Deciphering IR Excess Observed by the Spitzer Space Telescope in Short Period Interacting Cataclysmic Binaries

Howard Chun (Lead), Cranston High School East, Cranston, RI
howiec1@earthlink.net

Linda Stefaniak, Allentown High School, Allentown, NJ
stefanl@optonline.net

Beth Thomas, West Elementary School, Great Falls, MT
beth_thomas@gfps.k12.mt.us

Dr. Steve Howell, National Optical Astronomical Observatory, Tucson, AZ
howell@noao.edu

Dr. Don Hoard, Spitzer Science Center, Pasadena, CA
hoard@ipac.caltech.edu

Dr. David Ciardi, Michelson Science Center, Pasadena, CA
ciardi@ipac.caltech.edu

Dr. Carolyn Brinkworth, Spitzer Science Center, Pasadena, CA
csb@ipac.caltech.edu

During the first year of the Spitzer Space Telescope Observing Program for Students and Teachers, our team observed a small sample of short orbital period interacting white dwarf binaries. Our scientific investigation was aimed at detection and characterization of the low mass, cool, brown dwarf-like mass donors in these systems. We used the Infrared Array Camera to obtain photometric observations of the polars EF Eri, GG Leo, V347 Pav, and RX J0154.0-5947 at 3.6, 4.5, 5.8, and 8.0 microns. In all our targets, we detected excess emission in the 3-8 micron region over that expected from a brown dwarf alone.

We have fully reduced and analyzed our photometric observations and recently submitted a paper to ApJ letters with our findings. In addition, we had a scientific and an educational poster at the Jan. 2006 AAS meeting as well as a joint SSC/NOAO press release on our discovery. We explored the cause for the detected IR excess by examining the cases of bremsstrahlung, cyclotron emission, circumbinary dust, and the mass donor star being a late T dwarf-like star. While bremsstrahlung and cyclotron emission could not positively be eliminated as contributors to the excess, the most likely candidates at present are circumbinary dust or the cool, low mass secondary star.

If the dust was produced by aeons of mass outflow from the binary (winds or novae) or possibly remaining material from the common envelope stage ejected with some orbital angular momentum, dynamic arguments lead us to expect that this material would form into a circumbinary disk. If a dust disk is present and it is similar to that seen in GD 362, we would expect the inner disk temperature to be near 800K. The emitting volume of such a disk must be large compared to the component stars (which are Earth-sized, and Jupiter-sized respectively) as it outshines even the cool brown dwarf-like component in the IR.

Perhaps the excess emission is simply due to the secondary stars themselves. We have seen that they would have to be similar to late T dwarfs-a conclusion that is in general accord with theoretical predictions made by CV evolution models (e.g., Howell et al. 2001). The formation of these low mass, cool secondaries is probably due to mass stripping via the accretion process for many giga-years so they are unlikely to be exact replicas of T dwarfs but nearly equal, at the present epoch, in size and temperature.

However, neither a simple dust disk, as modeled here, or a late type T dwarf alone (or in combination) can fully explain the observed IR excess. Spectral observations are needed to distinguish between the possibilities discussed above and provide details to allow an understanding of the cause of the observed IR excess. No other telescope/instrument is capable of solving this mystery and with photometry alone, we cannot distinguish between the competing ideas.

One of the exciting discoveries we made with our IRAC observations is that the star EF Eri was found to be unexpectedly bright in the mid-IR (compared to its 2MASS magnitudes). This fact highlights an opportunity for us to observe EF Eri with the IRS as a follow-up proposal. EF Eri has a flux level of ~700 μJy at 8 microns. Thus, we are asking for time to obtain IRS data for only this star, our brightest source. We plan to obtain SL1 (7.4-14.5 microns) and SL2 (5.2-8.7 microns) spectroscopy only. We know the IRAC fluxes so our integration times are well constrained and the spectral region covered by SL1, SL2 will yield sufficient S/N to differentiate between cool dust (rising BB like spectrum with PAH and other molecular features allowing us to determine dust size, temperature, and disk extent) and a T type dwarf showing characteristic spectral signatures and a falling Rayleigh-Jeans tail.

Note: EF Eri has been previously observed with Spitzer as an add-on to a GTO nova program (Gehrz). EF Eri is not a nova. The GTO observations, summarized below, used integration times that were greatly insufficient (by ~150 times) to detect anything usable. Our team now knows the real flux of EF Eri at 8 microns based on our recent IRAC measurements.

