Photometric Analysis of Variable Star Systems

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May27th start date, 10 week length

Description of the project

Background:

At some point in their lives, everyone has looked up to the stars in wonder. Mankind has always been fascinated with what lies beyond our planet, and so too have Moravian students. The Physics and Earth Sciences department is working to add astrophysical research to our research programs, and this SOAR project would be the first research project to be part of this program. Notably, starting this program will not require additional funding for equipment or training. Long time adjunct for our department, Gary Becker, and his collaborator, Peter Detterline, are members of the Mars Society that is in the process of establishing the Mars Desert Research Station (MDRS) Robotic Observatory in Utah, which has committed a 25% share of the telescope time to Moravian College faculty and students. This past fall, Bryan and Dr. Malenda participated in an online course taught by Peter Detterline, which provided instruction about how to utilize the facility and analyze the data.

To take reliable data, each of the images must be calibrated for several factors; bias, dark, and flat. The images can be taken using the Skynet Robotic Telescope Network website and free software called AstoImageJ can be used to remove the variations and calibrate each image. Differential photometry uses several comparison stars with known brightness in the same field of view to determine the standardized magnitude of the variable object under observation. Differential photometry is one of the simpler photometry methods because both the target and comparison objects are observed at the same time, with the same filters, using the same instrument, and viewed through the same optical path. This also means that all the frames discussed earlier apply to both the target and comparison objects. Once you have images recorded and have calibrated them using the frames, you must identify the stars, not just the star of interest, but also the comparison stars that will be used to determine the standardized magnitude. The differential magnitude (Δv) is calculated by subtracting the magnitude of the comparison star (c_{meas}) from the magnitude of the target (v_{meas})

$$\Delta v = v_{\text{meas}} - c_{\text{meas}}.$$

To then standardize this value (V), it is added to the known magnitude value of the comparison star (C_{pub})

$$V = \Delta v + C_{\text{pub}}$$

This process is done for all the comparison stars, and averaged to get one standardized magnitude of the target star. Much of this can be done by computer software. **Figure 1** shows an example of an image analyzed with differential photometry using a software called

AstroImageJ. The process of differential photometry must be repeated for every picture taken. The variation in these brightness over time is called a light curve, and is used to determine information about the variable object, such as period of orbit or rotation, mass, and size.

By taking the online course, Bryan is already prepared for this SOAR project. He has general knowledge of accurately taking data using the MDRS telescope and then how to properly analyze that information. Bryan learned how to set up parameters such as different filters and exposure times for observations, as well as calibrate and process the images. Bryan also learned to used the software AstroImageJ to perform differential photometry. Dr. Malenda and Bryan were partnered for the final research project performed by in this class during which they studied the variability of light intensity of an eclipsing binary system. An eclipsing binary is a two star system in which the stars orbit one another. This specific star, **BH Aur**, has a relatively short period of orbit, thus observations were taken hourly throughout the course of many nights to be able to create a light curve of the intensity variability. It was from this light curve that we could measure the period of the stars revolving one another and a period of about 10 hours that was confirmed. Though this was a previously well known system, the project gave Dr. Malenda and Bryan experience with this type of research.

Professor Detterline has already proved to be an invaluable asset and we will continue to work closely with him throughout this project. Additionally, as this is a new area of research at Moravian College, Dr. Malenda has reached out to several potential collaborators with established undergraduate astrophysics research programs in the area. Alumna Brittani Costa completed an REU at Lehigh University last summer with Dr. Joshua Pepper investigating exoplanets. Both Brittani and Dr. Pepper gave talks about their work on campus this past year. Dr. Pepper expressed interest in helping us establish astrophysics research here at Moravian. At the AAPT-CPS Conference in April and at a talk Dr. Malenda gave at Kutztown in October, she spoke with Phill Reed from Kutztown University (also a Lehigh University alum she knows from graduate school) who currently has a successful undergraduate astrophysics research program. He was excited about the prospect of having additional collaborators, and has been in touch about helping establish future research projects.

Possible Project Routes:

There are several options for projects we could embark on. Dr. Pepper is part of the Kilodegree Extremely Little Telescope (KELT) project. This project collects vast amounts of data about variable star systems with the hopes of finding exoplanet systems. If the orbital plane of the system is along the line of sight from Earth, the planet passing in front of the star as it orbits blocks some of the star's light causing the variations detected as shown in Figure 2.. With the differential photometry skills learned in the online course, Bryan would be able to process the data to determine good candidate systems for investigation as exoplanets, and plot the light curves of these candidates.

