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Exploring the Universe with White Dwarf Stars: the First Year of the Freshman Research Initiative

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Abstract. We present results from the first year of the Astronomy Stream of the Freshman Research Initiative at the University of Texas. This program is designed to involve freshmen directly in our research on white dwarf stars. We describe the progress the students have made in the last year on (a) planet detection using pulsating white dwarfs including identifying a promising new candidate, (b) improving our data analysis techniques, (c) updating our web page interface for remote participation, and (d) making preliminary calculations for 3D hydrodynamic modeling of convection in white dwarf stars.

1. Introduction

The focus of our research group at the University of Texas is on using white dwarf stars to study fundamental questions in physics and astronomy. White dwarfs are stars at the end of their lives; they have exhausted their energy reserves and have shrunk to about the size of the Earth. They are supported by electron degeneracy pressure and slowly cool by radiating their energy into space. While they are faint, their simple structure makes them ideal astrophysical laboratories for studying many questions, such as:

- What is the age of the universe?
- What is the mass of the (hypothetical) axion particle?
- How and when does crystallization occur in a dense stellar plasma?
- How does convection operate in a high-gravity environment?
- Are neutrinos emitted at the expected rate in white dwarf interiors?
- Do white dwarf systems contain orbiting planets?

For the first time students in the Freshman Research Initiative (FRI) were involved in helping us answer these questions. Our research involves the application of specific observational techniques, data reduction methods, and theoretical modeling, and the FRI students participated in all of these areas, including two week-long observing runs at McDonald Observatory. In what follows we give a very brief sampling of some of the work of the FRI students.

2. The Projects

Each student in the program worked on one or more different research projects, and these projects covered a wide variety of topics, which we highlight below.

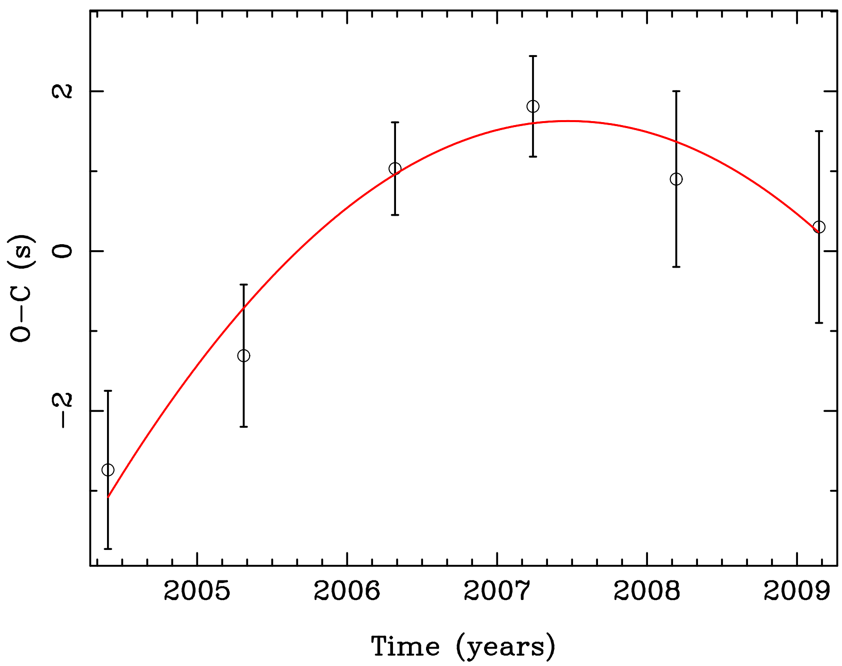

Figure 1. The O-C (observed minus calculated) diagram for the time of maximum for the pulsating DA white dwarf WD1354+0108. The curvature could indicate the presence of a planetary companion.

2.1. Planet Search

Many white dwarf pulsators exhibit extreme stability in their pulsations, allowing us to predict exactly when a pulse should arrive. An orbiting planet induces a reflex motion of the white dwarf, and due to light-travel-time effects can produce periodic variations in the arrival times of the pulses. In addition to the known candidate GD66 (Mullally et al. 2008), we have identified a new candidate, PG1354+0108, shown in Figure 1. If planetary in origin, this data could indicate an orbital period of ~ 12 years.

2.2. GD154

Several of the projects focused on improved reductions of archival data. In Figure 2, we show a light curve of the hydrogen-atmosphere (DA) pulsator GD154. A judicious choice of aperture sizes has resulted in data with significantly higher signal-to-noise; this allows us to find additional pulsation modes, aiding in the seismology of this star. For instance, while only 3 independent frequencies were previously known for this star, we have now identified at least 8 independent frequencies. This makes GD154 one of the richest known DA pulsators.