Summary of previous GTO observations

SL2: 6 sec x 5 cycles S/N = 1 (single exposure)
SL1: 6 sec x 5 cycles S/N = 1 (single exposure)
SH: 6 sec x 6 cycles S/N = 0.1 (single exposure)
LH: 6 sec x 6 cycles S/N = 0.1 (single exposure)

Educational Merit:

Lead teacher Chun and co-investigator Stefaniak are high school science teachers. Co-investigator Thomas teaches K-12 science. Each teacher has integrated research into his or her curriculum in one fashion or another. The addition of the results from the Spitzer Brown Dwarf and IR Excess study to the Spitzer results from the current Spitzer Brown Dwarf project will create an ideal model for the teachers to have to teach science and research in the classroom. The following descriptions highlight how each teacher uses research and how they will incorporate the Spitzer data.

Lead Teacher (Howard Chun): Each year I use research as the foundation for my honors 2 physics class (15-18 students). Astronomy research is the mechanism that drives my students to study modern physics (relativity, quantum physics-spectroscopy, nuclear physics-fission, fusion, nucleosynthesis) and related astronomy topics. Through their research projects my students learn how to effectively search archives, how to collect, analyze, and present (e.g., graphing) data, and how to organize and write effective and persuasive reports and papers. The students will also become adept at using various image processing programs (e.g., ImageJ, DS9, Graphical Analysis), EXCEL, and word processing. As a result of both the current Brown Dwarf project and the IR Excess study, I will also present to the class my research experience as a case study model for the scientific research process.

Co-Investigator (Linda Stefaniak): Each year I teach a minimum of two astronomy classes, one per semester, into which I incorporate a research project representing approximately 20% of our class time. My students learn to use a variety of image processing programs, learn to interpret data by graphing it a number of different ways and choose the graphing technique that best represents the data, giving arguments for and against all other approaches. As a component of the class I also stress the importance of the scientific method as a problem solving technique. They learn the necessity of a logical approach to a question, how to gather evidence with which they will support their interpretation and the importance of the peer review of these interpretations so that alternative conclusions might be considered. My students also provide volunteer services as astronomy ambassadors to the PTA's Science Night Live program where they teach simple concepts in astronomy from lessons they develop in class.

Co-Investigator (Beth Thomas): Last spring, I implemented infrared activities in my middle school science classroom. I also shared a great deal of information with students about the Spitzer Space Telescope and the projects, "Observing the Other Iron Stars" and "Detecting Brown Dwarfs in Interacting Cataclysmic Binaries". Students gained a new perspective of stellar evolution from authentic research. They also learned about spectroscopy and the process of scientific research. This past fall, I had an opportunity to transfer to a different teaching position in my school district. I am now a K-12 science teacher, but I primarily focus on grades K-6. I work with students from every school in the district in various science areas. The Brown Dwarf project in combination with the IR excess study is a terrific model to use to show my students how the process of questioning and authentic research works.

Learning Activities

The following statements describe learning activities developed for incorporation into lessons that could be used by the teachers as part of their current teaching situations. These lessons stress the importance of modeling in the interpretation of data and how they can be used to make a difficult concept more understandable to another teacher, a student or class. Models can be physical constructs that show the interaction of the components of a system, that elaborate on the details or inner workings of materials too small to be seen with the naked eye or too large to easily encompass as a whole. Models can also be theoretical, allowing patterns of known data to guide the interpretation of newly derived measurements that lead generally to the logical or unique development of new theories in science and specifically, in astronomy. We will share these lessons with other teachers via professional development seminars in our respective districts and at state teachers' conventions. Described below are the core lessons we suggest using with our classes and the additional elements we will provide.

