**Significance of Project:**

Up until the late 1980s imaging of celestial objects was done using photographic plates. These plates were cumbersome to use and only were able to detect 5% of the light that hit them. With the advent of CCDs (digital cameras) in the 1980s astronomers are able to collect light at an unprecedented efficiency, with roughly 20 times more light detected as compared to a photographic plate. Another benefit of CCDs is that the images taken are digital, and therefore can be analyzed by computer algorithms with far more precision (Percy 2007). Given the increase in efficiency, much more data is being collected than ever before. This has allowed telescopes of all sizes to become powerful research tools.

With these technological advances and with Butler University joining the SARA telescope consortium in 2008, new avenues of research are possible. Butler now has access to two 1-meter class telescopes, one in Arizona and the other Chile. By the start of BSI both telescopes will have been fitted with new CCDs which will collect images with impressive levels of precision. These telescopes can be remotely operated from Butler and provide ample time for observations by Butler faculty and students.

Globular star clusters have been of particular interest to Butler's research group in the years since we joined the SARA consortium. Globular star clusters are useful forensic tools for investigating star formation in the early universe. These clusters range in age from 9 to 13 billion years and each globular cluster has hundreds of thousands of stars. The stars in each individual cluster formed at roughly the same time out of the same cloud of gas and dust. Thus, the stars in each individual cluster have the same age and composition, and only differ in their initial mass, with mass being the factor which determines the star's evolution (Percy 2007). If we can determine the physical characteristics of these stars, such as composition and age, then we can learn a great deal about the early cosmos.

Roughly 95% of the stars in the night sky are burning hydrogen into helium in their cores, and these stars are stable. Eventually stars exhaust their supply of hydrogen and start to fuse helium into carbon causing them to become unstable and increase their radii by large factors. These so called "variable stars" start to pulsate because of helium ionization in the outer layers of the stars. Astronomers call these unstable objects variable stars because of the periodic variation in their radii. If you imagine a typical drumhead vibrating in two dimensions, it is easy to imagine a variable star as a three dimensional drum which vibrates in any of the three spatial directions. These vibrations or oscillations may occur in many different modes, unique to each star based on its internal composition. Variable stars can be distinguished from other non-variable stars by their change in luminosity over time which is a result of this pulsation. RR Lyrae stars are of particular interest because they have relatively short oscillatory periods (between 0.1 and 1 day) and are found in large numbers in globular clusters (Percy 2007). To study RR Lyrae stars we must observe the same globular cluster over many nights. The data from each of these nights may only be a small part of the oscillatory period of the star. Using computer software we can phase together different parts of the period of the star to generate what is called a "light curve". A light curve is a measure of the change in luminosity over one cycle of oscillation. The shapes of light curves can classify variable stars. The variable stars can be used to find the composition, age, and distance of the cluster they reside in.

To determine the variable stars' physical make-up, astronomers use a technique called Fourier decomposition. Fourier decomposition combines all of the possible modes from a given star's oscillations and represents them as a series of sine functions. This technique reveals the amplitudes of the frequencies with which the variable stars oscillate in luminosity over time which is characteristic of their composition. Fourier decomposition has proven useful in determining characteristics of RR Lyrae stars (Clement et al. 1992; Clement & Shelton 1997; Lazaro et al. 2006).

I will further analyze the light curves previously constructed by Butler students A. Darragh, E. Johnson and J. Liu from the globular cluster M14. With this data these students were able to classify the RR Lyrae Stars using their periods and relative magnitude changes by phasing together the data from an extended period of time. This process of identifying and classifying RR Lyrae stars has been common among BSI and other Butler students. My research is unique in that I will further analyze this data to determine the physical characteristics of the variable stars. Because all of the stars in a given cluster have roughly the same composition, we can learn about stellar evolution.

**Statement of Central Objective:**

I will analyze the data that has been collected for known variable stars in the globular cluster M14 to determine their compositions using Fourier decomposition. This information will allow me to determine the properties of the stars such as luminosity, radius, can help determine the cosmic distance parameter and help study stellar evolution. I will also look for new variable stars in globular clusters that are understudied using the new cameras on the SARA telescopes using the image subtraction method.

