical galaxies contain few UV emitting spectral type O or B stars that might contaminate the UV light from the AGN. Also elliptical galaxies contain less dust to obscure the AGN intensity

Archived Data

The NASA/IPAC Extragalactic Database (NED) was used to search for objects that fit the above criteria. Then of those targets 34 were identified that were observed by both Spitzer and GALEX.

There will be two types of archival data extraction for this project, one will be from the GALEX pipeline extracted magnitudes from the 5th public release of data and the other will be the images from the Spitzer archive. For GALEX, the magnitudes in the Far UV (135 - 175nm) and Near UV (175 - 280nm) are available via a web interface and can be easily downloaded. For Spitzer, the IRAC 4.5 and 5.8um images can also be easily downloaded.

The initial list of targets is attached in Appendix A.

The color-magnitude plot requires data for the absolute magnitude of the center of the galaxy as well as a color measurement. For each target AGN, four photometric values will be obtained from archived data:

1. Spitzer – 5.8 μm
2. Spitzer – 4.5 μm
3. GALEX – UV1 (155 nm)
4. GALEX – UV2 (227.5 nm)

Spitzer 5.8μm data is the ideal wavelength for studying AGN because the emissions from polycyclic aromatic hydrocarbons (PAHs) occur at longer wavelengths than 5.8 μm, and contaminating starlight occurs at shorter wavelengths. However, the the IRAC 5.8μm channel is significantly more noisy than the other IRAC channels, and as a result the data quality is poorer. Nonetheless, the Spitzer 5.8μm data is much higher quality than any previously collected IR data.

Spitzer 4.5μm data is also very important to this study. AT this wavelength the data does not suffer from PAH emissions, however, it does contain some starlight contribution. The

4.5µm data is particularly useful because it does not suffer from the excess noise as is experienced at 5.8 µm, and you can therefore achieve a higher signal-to-noise ratios..

The Spitzer 3.6µm data is contaminated with starlight. Most galaxies have a significant star population that emit at this wavelength. AGN also emit at this wavelength thus yielding confusion as to the source of the 3.6µm energy.

The Spitzer 8.0µm data is also contaminated, in this case with PAH emission that can come either from the host galaxy or the dust surrounding the accretion disk of the AGN... As a result, data from 3.6µm and 8.0 µm will not be used in this study.

The data obtained from GALEX and Spitzer archives will be taken from similarly timed studies—the data will be relatively contemporaneous. By choosing data sets collected at similar times, the variable nature of AGN will have less impact on the analysis. Data collected within a 5 year timeframe allows for much higher quality wavelength comparisons than has been available previously.

Education and Outreach Goals

One important aspect of engaging students and teachers in the process of science is to provide a set of tools that require thoughtful interaction from the students. When analytical tools become too automated, the understanding of the tools is sometimes lost. In this study, the intensities at different wavelengths will be obtained using two methods: (i) GALEX data has already been analyzed and intensities of the AGN UV emissions have been quantified in an automated manner; (ii) Spitzer data will be manually analyzed using the APT (Aperture Photometry Tool). Thus, students and teachers will interact with the data to determine relevant values for intensity and relevant background subtraction parameters. In this way, students will have an opportunity to understand the processes of background subtraction and the subtleties of data reduction.

The fundamental education and outreach goals are:

- ☐ Students and teachers will present their results at the 2011 American Astronomical Society Meeting in Seattle, WA.
- ☐ Some students will develop spin-off projects from the initial study and present them at regional Science & Engineering Fairs.
- ☐ Local news media will be invited when students or teachers make presentations.
- ☐ Workshops presented to students and teachers discussing the specific laboratory modules are listed below.

Specific laboratory modules will be developed for use in high school physics and astronomy courses that:
(a) obtain muliwavelength images of galaxies from NASA databases including: NED, Spitzer, GALEX, and Sloan Digitized Sky Survey (SDSS);
(b) make use of image inspection software including: APT, DS9, MaxImDL, and MOPEX;
(c) search for correlations between spectral data and space objects;

(d) seach for “peculiarities” in the data/images; and
(e) use color to represent different intensities or wavelengths of light to help students understand the images from space

Additional specific education and outreach projects are underway:

I. Integrating the AGN study with other astronomy courses using remote workgroups

Working with a group of students remotely from around the state of Wisconsin, students will work through the introductory information in the iCollaboratory course, Variable Quasar Research Scenario II, take part in a number of discussions, and review images from the target list of quasars. These students will then progress to understanding data acquisition and processing as is described for the AGN project.

II. Using Image Processing in Summer Science Enrichment

Summer science enrichment classes (http://www.skokieparkdistrict.org/spdcm/SizzlingSummerScience.aspx) are offered to the elementary and middle school students of Illinois High School District 219 located in Skokie, IL. These classes will provide a unique opportunity to teach image processing techniques. In addition, students will use professional image processing techniques to create color images of astronomical objects.