Another possibility is to work with Phill Reed at Kutztown University to perform our own observations. The target stars in this case would be eclipsing binaries, the same variety of variable star Bryan and Dr. Malenda observed during their final project. Dr. Reed would help us to identify useful and interesting candidates for observation. Bryan would then perform the observations and process the images as described above to perform differential photometry and analyze the light curves. These light curves can then in turn be used to determine the particular properties of the system, including stellar density of the star, mass, radius, etc.

Roles and Responsibilities

- Project advisor Dr. Malenda, will lead and instruct Bryan through the process of data analysis.
- Dr. Malenda will work with Bryan and collaborators to determine the best possible project, including determining a target star and ensuring telescope observation time if needed.
- Bryan will document the process through a laboratory notebook, and will report the progress to Dr. Malenda regularly.

Summary of Benefits

Through the course of this project Bryan will gain valuable research experience and extensive knowledge of the research process. This project will require application and refinement of the skills Bryan learned in the online course, such as performing observations, processing observations, and generating light curves. Bryan will also have to work with large amounts of data and learn to manage and analyze the large amounts of data. Additionally, Bryan will likely interact with with researchers at Lehigh University and/or Kutztown University. The experiences and insights gained working with these colleagues will be invaluable. This work will would provide valuable networking opportunities with graduate students and faculty at Lehigh University and/or Kutztown University. Bryan's ultimate goal is to pursue a graduate degree in astrophysics, thus this project will provide valuable research experience to prepare him for his work after Moravian College.

Timeline of Project

Exoplanet research with Lehigh/ *Eclipsing binary collaboration with Kutztown*

1-2 weeks; Gaining background knowledge/ *Research and select target system*

1-2 weeks; Learning to access and navigate KELT database/ *Perform observations of target system*

1-2 weeks; Evaluating possible systems for likelihood of exoplanets/ *Process and analyze observations to determine target magnitudes*

1-2 weeks; Light Curve analysis of likely exoplanet systems/ *Generate light curve from observations*

1-2 weeks; Use Light Curves to determine physical parameters of systems/ *Use light curve data to calculate physical parameters of target*

