



Spitzer Space Telescope Research Program for Teachers and Students: Using Spitzer Data to Teach About Active Galactic Nuclei



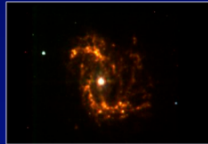
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Abstract: The combined Spitzer Space Telescope and Wide-field Infrared Survey Explorer (WISE) Research Program for Teachers and Students developed through a partnership between the Spitzer Science Center (SSC), the WISE EPO program, and the National Optical Astronomy Observatory (NOAO) provides teachers and students the opportunity to do research using data collected by the Spitzer Space Telescope and eventually the WISE mission. The NGC 4051 team is studying variability in this active galactic nucleus in order to place limits on the dust distribution around its nucleus. The team of 26 teachers and students met at the SSC in August 2008 to analyze data collected by Spitzer's IRAC camera as well as optical data collected by team members using remote ground based telescopes. The team is mentored by Spitzer scientist Dr. Varoujan Gorjian. In this poster we will describe the tools used for data reduction. In addition, we describe how the relationship between optical and infrared signals can be obtained through cross-correlation analysis. We start with very simple examples and then show how this technique is used to obtain the time lag for Markarian 744 from published optical and infrared data. For the science results please see our companion poster, Gorjian, et al.

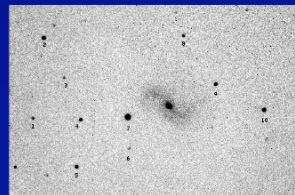
Overview of Project

NGC 4051 is a Seyfert 1 galaxy containing a supermassive black hole at its center. Our team monitored this AGN in optical and infrared wavelengths. We hoped to detect variability that would allow us to place limits on the dust distribution around the galactic nucleus. Right: Tri color image of NGC 4051 in 4.5 (blue), 5.8 (green), and 8 (red) microns.



How the data was collected:

Students from across the country monitored the brightness of NGC 4051 using remote telescopes. Each night, the students took five images using the blue, visible and red Johnson filters each with exposure times of 180 seconds. Images of NGC 4051 were collected from May 20th to June 20th using telescopes at New Mexico Skies Observatory (paid for by NOAO), Grainger Observatory telescopes at Exeter Academy, the Faulkes telescope in Hawaii and the 0.9m telescope at Kitt Peak.



Left: A finder chart was created to enable students to quickly identify reference stars used in measurements of brightness.

How do you reduce 2.26 gigabytes of image data?

Sifting through hundreds of images and finding the relevant data is a time consuming process. Finding an efficient way of doing this can be challenging. How do you know where to look and what to look for? By using a research team approach, we split up the data amongst the groups. Students were separated into groups of 2 or 3 people and assigned a proportional amount of images to examine. Each student examined roughly 50-100 images. This cut down on the required reduction time; however, it created a greater possibility for mathematical errors to be introduced into our findings. The team compensated for this by double-checking each other's work. Each group examined a sample of images from another group and compared their results to verify the group's accuracy.

The students opened each image and used the APT program to measure a variety of parameters in each image including the brightness of the center of the galaxy and of the nearby stars which were used as a references for comparison. The data was collected and stored in a separate output file on our computers. These files were then exported into an excel spreadsheet and combined into one master sheet.

DETERMINING DUST DISTRIBUTION THROUGH CORRELATION FUNCTIONS

THIN SPHERICAL MODEL OF DUST REVERBERATION

Response to an Instantaneous Outburst From O

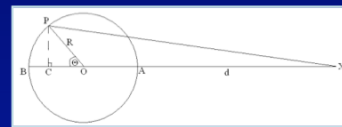


FIGURE 1: Schematic view of near-infrared emission from a thin spherical shell of radius R. The centre O is the source of UV/optical radiation and the dust lies on the surface of the shell. The observer, to the right, sees the optical outburst and the infrared response at a time delay t that varies from 0 to $2R/c$ (see below). A and B are points on the spherical shell that lie along the observer's line of sight. Point P is inclined at an angle of θ to AB. (Diagram not drawn to scale.)

$$\chi P^2 = d^2 [1 + \frac{2R(1 + \cos \theta)}{d} + \frac{2R^2(1 + \cos \theta)}{d^2}]$$