Appendix A. Initial list of targets for the AGN study

Below are the search results for all Type I AGN observed by the IRAC camera on Spitzer. There are 34 sources, many with multiple different AORs.

Search #1: NGC4639, 12h42m52.4s,+13d15m26s, IRAC
Number of programs found: 1

PID	ReqKey	AOT Type	Status	Release Date	Coordinates	Target Name
30496	18288896	IRAC Mapping	nominal	2007-08-31	12h42m52.37000s,+13d15m26	NGC 4639

Search #2: NGC4593, 12h39m39.4s,-05d20m39s, IRAC
Number of programs found: 1

PID	ReqKey	AOT Type	Status	Release Date	Coordinates	Target Name
3269	12448768	IRAC Mapping	nominal	2006-06-23	12h39m39.43s,-5d20m39.3s	NGC4593

Search #3: NGC0931, 02h28m14.5s,+31d18m41s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

3269 12446464 IRAC Mapping nominal 2006-02-15
2h28m14.48s,+31d18m42.0s NGC931

Search #4: UGC08823, 13h53m03.4s,+69d18m29s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

1108 9577472 IRAC Mapping nominal 2004-06-24
13h53m03.45s,+69d18m29.6s MRK 279

Search #5: NGC5216, 13h32m06.9s,+62d42m02s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

3247 10531584 IRAC Mapping nominal 2005-12-08
13h32m08.90s,+62d44m02.0s Arp104

Search #6: UGC01841, 02h23m11.4s,+42d59m31s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

3418 10919168 IRAC Mapping nominal 2006-02-15
2h23m11.41s,+42d59m31.5s 3c66b

Search #7: NVSSJ173728-290802, 17h37m28.4s,-29d08m02s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

20201 14299904 IRAC Mapping nominal 2006-06-01 358.93625d,1.66166d
358.93625GLIMPSE
20201 14299648 IRAC Mapping nominal 2006-06-01 358.80125d,1.41354d
358.80125GLIMPSE
20201 14301952 IRAC Mapping nominal 2006-06-01 359.23959d,1.17428d
359.23959GLIMPSE
20201 14332160 IRAC Mapping nominal 2005-10-06 359.25976d,1.13004d
359.25976GLIMPSE
20201 14329856 IRAC Mapping nominal 2005-10-06 358.76797d,1.42639d
358.76797GLIMPSE
20201 14330112 IRAC Mapping nominal 2005-10-06 358.90479d,1.67069d
358.90479GLIMPSE

Search #8: NGC0235A, 00h42m52.8s,-23d32m27s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

3672 12342784 IRAC Mapping nominal 2005-06-09 0h42m49.40s,-
23d33m08.3s IRAS F00402-2349; NGC 0232

Search #9: SDSSJ172319.95+593834.6, 17h23m19.9s,+59d38m34s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

26 3861504 IRAC Mapping nominal 2004-05-10
17h18m00.00s,+59d30m00.0s FLS-CVZ-center
26 3861760 IRAC Mapping nominal 2004-05-10
17h18m00.00s,+59d30m00.0s FLS-CVZ-center

Search #10: IC0486, 08h00m21.0s,+26d36m48s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target
Name

50128 25470464 IRAC Mapping nominal 2009-05-21
8h00m20.59,26d36m50.35 IC486

Search #11: SBS1116+583A, 11h18m57.7s,+58d03m23s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

40757 23180800 IRAC Mapping nominal 2009-01-08 11h19m07.62s,+58d03m14.3s 951_128_52398

Search #12: ARK120, 05h16m11.4s,-00d08m59s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50253 25819392 IRAC Mapping nominal 2009-11-13 05h16m11.4s,-00d08m59s ARK120

Search #13: MRK0618, 04h36m22.2s,-10d22m33s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50253 25818880 IRAC Mapping nominal 2009-11-13 04h36m22.2s,-10d22m34s MRK0618

Search #14: ESO198-G024, 02h38m19.7s,-52d11m32s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50253 25818368 IRAC Mapping nominal 2009-11-13 02h38m19.7s,-52d11m32s ESO198-G024

Search #15: 2MASXJ14424260+0119114, 14h42m42.6s,+01d19m11s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

3221 10479360 IRAC Mapping nominal 2005-08-08 14h42m31.73s,+1d10m55.3s SDSS J1442+0110

Search #16: VIIIZw415, 14h25m05.5s,+03d13m59s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

20187 14280960 IRAC Mapping nominal 2006-08-11
14h25m06.48s,+3d13m57.6s 209126

Search #17: UGC05101, 09h35m51.7s,+61d21m11s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

32 3893248 IRAC Mapping nominal 2005-05-13
9h35m51.70s,+61d21m11.3s UGC 5101

Search #18: SDSSJ124404.52-012841.1, 12h44m04.5s,-01d28m41s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

30856 19070720 IRAC Mapping nominal 2008-03-01 12h44m28.63000s,-1d18m54. WD1241-010