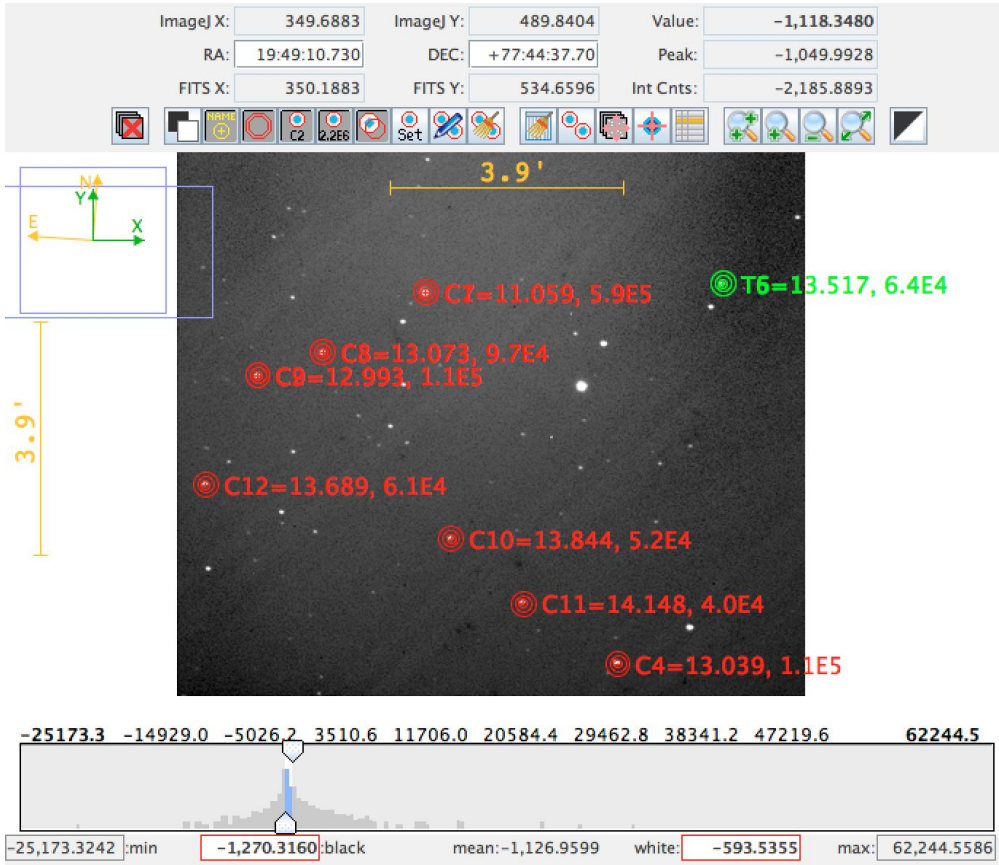

Figure 1: *This graphic shows an example of differential photometry performed by Bryan Kelly. This process is used to find the relative magnitude of the target star, in this case, T6, to the comparison stars, C4, C7-C12, and their known magnitudes.*

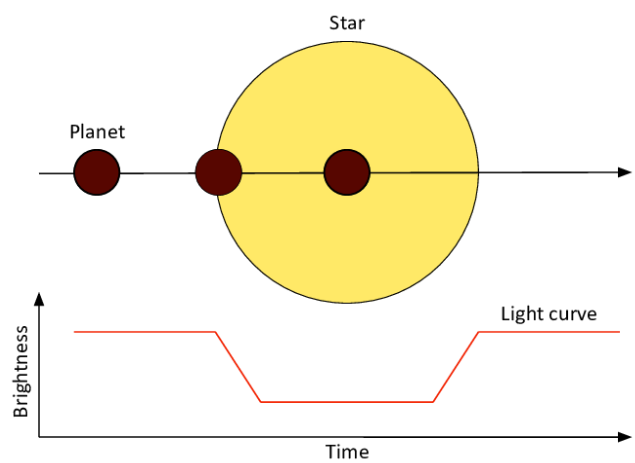

Figure 2: *This figure shows the dimming effect on the light curve as an exoplanet orbits in front of a star.*[1]

[1] Cowley, Michael and Hughes, Stephen. *Characterization of transiting exoplanets by way of differential photometry*. Physics Education. **49**, 293 (2014).

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Bryan Kelly, Physics major & Mathematics minor, Spring 2020
Dr. Ruth Malenda

Rationale

I have always been drawn to the unknown and driven to find an explanation for things that cannot be immediately explained. Astrophysics has become the best way of using my interest in applicable situations. After taking the online astronomy course taught by Professor Peter Detterline, I knew for sure that astrophysics is something that I would love to pursue post graduation from Moravian. My goal is to pursue a graduate level degree in the study of astrophysics. Participating in this program will help me further explore my passion and help me hone the direction of study for my my career. Studying eclipsing binary systems in an astronomy course that I took this past fall semester has given me a taste of what this type of research will be like. I studied a specific system, BH Aur, and created a light curve in order to obtain a measurement for the systems period. Throughout this semester I have continued to broaden my knowledge of different astronomical phenomena by researching scholarly articles online and am willing to continue this research outside beyond my comfort zone hopefully discover what will one day become my area of research.

Furthermore, an idea that is stressed in both my courses for my major required is the idea of teamwork and communication. I have given many formal presentations on topics I am very well versed in and an important role is how to depict information to the general public that may not be as knowledgeable in your research in a concise, detailed manner. In my recent Quantum Mechanics course, our labs had very minimal guidance where we had to go about finding resources and performing the experiments on our own hand. We would meet with our lab professor once a week to address any questions or guidance where it need be. I believe this has given me the experience to perform experimental tasks and resolve problems without having a professor around at all times to give me the answers whenever I need them. I would benefit from learning to use other equipment setups and improve my skills as an astrophysicist. Collaborating with faculty at different universities will broaden my researching skills, expose me to new techniques, and improve the efficiency of my data analysis.

Additionally, taking part in this research experience will create exposure for this avenue of research at Moravian College and inspire interest in other students studying astronomy or astrophysics in the years to follow. Moravian student's access to a telescope out in Utah and ¼ share of the operating time for observations and taking exposures makes this type of research easily accessible for the future candidates. Along with this, I hope I am able create more networking connections with faculty here at Moravian as well as at other institutions. Also, I hope to portray the research that I found to others here at Moravian to hopefully interest them in their future studies.