First Time Observations of Variables in Mid-Infrared using Spitzer

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ABSTRACT
The variability of stars, especially at rapid time scales, in the mid-infrared wavelength region has had limited investigations and has not been thoroughly explored. By using archival Spitzer data, our science team would like to explore the variability of stars at mid-infrared wavelengths. We will examine images obtained in the 3-8 micron range and will produce photometric measurements for each point source measured. We have developed criteria for selecting aperiodic candidates which includes the length of time, the filter type, position, galactic longitude and latitude, and the integration time. Utilizing DS9 and APT, three target fields were selected and we will use IRAF at SSC to further examine the images at different wavelengths, create light curves, and compare color differences. If variable stars are found, we can compare with data from one of the other wavelengths previously obtained such as x-ray all sky surveys, VLA FIRST, etc., to further classify the variable stars.

SCIENTIFIC MERIT

Goals

Our goal is to examine Spitzer Space Telescope Infrared Array Camera [IRAC] data from the archive for fields that have been looked at continuously for five to eight hours. We will measure photometry for all point sources in the field of view [FOV] and compile light curves for up to several hundred stars. We plan to explore and catalog the variability of stars in the mid-IR sky in these fields.

Background

The following observations are presented as examples of differences between variations found for variable stars in the near-infrared and at visible wavelengths. Although we shall construct light curves in the mid-infrared for stars with periods of less than a day, these examples illustrate that new behaviors may be found when stellar variations are examined at lesser-studied regions of the star's spectrum. One of the more well known variables is Mira [Omicron Ceti], the Wonderful, whose variation was recorded in 1596. Mira varies from magnitude 9 to 3 in the visible over some 330 days. However, in the IR J band, AAVSO observers have found the variation in J-mag to be much less, from about magnitude -0.9 to -1.9, with the IR response lagging the visual by ~0.2 cycles in its phase plot. [West and Templeton, 2006]. These substantial differences indicate that a star's IR variation has information to convey. In this instance Mira is much brighter in the IR throughout its variation and the IR tells us more about the actual temperature of the star [AAVSO "Infrared Photoelectric Photometry"]. The Cepheid variable Eta Aquilae displays similar differences. In the visible this star varies about 1 magnitude from 4.4 to 3.5 on average, with a period of some 7.2 days, much shorter than for Mira. Eta Aquilae is, as Mira, much brighter in the near IR, with an average J magnitude of 2.42 and a range of only 0.3 [H magnitude 2.05, range only 0.2 magnitude].

The RR Lyrae variables have periods of 0.2 to 1 day that are more nearly in the range we will explore. These are one of the more numerous of the variable types. These stars are used as a distance indicator, but there remain difficulties in using their V-magnitude to precisely determine distances. However, the light curve for RR Lyrae variables in the K band [2.2 microns] yields a Period-Luminosity relationship that is more precise. This demonstrates that the information given by light curves in the IR for variables can be even more useful than information deduced from the visible light [M. Dall'Ora1 et al. 2004].

Methodology of Target Selection

In order to identify rapid variability (on the order of minutes to hours) of stars in the mid IR region, we will select a set of three fields of view (FOVs) that will provide us with enough images to create the light curves we'll use in the identification of these objects. Because we are using archival data, we began with FOVs which had been imaged using parameters which would also allow analysis for rapid variability in the surrounding star field; namely, thirty exoplanet fields observed using Spitzer's IRAC full array mode. These fields have been observed for a continuous block of at least several hours and contain "ordinary" field stars. The DS9 program was utilized to view the thirty targets using 2MASS images. An image size of 5' X 5' was selected as it was determined it would match the FOV that is imaged by IRAC. Each image was also viewed in the K-band since this is the 2MASS detector that most closely approaches the IRAC mid-infrared channels. A subset of the targets was close to the plane of the galaxy and had an object density that would make it too difficult to use APT to create light curves. These were eliminated from consideration. Of the remaining targets, our initial list has been reduced to three. The targets are: HAT-P-1b, TrES-2, TrES-4. Data from all four channels of IRAC is available for these three targets. All of these were obtained using the full array mode which gives us a wider field of view. Each of these fields was observed continuously for five to eight hours with individual exposures of twelve seconds.