**Methods:**

The Butler research group has confirmed over 100 variable stars in the globular cluster M14 with nearly half of them being newly discovered (Conroy et al. 2010). I will conduct most of my research using this prior data and if time permits, I will make observations using the SARA telescopes of one or two other clusters studied by Toddy et al (2012) and Darragh & Murphy (2012). The data mentioned above has already been partially analyzed for period and classification, however the light curves need to be converted from relative flux to absolute flux using software called DAOPHOT (Stetson 1994). I will analyze this data using a computer program that employs a technique called image subtraction to determine which stars are variable. Next I will in put this data into PERIOD04 (Lenz & Breger 2005) and produce light curves, just as with the other data I will be analyzing. The data will be used to produce light curves using a program called PERIOD04. The process of phasing data from variable stars together using PERIOD04 is described above. The fully processed light curves from new and old data with allow me to classify the different kinds of variable stars I find in these clusters.

The next step after classifying the variable stars is to determine their composition using Fourier decomposition. So I will use PERIOD04 to perform Fourier decomposition to determine the amplitude and phase of the oscillating stars. Fourier decomposition is a technique which sums all of the sine functions which describe a star's oscillation into one wave function (example below).

$$V_{mag} = A_0 + \sum_n \{A_n \sin(2\pi[n\omega_1 it + \varphi_n])\}$$

Using this technique I will characterize each star by its amplitude ($A_n/A_0$) and fundamental angular frequency ($\omega_l$) as well as phase of the different modes ($\phi_{31}$). Each star is oscillating at some fundamental frequency and the additional frequencies ($n$>1) are multiples of the fundamental frequency. Knowing the amplitudes of the various components will allow me determine the characteristics of the cluster using hydrodynamic models seen in Clement et al. (1992); Clement & Shelton (1997); Lazaro et al. (2006).

**Progression of Project**

| Week | Progression |
|---|---|
| 1 | Hone skills with DAOPHOT and PERIOD04 |
| 2-3 | Extract absolute flux from data already taken by BSI students |
| 4 | Gather images with SARA telescopes and preprocess them using image subtraction. |
| 5-7 | Determine Fourier parameters |
| 8-9 | Determine cluster characteristics using Fourier parameters |

**Feasibility:**

Butler's Department of Physics and Astronomy and former BSI students have already collected most of the data I will be analyzing for this project. The resources I need for my research (software and computers) are already available in the new remote observation laboratory in 222 Gallahue Hall. I will also have remote access to the SARA telescopes to look for new variable stars with the new CCDs. Butler will have adequate time scheduled for me to utilize these telescopes this upcoming summer.

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**Personal:**
I have always had a love for science. My father is a biology teacher and a science nerd at heart. Working on science fair projects with my father as early as second grade showed my knack for science and this thirst for science has never ceased. In my high school years I had an inspiring physics teacher who was doing amateur research involving globular star clusters as well. He helped me foster my interest in physics and I went on to study Physics and Middle/Secondary Education, as well as study Astronomy briefly here at Butler University. At Butler I have completed Physics 201 and 202, Calculus I, II and III, Differential Equations, The Astronomical Universe and Modern Physics. This semester I am enrolled in Modern Physics Lab, Statistical Thermodynamics, and Modern Astronomical Techniques. These classes have and will prepare me to be a knowledgeable and motivated BSI student. My path at Butler is a unique one; very few pursue both a degree in physics and a degree in education simultaneously. As interested as I am in physics and astronomy, also I feel I have a calling for teaching. At this time I am unsure what kind of career I want to pursue. This research will help me to decide what kind of graduate work I want to pursue, whether it be in physics, astronomy, or education. The time consuming nature of my unique major has required careful time management and a strong work ethic. I believe all of this has prepared me to be a participant in BSI and I would be honor to participate in such an outstanding program.

**Evaluation**

My work will be published in the Journal of the Southeastern Association for Research in Astronomy (JSARA) and the Astronomical, two refereed scientific journals. I will also present my findings at the end of the BSI program. I will most likely present my findings at the American Astronomical Society Meeting next January as have all of Dr. Murphy's prior BSI students.