2.3. Argos Online

One project focused on revising our online web pages so that they once again offered a real-time view of our observations at the telescope (see Figure 3 and http://rocky.as.utexas.edu/argosonline/page2.html). This web page displays the current starfield frame (upper right) along with a preliminary light curve (lower

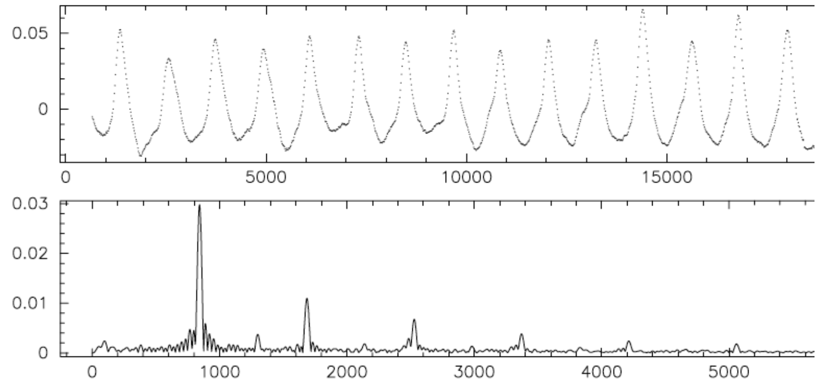

Figure 2. The light curve (upper panel) and Fourier transform (lower panel) of the DA white dwarf GD154. An aperture size of 8 pixels was used.

left) and Fourier transform (lower right). The left sidebar gives current information, such as the names of the target and the observers, as well as the frame number and the integration time. Besides being informative for other members of our group, this real-time interface is ideal for outreach activities such as lock-ins at local area high schools.

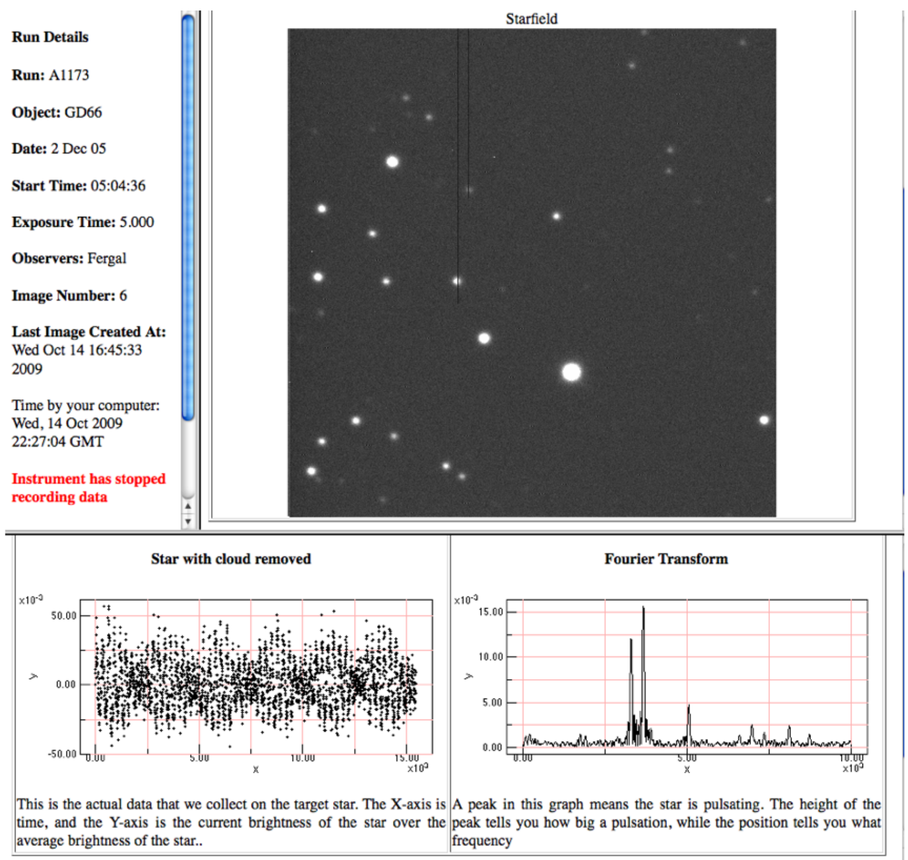

Figure 3. The real-time Argos Online website.