Each of our fields has a single star near its center that was the original target. We shall examine numerous stars, approximately fifty to one hundred per field, in the field surrounding this central object. The original targets were stars having exoplanets and were observed for periods of many hours [in our cases for 3.5 to 8 hours] in order to determine the periods of the exoplanets. In order to get our bearings within these fields we wanted to find the original target and verify that it was indeed within our field. The 2MASS identification number of the original target was obtained from SIMBAD. We then used DS9 to examine the 5' by 5' image of the original target and used Analysis→Catalogs→Infrared→2MASS Point Source to obtain the Catalog Tool list of the objects within the field, including the 2MASS identification number and magnitudes of the original target and the surrounding stars in J, H and K bands. We verified that each was indeed within the image that we obtained from 2MASS.

Using Spitzer Data

The observations we have described above are from the near-IR. Our goal is to explore stars in the mid-IR sky to see what light curves we can establish for that region of the spectrum. We will derive an atlas of mid-infrared light curves of variable stars from three Spitzer IRAC fields. Some of our observations will be of variable types that are already known from the visible and our observations would extend the information we could deduce about the nature of these objects. The more exciting prospect of our work would be that some of the mid-IR variations we discover would not be obviously related to corresponding variations in the visible, but could be the discovery of previously unknown variations that result from object types that have not yet been described.

Our basic proposal is to perform a survey of stars within our chosen FOV. Based on a visual inspection of IRAC imagers of our selected fields, we estimate up to several hundred detectable stars. We intend to determine what percentages of such stars vary in the mid-IR. The FOVs we choose will have at least two and as many as four mid-IR channels [IRAC 3.6, 5.5, 5.8 and 8.0 microns] so that we would characterize our variables in more than one filter. There are a number of types of short period variables in the visible that we could expect to find in the IR as well. These include eclipsing binaries, delta Scuti variables and "spotted stars" such as RS CVn stars. We discuss aspects of each of these in the following three paragraphs.

For eclipsing binaries the IR light curve may well show us details of the binary system that are not found from the visible light curve. For example, the well-known eclipsing variable Algol shows more detail in its IR light curve than in its visible-range light curve. This leads to more accurate determination of the physical properties of the Algol system [AAVSO "Infrared Photoelectric Photometry"]. We anticipate that our search will discover eclipsing variables in the mid-IR that have not been observed previously.

Delta Scuti variables are short-period variables with periods ranging from 0.03 to 0.3 days, a time scale that matches the data we plan to look at. High-amplitude delta Scuti stars [HADS] have magnitude variations in the visible of > 0.1 and Low-amplitude delta Scuti [LADS] has delta m < 0.1. Astronomers are able to infer interesting information from the activity of Delta Scuti stars. LADS give us information about stellar structure through the tool of asteroseismology , while HADS subtypes are used as standard candles. [AAVSO: "VSOS: Delta Scuti and Delta Scuti variables."] Studying the behavior of these variables into the mid-IR would extend our knowledge of astrophysics in general. For example, because Delti Scuti stars lie on the instability strip, expanding our understanding of how they vary could well improve our models for the causes of these instabilities. [IRAS observations of Delta Scuti variables-Implications for main-sequence mass loss and an IR period-luminosity relation, Jeremy King, PASP, 1990]

Another type of variable that would be appropriate for our study is the short-period subgroup of RS Canum Venaticorum variables. These are eclipsing variable stars that show aperiodic excursions. These variations may be caused by "starspots," caused by activity in the star's chromosphere that is analogous to sunspot activity that occurs in our own sun. By finding light curves in the mid-IR that correspond to these variables in the visible, we could again improve our models for these binary systems.

For stars we found that merited further work we could use the multi-channel Spitzer data to create magnitude-color curves or color-color curves [such at channel 3.6-4.5 vs.5.8-8.0]. We could determine where the bulk of our measurements occurred on these diagrams, which would then allow us to focus on the objects that were not members of standard populations. Further investigations in another proposal could include comparing the most interesting such objects to 2MASS optical, x-ray etc. surveys where additional information would provide further insight into the nature of the target.

