Classroom Applications of Cataclysmic Variable Z Cha

Lynne Zielinski (1), Beth Thomas (2), Virginia Jones (3), Jennifer Tetler (4), Samantha Hopkins (1), Micheal Dzakovich (1), Megan McDunn (2), Whitney Milos (2), Marco Mendoza (3), Lindy Rice (3), Brent Carter (4), Channy Kong (4), Steve Howell (5), Don Hoard (6)
(1) Glenbrook North High School, Northbrook, Illinois, (2) Great Falls Public Schools, Great Falls, MT, (3) Bonneville High School, Idaho Falls, Idaho, (4) Lynnwood High School, Lynnwood, Washington, (5) NOAO, (6) Spitzer Science Center

Abstract:

Z Cha is an eclipsing cataclysmic variable star with some unusual features. This binary system consists of a white dwarf, which pulls a stream of mass away from its red dwarf companion, resulting to the formation of an accretion disk around the white dwarf. We hereby present the first mid-infrared (Spitzer/IRAC 4.5 and 8 micron) light curves of the system and compare it with the optical counterpart. Scientists, students and teachers involved with the Spitzer Teacher Observing Program obtained data of the eclipsing cataclysmic variable Z Cha with the Spitzer Space Telescope, May 14, 2008. These observations yielded a light curve for Z Cha in channels 2 (4.493 microns) and 4 (7.872 microns) from IRAC. Photometric observations were also made in March of 2008 with the 0.9-meter telescope of the Cerro Tololo Inter-American Observatory, located in Chile, and light curves were constructed from these data as well. Data reduction of both the Spitzer and ground-based photometric observations completed by the students and analyzed by our team using the Image Reduction and Analysis Facility (IRAF) package. The scientific results of these observations will be presented in a separate poster. The teachers and students developed inquiry-based educational materials and activities that convey the conceptual background necessary to interpret these light curves, cataclysmic variables, and stellar evolution. The Spitzer Science Center, and the National Optical Astronomy Observatory supported this work.

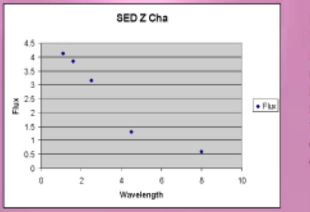
Spitzer Space Science Center Data Reduction

Summary of Spitzer Science Center Visit:

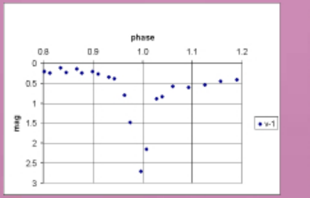
Our rationale for observing the cataclysmic variable Z Cha is that previous observations of WG Sge observations reveal that the mass and radius of the accretion disk are far greater then currently believed and modeled (based on optical and UV observations) over the past few decades. Our preliminary findings of WZ Sge suggest that the accretion disk contains a large, cool outer ring likely to extend to far greater radius and contain perhaps 1-2 times more mass than currently believed. These observations have great relevance for accretion disks in general, those in binary systems as well as in active galaxies. This Spitzer teacher project will provide observations that will test and confirm our new findings. We obtained multi-wave length data from both the Spitzer Space Telescope and optical B-band light curves from CTIO (0.9 m) in Chile. Data was collected for Z Cha at 4.5 and 8.0 microns on May 14, 2008 by Spitzer and March 28, 2008 from CTIO. Z Cha is an eclipsing system containing a white dwarf as the primary star and a red dwarf as the secondary, donor star. It is a non-magnetic system with an orbital period of 1.788 hours. It is 313 light years away. As Z Cha is a nova-like cataclysmic variable, it has a relatively high rate of mass accretion and thus its disk is optically thick and not subject to the thermal/viscous instability that causes dwarf nova eruptions. Normal eruptions have amplitudes near 3.1 magnitude, and recur at a mean interval of 85 days.

We reduced the Spitzer images using IRAF and DS9. We selected three comparison stars and recorded their time-tagged fluxes producing light curves. The data was imported into an excel worksheet in which the fluxes were converted from Spitzer standard output and optical magnitudes to mJy. The formula, constants, and conversions are listed in the table below.

Wave Band (2MASS)	Constant	Jy (Jansky's) Constant/10^(magnitude/2.5)	mJy (mJansky's)
J	1594	0.004123712	4.12371191
H	1024	0.003843262	3.843261688
K	666.7	0.003156144	3.156144361



Using these values, a SED was created using UV light from the HST, the J,H, and K bands from 2 MASS, and the points from our Spitzer data at 4.5 µm and 8.0 µm. The SED revealed a flat, level particularly between 4.5 and 8 microns. This increase in flux at long wavelengths reveals that an additional component is present, the most likely explanation for which is warm dust.



A light curve was then created by plotting the time vs. the flux in mJy. In addition we reduced the photometric data collected from the 0.9 meter telescope at CTIO in Chile. There were 50 points with 150 second integration times. Light curves were created and compared with the Spitzer light curve. Three comparison stars were selected and compared to Z Cha. The results of the light curve show there is an additional flux component at the longer wavelength. Modeling will help us make predictions and further explain this system.

Classroom Activities

Julian Calendar

This lesson is intended to familiarize students with the Julian calendar while providing background and experience in converting to Julian time. The principal astronomical cycles are the day (based on the rotation of the Earth on its axis), the year (based on the revolution of the Earth around the Sun), and the month (based on the revolution of the Moon around the Earth). The complexity of calendars arises because these cycles of revolution do not comprise an integral number of days, and because astronomical cycles are neither constant nor perfectly commensurable with each other. While working with students in astronomical research, the concept of using the Julian calendar is new and unfamiliar. Students will become familiar with the history and how different cultures in different countries at different times addressed the same problem of time-keeping and developed interesting variations of the same basic solution. Students will also be able to describe the difference the Persian, Metonic, Gregorian and Julian calendars. After completing the scavenger hunt, students will gain knowledge and experience in converting to the Julian date which will ease the transition to accurate astronomical research!

