Detecting Brown Dwarfs in 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, East Middle 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

Recent observations and research indicate that interacting binaries may harbor brown dwarfs (BD) as the mass donor if their orbital periods are less than about 90 minutes. One such system, EF Eri, has been proven to contain a BD mass donor (Harrison, Howell, et al, 2004 ApJ, 614, 947). After a correlation of the 2MASS database with known ultra-short period binaries, three systems have been identified that have orbital periods less than about 90 minutes and contain highly magnetic white dwarfs (similar to EF Eri) which are likely to contain brown dwarfs (see list below).

In the near-IR (JHK bands), interacting binaries with magnetic white dwarfs can create complex spectral energy distributions (SED). The accretion flux can often be observed in the near-IR. In addition, the high magnetic fields (30MG) typical of polars can also contribute heavily in the near-IR in the form of cyclotron humps. These humps are most prominent in the 6000Å to 2.5μm range. To complete the SED or spectral picture of these interacting binaries, the longer wavelength IR needs to be added. The mass donor (whether an M star or brown dwarf) will radiate into the IR and should be clearly identifiable at wavelengths longer than those possibly contaminated as described above. By using the Spitzer Infrared Array Camera (IRAC) the SED of the mass donor star can be isolated and the spectral type can be determined.

A SED from the optical through IRAC wavelengths will be created for each of the three systems by combining the existing optical, three measurements (JHK band) from 2MASS, and the four measurements (3.5μm, 4.5μm, 6.3μm, and 8.0μm) from IRAC. The SED then can be used to determine if the mass donor star is an M class star, a brown dwarf, or something else altogether. If the mass donor star is a brown dwarf, then the SED can also be used to estimate its temperature and further quantify what defines a brown dwarf.

The three candidate systems are as follows:

2MASS Name	Period (min)	K	IRAC Exposures per λ (sec)	Total Duration (sec)
V347 Pav	90.1	14.985	150 (5x30)	649

GG Leo	79.8	14.635	60 (5x12)	468
J0153.9-5948	89.0	15.149	150 (5x30)	649

The IRAC exposure times and total duration times were estimated based on Spitzer observations of similar objects and from running SPOT. The IRAC exposure times were based on the K magnitude of the three candidate sources compared with the K values of previously observed Spitzer objects provided by Steve Howell (NOAO) and Don Hoard (Spitzer Science Center). These exposure times produced excellent results for the objects observed by Steve Howell and Don Hoard and should produce excellent results for the three candidate systems. Running SPOT determined the total duration times for each system. The total duration time for each system is composed of the total IRAC exposure time and the overhead time (see AOR for complete details). The entire observation run will require 29.4 minutes.

Educational Merit:

Lead teacher Chun and co-investigator Stefaniak are high school science teachers. Co-investigator Thomas teaches middle school science. Each teacher has integrated Research Based Science Education (RBSE) into his or her curriculum in one fashion or another. The Brown Dwarf results from the Spitzer observations will be another exciting avenue for the teachers to have to teach science and research in the classroom. The following descriptions highlight how each teacher uses RBSE and how they will incorporate the Spitzer data.

Lead Teacher (Howard Chun): I use RBSE as the foundation for my honors 2 physics class (12-15 students). I combine modern physics (relativity, quantum physics-spectroscopy, nuclear physics-fission, fusion, nucleosynthesis), related astronomy topics, and five areas of research: Sunspot monitoring, Active Longitude monitoring, stellar spectroscopy, M31 novae search, and AGN spectroscopy. My students work in small groups on each research project for a few weeks (just to get a flavor of each one). Around the middle of the second quarter, each student selects one of the research topics (2 or 3 students on each topic) and spend weeks searching archives, collecting and analyzing additional data, and developing a science fair project for the school science fair (early to mid February). Finally the science fair project is turned into a paper for submission to the RBSE Journal (early April). The SED for the three candidate systems will fit very well into the stellar spectroscopy portion of my class. My students will create a science fair project around the three candidate systems and perform a library search for similar objects.

Co-Investigator (Linda Stefaniak): My students include 22 sophomores in honors level chemistry I and 20 juniors and seniors in astronomy class. All students are introduced to atomic structure through a series of lessons that include a demonstration of the production of emission lines in tubes of excited gases. They then learn a direct application of atomic spectroscopy in modern astronomy by calculating the surface temperatures of stars using their spectra and a current version of Graphical Analysis. As an extension, they also learn to classify active galactic nuclei from spectra and determine the Doppler shift of these objects from the relative positions of emission lines of the elements in their spectra. Additionally, I currently use lessons incorporating spectra from a variety of wavelengths (x-ray, radio, visible) and want to introduce my students to the infrared portion of the EMS. My students are encouraged to develop original questions in one of these areas of study and work in teams, or individually, to answer these questions, culminating in a paper for publication in the current year's RBSE journal of student work. They are expected to perform a search of research papers in the ADS Abstract Service similar to the work they propose and are encouraged to write to the authors of these papers. I plan to have my students help me interpret data from this brown dwarf research proposal as well as search Spitzer's data archive of hundreds of targets to describe the chemistry of cool stellar objects.