IRAC provides a wealth of observations in the mid-IR. We will use these data to identify fields suitable for further exploration. Creating light curves will provide information as to whether the objects are rapid variables or not. Future studies may include comparing the variations we find in the mid-IR with types of variable star behavior that is already known to occur in the visible, through which we will extend our knowledge of the nature of the various types of our shorter period variables. Most exciting to us is our expectation that we will observe light curves of rapidly varying objects at mid IR wavelengths that have not previously been described.

DATA ANALYSIS TECHNIQUES

DS9 was utilized to preview possible star fields from our list of thirty-three candidate IRAC. We used the Analysis→Image-Servers→IPAC-2MASS tool to select 5' by 5' images of our fields that matches the IRAC fov. We then used the Catalog Tool, via Analysis→Catalogs→Infrared→2MASS Point Sources to determine the number of stars within that central target's surrounding field of view. From this list we selected the three fields that we judged would have a star density that would allow us to use the Aperture Photometry Tool to measure the source intensity effectively.

We studied the document Aperture Photometry Tool [Laher R. R., et al., 2010] and utilized this tool on "practice" images in order to become familiar with this program. Our goal is to use this tool to manually determine the light curves for approximately thirty stars within our three fields in preparation for our automated analysis this summer. Ten possible aperture settings that we might use are listed in Table 5.7: "IRAC aperture corrections" from the IRAC Data Handbook. To achieve our goal we must determine which aperture setting would provide us with light curves with the smallest scatter. For example, would a radius of source = 3 pixels and background annulus with inner radius 3 pixels and outer radius 7 pixels provide more or less scatter than aperture with radius = 3 pixels and a background annulus of 10 to 20 pixels? Choosing among the four possible sky background subtractions will be the next step. Once these choices are made, we will approximately center the cursor on the source; then use the "Snap" button to nudge the cursor to the pixel that the operator will judge to be at the center of our stellar source. We will check this choice by using the "aperture slice" tool to verify that the cursor is properly centered. Then we will save the properly recomputed photometry of a file. This gave us the background-subtracted Flux in units of MJy/sr.

Finally we will use the aperture correction, a_{cor},that is appropriate for our choice of aperture radius and background annulus to convert from source Flux to Flux Density in units of mJy, using the conversion equation given in the IRAC Data Handbook.

Once we have determined our approximately thirty light curves using APT from this hands-on approach, we shall use the IRAF software to analyze the several hundreds of stars that we judge to be present in our three target fields. By examining these light curves we will determine whether or not we have found any variable stars.

EDUCATIONAL MERIT

Students of all the teachers involved in the project will play active roles in the process of project development, teamwork, literature searches, data collection and analysis, interpretation of results and formal scientific presentations. Students will gain knowledge about the physical properties of light, such as wavelength, flux, and the processes that affect the luminosity of stars. The need of space-based telescopes will also be reinforced. Both teachers and students will learn how to use and the importance of using DS9 and APT as astronomy tools.

Rich Decoster's Outreach Plan

Rich plans to involve the twelve physics teachers in the surrounding area through sessions at the annual institute days. The Chicago Section of AAPT holds meetings twice a year in which an afternoon workshop about the Spitzer and our project could be shared. Rich also intends to present a sectional at the Illinois Science Teachers Association and possibly to a given nucleus of teachers in the Chicago area to interested teachers. Many of the NITARP teachers t are associated the Yerkes Observatory outreach program. We could put together ideas from our three groups and form a joint presentation for area teachers.