If $R \ll d$ then,

$$\chi P \approx d + R(1 + \cos \theta)$$

and the time delay is,

$$\tau(\theta) = \frac{R}{c} (1 + \cos \theta)$$

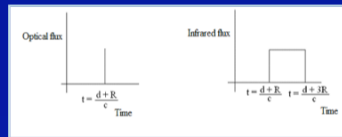


FIGURE 2: Optical and Infrared response to an instantaneous outburst at O. Note that the optical pulse arrives at $t = (d+R)/c$ while the infrared pulse due to contributions of the dust particles that are situated at various distances from the observer occurs continuously from $t = (d+R)/c$ to $t = (d+3R)/c$. (Diagram not drawn to scale.)

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USING CROSS-CORRELATION FUNCTION TO OBTAIN THE TIME LAG FOR MARKARIAN 744

The cross-correlation function, CCF, is defined as,

$$CCF(\tau) = \frac{1}{N} \sum [C(t_i) - \langle C \rangle][I(t_i + \tau) - \langle I \rangle]$$

Where $C(t)$ is the radiating V band and $I(t)$ is the K' band. The angled brackets represent averages, and N is the number of data points.

Date (UT)	V Band (Magnitude)	K' band (Magnitude)
12.16.94	14.6	10.59
02.16.95	14.56	10.39
02.20.95	14.38	-----
03.24.95	14.34	10.26
04.25.95	14.52	10.17
06.11.95	14.65	10.45

Procedure to calculate CCF

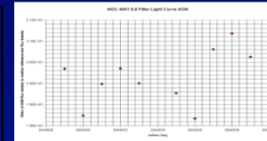
We used linear interpolation to calculate the magnitude in the V and K' bands for every ten days starting from 12.16.94 to 06.11.95. We then calculated the CCF and the results are shown below.

Time lag (days)	CCF
0	0.007098
10	0.00837
20	0.009183
30	0.00925
40	0.008138
50	0.005911
60	0.002499

The time lag is defined as the peak of the CCF which in this case is 30 days.

References

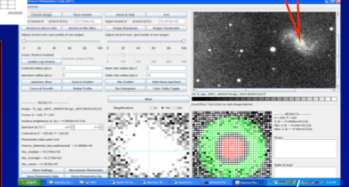
1. Nelson, B.O. 1996, ApJ, 465, L87.



Left: Light curve of NGC 4051 at 5.8 μ m. Students collected the optical data to be used for comparison with IR data.



Right: Sample picture of the APT screen that is focused on a star. The red circle represents the aperture radius, the green circle represents the inner-sky radius and the yellow circle represents the outer-sky radius.



<http://spider.ipac.caltech.edu/staff/laher/ap/>

In our research when we analyzed the photos taken by the Spitzer telescope and other ground based telescopes. We used a program called Aperture Photometry Tool (APT). Currently you can download version 0.994, but when we used this tool we used version 0.992. When we used this tool we adjusted the aperture settings. We adjusted the aperture setting according to the size of the star in the photo. A majority of the time we set the aperture radius to 8, the inner-sky radius to 10 and the outer-sky radius to 15. The purpose of the aperture ring is to measure the background so it can be subtracted from the star's flux measurement. We measured the Galaxy NGC 4051 and 10 background stars (when visible) in every picture. We chose an image to analyze then moved the cursor over the star we wanted to analyze and clicked on it. Then we clicked the button labeled "Save Photometry Data". To view all of our data we clicked the button labeled "Show Photometry Data". After all measurements were made we viewed all of the data and copied it into an Excel spreadsheet.

What are the benefits for students?

- The students participating in this research study agree that this invaluable opportunity has allowed them to learn about conducting authentic astronomical research and to work together in a cooperative effort.



- The students assumed the responsibility for data reduction and analysis. They learned valuable lessons concerning team involvement, personal responsibility and cross-country collaboration.



- Guided by their mentors the students found they were adept in the tasks of research analysis and continue to work on the project at their individual schools. Their increased interest in scientific research resulting from this experience may serve as a catalyst to encourage their future study in the sciences.