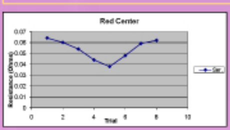
______ 1. What is the rotation period of the Earth?
______ 2. Who instituted the Julian calendar? When?
______ 3. What is meant by a solar year?
______ 4. What is the name of the period of nine days the Romans called a week?
______ 5. The seven day week was adopted in 321 A.D. by whom?
______ 6. What day of the week is Dies Mercurii?
______ 7. What is a metonic calendar?
______ 8. In the Persian calendar, when does the new year always start?
______ 9. When was the "Year of Confusion"?
______ 10. Who proposed the Gregorian calendar?
______ 11. How many hours does .1 of a Julian day represent?
______ 12. What was the starting Julian date and time for Julian calendar?
______ 13. What is a modified Julian date for the Julian date 245000
______ 14. What measurement is based on the rotation of Earth on it's axis with respect to the stars?
______ 15. In Roman Catholic countries when was the Gregorian calendar system instituted?

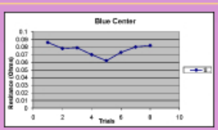
Calculating Julian Time: Astronomical software widely uses Julian dates as time variables. Julian dates (abbreviated JD) are simply a continuous count of days and fractions since noon Universal Time on January 1st, 4713 BCE on the Julian calendar. Almost 2.5 million days have passed since this date. Here are some sites to use for Julian Date conversions: [illegible] or http://www.aavso.org/observing/aids/jdcalendar.shtml

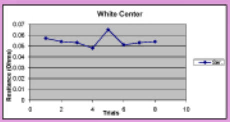
______ 1. What would the JD be for 1:00 PM in London on January 1st, 2000?
______ 2. What would the JD be for your birthday?
______ 3. What would the JD be for when Apollo 11 landed on the moon?
______ 4. What would the JD be for Isaac Newton's birthday?
______ 5. What would the JD be for the launch date of the Spitzer Telescope?
______ 6. What is the JD for today?

Photogate

After students are introduced to variable stars and how astronomers study them, students will use a solar cell, meter, and light bulbs to simulate an interacting binary star system. During the simulation, students will understand how a binary star system's orbit can cause changes in the observed brightness of the system. In addition, students will create a light curve using their data and compare it with authentic data of two variable stars, Z Cha and WZ Sge, taken from the Spitzer Space Telescope. As a result of the simulation, students will describe what a light curve is and what information can be learned from a light curve.







These graphs represent light curves of binary systems. Each with a different colored central star. The x-axis represents the location of the "orbiting star". Positions 1 & 8 are defined to be where the central star is between the orbiting star and the solar cell. Position 5 locates the orbiting star between the central star and the solar cell detector. The y-axis represents the "brightness or luminosity" of the system by the "resistance" value produced from the solar cell. Changing the color of the "central star" between white, red, and blue produces graphs that show different characteristics associated with eclipsing binary systems. Students can use these graphs to conceptualize how the orbiting star is effecting the luminosity of the the orbiting system. Comparing these graphs with the graphs produced from Spitzer data on star systems like WZ Sge and Z Cha will allow students to visualize and explain what might be happening in these systems.

Simulation and 3D Model

This model is an extension of the WZ Sge simulation, in order to add to students understanding of differences in binary systems. During this paper model of Z Cha, students will use their knowledge of cataclysmic variables and binary systems to simulate an eclipse of a system. They will graph a light curve of the data they collect by calculating the total brightness between the white dwarf, accretion disk, and the red dwarf. After completion of the simulation, students will understand the graph of an eclipsing binary, like that of Z cha. They will find and comprehend similarities and differences between a system with a hotspot and one without.

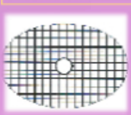


Figure A

Directions:
Cut out these shapes which represent the components of the Z Cha system. Figure A represents the white dwarf in the center surrounded by the accretion disk with a hot spot on the perimeter.
Figure B represents the red dwarf.
Again, do not enter values in fractional squares.
For the red dwarf, enter a '1' in every whole square.
For the accretion disk, enter a '5' in every whole square, except the two squares with a gray X.
In that enter a '15' in each of the two squares.
For the white dwarf (the small circle in the center of the oval) enter a '30'.

Figure B

What if Questions:
1. At what point during the eclipse, is the overall brightness the dimmest? brightest?
2. Did the graph change as you suspected it to in question 5 of Part 1?
3. What would the graph look like if the hotspot was closer to the white dwarf?
4. What if the hot spot was much larger in size, how would the graph change?
5. What if the hot spot was much brighter, how would the graph change then?
6. If the inclination of the system was 81°, like that of Z cha, would there be much difference in the graph and the amount of light seen in the different phases? What if the inclination was 30°?
7. Compare the graphs of the two binary systems, in what ways are they different? alike?
8. If you constructed a 3-D model of Z Cha, would the brightness change? If yes how?

Phase Number	Total Brightness of red dwarf	Total Brightness of white dwarf and accretion disk	Total brightness of system
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

Students will make a physical model of a binary star system that demonstrates the components of which it is made, including the accretion disk. Materials needed include two styrofoam balls, a cardboard disk, spray paint, yarn, a wire hanger, glue and toothpicks. After construction of the model, students will have a visual understanding of a binary systems' size and shape.

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