Search #19: 2MASXJ10005519+0223437, 10h00m55.2s,+02d23m44s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

20070 15537152 IRAC Mapping nominal 2006-01-17
10h01m18.00s,+2d25m30.0s COSMOS 6
20070 15536640 IRAC Mapping nominal 2006-01-17
10h01m12.00s,+2d27m30.0s COSMOS 6
20070 15540736 IRAC Mapping nominal 2006-01-17
10h01m18.00s,+2d27m30.0s COSMOS 6

Search #20: 2MASXJ00584747-0105497, 00h58m47.5s,-01d05m49s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50667 26686208 IRAC Mapping nominal 2010-02-25 0h59m10.00s,-1d14m01.0s CFBDS1

Search #21: 2MASXJ02293862+0023133, 02h29m38.6s,+00d23m13s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50660 28890112 IRAC Mapping nominal 2009-04-06 2h29m13.00s,+0d35m00.0s deep2-f4-3
50660 28890368 IRAC Mapping nominal 2009-04-06 02h29m15.00s,+0d35m00.0s deep2-f4
50660 28890880 IRAC Mapping nominal 2009-04-06 02h29m14.00s,+0d35m15.0s deep2-f4
50660 28890624 IRAC Mapping nominal 2009-04-06 02h29m14.00s,+0d34m45.0s deep2-f4

Search #22: VIIZw468, 12h32m37.5s,+66d24m52s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

20369 15695360 IRAC Mapping nominal 2006-12-14 12h32m04.80s,+66d24m11.0s VIIZw466

Search #23: VIIIZw386, 14h14m47.2s,-00d00m13s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50292 25918208 IRAC Mapping nominal 2010-04-06 14h14m43.90s,-0d23m53.4s Abell 1882

Search #24: 3C111, 04h18m21.3s,+38d01m35s, IRAC
Number of programs found: 2

PID ReqKey AOT Type Status Release Date Coordinates Target Name

3327 10755840 IRAC Mapping nominal 2005-10-27 4h18m30.00s,+38d02m30.0s 3C111
30574 19967744 IRAC Mapping nominal 2007-04-12 4h19m30.00000s,+38d12m47. auri_irac1
30574 19984640 IRAC Mapping nominal 2007-04-12 4h19m30.00000s,+38d12m47. auri_irac1

Search #25: 2MASXJ04372814-4711298, 04h37m28.2s,-47d11m29s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

23 12541952 IRAC Mapping nominal 2005-12-08 4h37m15.76s,-47d15m07.8s psr J0437-4715

Search #26: CGCG173-014, 18h35m03.4s,+32d41m46s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

3418 10924544 IRAC Mapping nominal 2006-06-01 18h35m02.15s,+32d41m50.2s 3c382

Search #27: PG0844+349, 08h47m42.5s,+34d45m04s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

40183 22497024 IRAC Mapping nominal 2008-12-02 8h47m42.40000s,+34d45m04. PG0844+349

Search #28: MRK0205, 12h21m44.0s,+75d18m38s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

30603 18598144 IRAC Mapping nominal 2008-03-01 12h21m43.87s,+75d19m21.3s ngc4319

Search #29: 2MASXJ08131934+4608496, 08h13m19.3s,+46d08m49s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

59 4328704 IRAC Mapping nominal 2005-05-26 8h13m14.73s,+45d59m26.3s NGC2537

Search #30: IRAS09149-6206, 09h16m09.4s,-62d19m29s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

50763 27092224 IRAC Mapping nominal 2009-05-21 139.039200d,-62.324850d IRAS09149-6206

Search #31: 2MASXJ09155946+5326576, 09h15m59.5s,+53d26m57s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

2313 10123008 IRAC Mapping nominal 2005-12-08 9h15m56.20s,53d25m22.8s WD0912+536

Search #32: 2MASXJ16363129+4202429, 16h36m31.3s,+42d02m42s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

183 10054912 IRAC Mapping nominal 2004-07-16 16h36m48s,41d01m45s ELAIS_N2
183 5861632 IRAC Mapping nominal 2004-07-16 16h36m48s,41d01m45s ELAIS_N2

Search #33: MCG+06-37-020, 17h00m07.2s,+37d50m22s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

30344 18085120 IRAC Mapping nominal 2007-08-29 16h59m19.97000s,+37d43m32 SDSS165919.97+374332.7

Search #34: 2MASXJ05030396-6633456, 05h03m04.0s,-66d33m46s, IRAC
Number of programs found: 1

PID ReqKey AOT Type Status Release Date Coordinates Target Name

20203 14362880 IRAC Mapping nominal 2005-12-08 4h59m28.50s,-
66d00m32.27s LMC
20203 14352128 IRAC Mapping nominal 2005-12-08 5h03m50.48s,-
66d41m51.83s LMC
20203 14364672 IRAC Mapping nominal 2005-11-22 5h07m38.12s,-
66d37m39.15s LMC