- "Black Box" Hypothesizing: Students gain an understanding of making indirect observations when all of their senses may not necessarily be available. Commercially available materials such as the Obscertainer can be purchased, or easily made from materials readily available at the school. Provide students with sealed, opaque containers, such as those from ice cream or yogurt, and fill them with objects of various shapes, sizes and composition. Students manipulate the containers without unsealing them to hypothesize what they believe may be inside. Based on the dimensions of the container and any clues they may derive from their manipulations, students should include what the unknowns may be made of, their approximate dimensions, shapes, etc. Suggested contents might include: dominoes, marbles, cotton balls, rice, sand, toothpicks, pencil erasers, etc.
- Data interpretation: Students learn to derive a best fit curve to a scatter plot of data using magnetogram images of the sun collected by the Vacuum Telescope at Kitt Peak National Observatory in Tucson, AZ. Students will notice considerable variation and noise in their data as they fit their trend line to the data. They will then determine the eccentricity of the earth's orbit from this data, noticing that they can manipulate their trend line to achieve a better fit to the accepted measurement of this value
- Physical model building: Students can use the Exploratorium's solar system scale model calculator to determine the dimensions of a scale model of the Sun and as many planets as can fit within a specified area. Students should discuss the limitations of their model and the practicality of what they have constructed
- Sample prepackaged model of scientific research using the Brown Dwarf and IR Excess studies:
    a) Select question or determine hypothesis: "Could a characteristic blackbody curve (SED) of the brown dwarf companion star of a Polar be detected using IRAC on the Spitzer telescope?"
    b) Have students perform Spitzer and other archival research to learn about Polars and the capabilities of the Spitzer Telescope.
    c) Collect data: Present the processed Spitzer Space Telescope IRAC data of the four observed objects and have the students perform Spitzer and other archival search for more photometric information in the near IR wavelengths.
    d) Analyze data: Graph photometric values (create SEDs) from the Spitzer data and include near IR photometric data from other sources (provide 2MASS and journal data if the students cannot find this information). Unexpected results: the blackbody curve of the brown dwarf companion appears hidden by IR excess of unknown origin. Research is required to determine the possible sources of the IR excesses. Once again, the students will perform a Spitzer and other archival search for background material on white dwarfs, low mass stars, brown dwarfs, dust disks, and bremsstrahlung, and cyclotron emission (some of these areas of

study will be suggested by the teachers) With some guidance from the teacher, the students will understand how the teachers and astronomers came to their conclusions.

e) Conclusions: Source of IR excess most likely circumbinary dust disk. Possibly T-type dwarf. Least likely Bremsstrahlung and cyclotron emission. However, a spectrum needs to be taken of one of the four objects to ascertain which conclusion is the correct conclusion. Strong argument for more Spitzer observation time.
f) Provided that a spectrum is obtained, the scientific research process starts again. Results yet to be determined.

Just as in the Brown Dwarf project, students will aid in the interpretation and reduction of the data collected from the IR excess study. Through both the Brown Dwarf and IR excess projects, 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).

Professional Development:

Lead Teacher (Howard Chun): Last fall, I held two district-wide workshops on using research in the science classroom. I demonstrated what I did in the classroom and then showed the attending science teachers what they could do in their chemistry and physics classroom (using spectroscopy in particular). I emphasized IR, but I also include the visible portion of the EM spectrum. I also gave a two-hour lecture on the Spitzer Space Telescope Observing Program for Students and Teachers, the telescope design, and the Brown Dwarf research to a local astronomy club (Skyscrapers). I plan to run similar workshops this coming fall with prepackaged activities developed around the original Brown Dwarf project and the proposed IR Excess Study project. Creating prepackaged (canned) activities out of our research projects (ideally accessible from a central website) will provide inexperienced teachers with set of useable classroom exercises and a positive concrete experience with IR research.

Co-Investigator (Linda Stefaniak): I am an active member of the National Science Teacher's Association as well as my state association and am a New Jersey Department of Education certified instructor for professional development. I will provide three astronomy workshops at the New Jersey Science Teachers' Association Convention in October 2006. I am the astronomy and earth science content provider to the third grade classes at Upper Freehold Regional Elementary School where I work in close contact with more than 150 students, their parents and teachers.

Co-Investigator (Beth Thomas): I work with elementary school teachers informally everyday. Being a resource to teachers is a large portion of my job. In my new position, I plan to offer in-service and professional development opportunities throughout the school year and in the summer in the area of science for all interested K-12 teachers. I will include topics related to infrared and Spitzer. I also plan to attend the 2006 NSTA meeting in Anaheim, CA and present a two-hour sectional on my experiences with TLRBSE, the Spitzer Space Telescope Teacher Program, and its implementation in the classroom.

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We double-checked all coordinates, and proper motion calculations. We also checked visibility windows of Aug - Oct and Jan - Mar, slits don't overlap star west of EF Eri. The complete observation will take 84 minutes

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