Peggy Piper's Outreach Plan

Peggy's outreach plan includes bringing together the physics and astronomy teachers at the 4 high schools in her district as well as members of the Air Force ROTC (Reserve Officer's Training Program). She will introduce these leaders and their students to the world of imaging and infrared wavelength astronomy through involvement in the HOU/WISE (Hands-on-Universe/Wide field Infrared Survey Explorer) asteroid search program. Use of SOFIA (Stratospheric Observatory For Infrared Astronomy), Active Astronomy and HOU imaging is integral to this effort. Building on this introduction, she plans on presenting information relevant to the Spitzer Program and the value of using authentic data to her district Science Department, again composed of 4 schools, over 80 science teachers. Additional opportunities for outreach are under development with colleagues in the ARCS (Astronomy Resources Connecting Schools) teacher leadership group working out of Yerkes Observatory in Williams Bay Wisconsin. Along with Rich and several other NITARP teachers, we will present workshop sessions to our wide range of K-12 teachers who reside as far north as Minnesota and as far south as Southern Illinois.

Beth Thomas' Outreach plan

Beth's outreach components will involve presenting information about the Spitzer Space Telescope and infrared astronomy at the Montana Education Association in Helena, Montana in October of 2010. In addition, she will also use infrared and electromagnetism as one of the topics at a four day summer teacher inquiry professional development for middle school teachers she is teaching at the Montana Learning Center. These standards-based lessons will utilize materials from SOFIA and will promote inquiry and interest in space research, technology and in general science. Science colleagues at large will further develop and increase science awareness and interest in infrared astronomy through education outreach. Tim Spuck and Beth are going to propose to present information about the Spitzer's Teacher Program, NITARP and support lessons/activities at the National Science Teacher's Convention in San Francisco in March 2011.

Learning Activities

The following are examples of the types of activities and lessons that can be incorporate in classroom and extra-curricular activities to enhance student's ability to successfully participate in the NITARP program. These activities focus on visual, kinesthetic (i.e. hands-on) activities which will help students connect to the material being presented. Kits were previously designed to teach students about infrared astronomy, imaging, and the electromagnetic spectrum will be incorporated in these lessons. Several computer imaging activities are included as well to help students more fully understand the process of data collection that was used to gather Spitzer archival data and will be used to analyze selected data.

- Multiwavelength Astronomy Activities: Students will gain an understanding of the electromagnetic spectrum, radiation of blackbodies and the purpose of study specific wavelengths. Using hands on lessons such as those incorporated into the SOFIA Active Astronomy Kit, students will gain knowledge of the electromagnetic spectrum and the relationship between wavelength, frequency and the energy of emitted light. They will then practice using visible light filters to observe everyday objects as well as astronomical slides to appreciate the use of filters to study specific features of an object. Additional focus will be given to infrared light. Students will learn how the wavelengths of infrared light emitted by objects of various temperatures and the ability of infrared light to pass through some materials, yet be blocked by others.

- Imaging Activities: Students will learn to manipulate images and understand that changes to the apparent image do not affect the quantitative measurements of that image. Using appropriate imaging software and lessons such as those provided by HOU (Hands on Universe), students will practice manipulating a various images to understand the basics of CCD data collection and produce images to study specific aspects of interest. Students will learn to collect quantitative data from these images and learn that this quantitative data remains constant as they change visually.

- Variable Stars: Students will learn about what variable stars are and how scientists study them using lessons such as the Spitzer hands on lessons "Interacting Binary Star System Activity"," Simulation of an Eclipse of WZ Sge", and HOU imaging of variable star lessons. The students will practice producing light curves for variable stars and the concepts of variation and period will be incorporated as will discussion of the various types of variable stars.

- Understanding of Timekeeping: Students will be exposed to the various methods of timekeeping and in particular the Julian calendar using various methods including the Calendar Scavenger hunt.

- These student exercises and lesson plans will be available on the NITARP wiki site.

Students will aid in the interpretation of the data collected from this project. These students will gain a unique insight into the research process. Our students will learn how to research archival data and perform literature searches to support their interpretations. Once students know how to access Spitzer and other archival data and perform literature searches, they can design research questions that can be answered using existing data in infrared and other wavelengths. This work will potentially lead to new research projects by interested students and/or classes.

All the activities described above are aligned with the National Science Educational Standards and associated benchmarks. The standards of note are A (Scientific Inquiry), D (Evolution of the Universe), and E (Abilities of Technological Design).

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