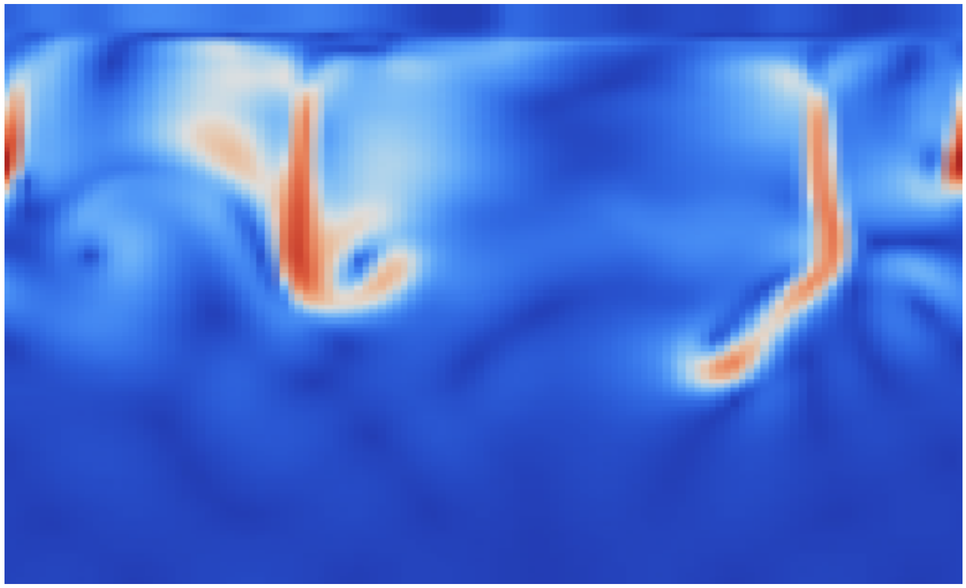

Figure 4. Snapshot of a 2D simulation of convection in a white dwarf star. The figure is oriented so that the photosphere of the star is along the top boundary. The plume-like features are regions of descending, cooler fluid.

2.4. Simulations of Convection

In collaboration with H. Muthsam and F. Kupka we have begun adapting the ANTARES fluid dynamics code (Muthsam et al. 2007a,b) to make simulations of convection in white dwarf stars. We have made many test calculations and will soon begin using the code in production mode. Our initial calculations have been done in 2D (e.g., see Figure 4), with the ultimate goal of making 3D simulations of white dwarf convection zones. This will allow us to make a direct comparison between the inferences we obtain from nonlinear light curve fits (Montgomery 2008, 2005) and the results of numerical hydrodynamic simulations of convection.

2.5. Visualizations

Other projects have focused on new ways of visualizing our data and the pulsations themselves. The intensity variations we observe are caused almost exclusively by temperature variations on the surface of the white dwarf and *not* by changes in the radius of the star (Robinson et al. 1982). To first order, the angular structure of the temperature perturbations are given by spherical harmonics, $Y_{\ell m}(\theta,\phi)$, where ℓ and m are integers, with $\ell > 0$ and $m = -\ell, -\ell+1, \ldots, \ell-1, \ell$. Examples of these functions are shown in Figure 5.

Using *Mathematica*, we developed a tool for visualizing the geometry of the temperature perturbations which allows us to interactively rotate the surface of the star. This allows the students to develop their intuition concerning the geometry of the pulsations.

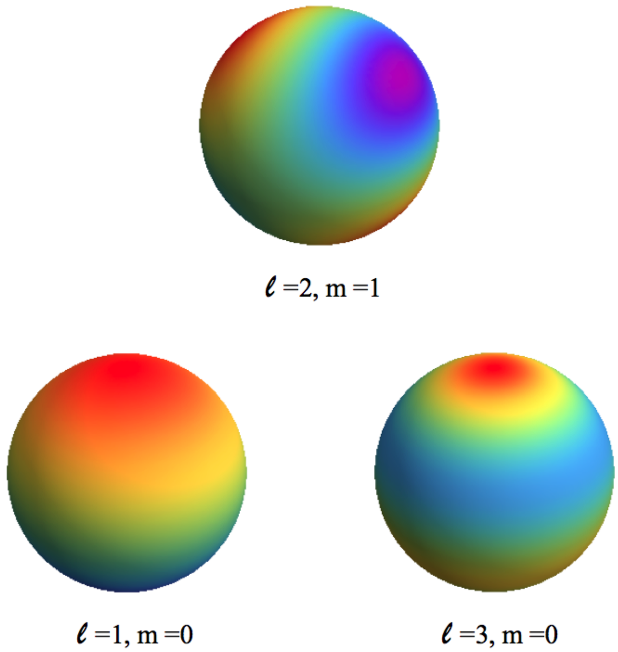

Figure 5. The angular structure of temperature perturbations of modes with different ℓ and m values.

3. Conclusions

This marks the end of the first year of the Astronomy Stream of the Freshman Research Initiative at the University of Texas, which involved freshmen (who are now sophomores) directly in our research. During this year the students identified a promising new planetary candidate, refined our aperture photometry techniques, revamped our real-time web page interface, and made preliminary hydrodynamic simulations of convection in white dwarf stars. Contrary to a traditional lecture course, they have learned by doing, from the senior personnel, the mentors, and most importantly, each other.

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References

Montgomery, M. H. 2005, ApJ, 633, 1142
—. 2008, Communications in Asteroseismology, 154, 38
Mullally, F., Winget, D. E., Degennaro, S., Jeffery, E., Thompson, S. E., Chandler, D., & Kepler, S. O. 2008, ApJ, 676, 573
Muthsam, H. J., Löw-Baselli, B., Obertscheider, C., Langer, M., Lenz, P., & Kupka, F. 2007a, MNRAS, 380, 1335
Muthsam, H. J., Löw-Baselli, B., Obertscheider, C., Langer, M., Lenz, P., & Kupka, F. 2007b, in IAU Symposium, ed. F. Kupka, I. Roxburgh, & K. Chan, Vol. 239, 89
Robinson, E. L., Kepler, S. O., & Nather, R. E. 1982, ApJ, 259, 219