Co-Investigator (Beth Thomas): I teach astronomy, chemistry, physics, and the electromagnetic spectrum to my 140 middle school children. Being a TLRBSE teacher, I have incorporated research into my curriculum and provide motivated students the opportunity to conduct authentic research. This past fall (2004) I had two students gain hands-on experience when they conducted research observations on Kitt Peak as part of the NOAO Teacher Observing Program. The IR Spitzer data will integrate well with the EM spectrum portion of my curriculum.

Learning Activities

The following statements describe learning activities developed by and incorporated into lessons that are used by the teachers as part of their current teaching situations. These lessons will be expanded and made more concrete through the use of Spitzer data. These expanded lessons will depend heavily on the data we will receive from our observations and, as needed, pertinent archival Spitzer data. The SEDs of the three candidate systems will strengthen and expand the stellar spectra component of each of the teacher's existing curricula. We will share these expanded lessons containing an infrared focus with other teachers via professional development seminars in our respective districts and at state teachers' conventions. Described below are the core lessons we have been using with our classes and the additional elements we will provide.

- Stellar Temperature: Students will use Spitzer data in graphing programs (i.e., Excel, Graphical Analysis) to make a best fit 2^{nd} - 4^{th} order polynomial curve to a continuum of a variety of stars to determine the peak wavelengths of their output. This is then used to determine a star's surface temperature via Wien's law. Students classify the stars from their surface temperatures and look for features that show a deviation from a blackbody curve.
- Students learn the difference between absorption and emission lines as well as the circumstances under which each is produced via classroom discussion and laboratory demonstration (i.e. spectra of gas tubes). Students will then learn about infrared spectral features due to molecules such as polycyclic aromatic hydrocarbons which have features in the infrared.
- Students describe the evolution of low-mass main sequence stars and contrast them with atypical, exotic stellar species like brown dwarf stars. Students will predict what wavelengths would best allow one to observe these different classes of objects, using their previously obtained knowledge of blackbody spectra and temperature.

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).

Professional Development:

Lead Teacher (Howard Chun): Next fall, I am holding school and district-wide workshops on using research in the science classroom. I will demonstrate what I do in the classroom and then show them what could be done in the chemistry and physics classroom (using spectroscopy in particular). I will emphasize IR, but I will also include the rest of the EM spectrum. What I do at the school and district level will also be adapted for the state and national level. I plan to present my classroom experiences on doing research at regional and national NSTA meetings and demonstrate to attending teachers how they can use research in the classroom. Of course, when the project results come into our hands, we will present our findings at AAS and NSTA meetings.

Co-Investigator (Linda Stefaniak): I am an active member of the National Science Teacher's Association as well as my state science teacher's association. I am presenting workshops this summer (through the Brookdale Community College's office of Community Education) on using solar and infrared astronomy in the middle and high school science class, a workshop on multi-wavelength astronomy, and a second workshop on infrared astronomy for the October 2005 New Jersey Science Teacher's Convention.

Co-Investigator (Beth Thomas): This summer I am presenting a six-hour district level workshop on the EM spectrum. The attending teachers will experience infrared activities and learn how to implement them in the classroom. In addition, the teachers will be introduced to the Spitzer Space Telescope web site and archives. 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.

AOR for the Three Candidate Systems

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#  Please edit this file with care to maintain the
#  correct format so that SPOT can still read it.
#  Generated by SPOT on:  1/17/2005     10:34:12

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     AOR_LABEL:  bd binary
    AOR_STATUS:  new

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  COORD_SYSTEM:  Equatorial  J2000
      POSITION:  RA_LON=18h44m49.10s,  DEC_LAT=-74d18m40.0s, PM_RA=0.0",
PM_DEC=0.0", EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
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            FRAME_TIME: 30.0
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          DITHER_SCALE: medium
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SPECIAL: IMPACT = none, LATE_EPHEMERIS = NO,SECOND_LOOK = NO
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SLEW_OVERHEAD=215.0, SPECIAL_OVERHEAD=0.0, UPLINK_VOLUME=881,
DOWNLINK_VOLUME=3093904, VERSION=S11.0.3
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COMMENT_START:
This is one of three brown dwarf targets in an interacting binary with a known
polar.
COMMENT_END:

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     AOR_LABEL:  bd binary 2
    AOR_STATUS:  new

 MOVING_TARGET:  NO
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   TARGET_NAME:  gg leo
  COORD_SYSTEM:  Equatorial  J2000
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PM_DEC=0.0", EPOCH=2000.0
OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES
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RESOURCE_EST: TOTAL_DURATION=467.7, SLEW_TIME=39.1, SETTLE_TIME=0.0,
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DOWNLINK_VOLUME=3093904, VERSION=S11.0.3
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COMMENT_START:
Brown dwarf target 2 of 3 interacting binaries with polar companion.
COMMENT_END:
```

```
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    AOR_STATUS:  new

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OBJECT_AVOIDANCE:  EARTH = YES, OTHERS = YES

          READOUT_MODE: FULL_ARRAY
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            HI_DYNAMIC: NO
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