Simulating Realistic Light Curves of Cepheid Variable Stars

Caroline E. Kuczek[1] and Robert Kehoe[2]

[1]*Department of Physics, John Carroll University, University Heights, OH, USA*

[2]*Department of Physics, Southern Methodist University, Dallas, TX, USA*

Abstract

Cepheid variable stars are essential to decoding the universe due to their period-luminosity relationship. This makes them the best way to make distance measurements at cosmic distances. In producing a theoretical model of Cepheid light curves, more accurate measurements of Cepheid period changes can be taken by comparing the observations to the stellar evolution predictions. The variation in a Cepheid's period is one of the main contributors to its usefulness for cosmic distance measurements. In starting with the Modules for Experiments in Stellar Astrophysics (MESA) to simulate the stellar evolution of the Cepheid, I present my software design to improve this simulation to create a realistic light curve using Python.

Introduction and Motivation

- Many efforts have been made to compare Cepheid light curve observations to theoretical models[1] to analyze the variations between the observed and expected
- My Goal: Write code that improves upon the VSP's MESA Cepheid simulation
- Make the theoretical model account for the data quality effects that act on the observed data
- Flag data points that the ROTSE III telescope would not observe due to the astrophysical effects on the light data as it travels from the star to the telescope
- In producing a theoretical model of Cepheid light curves, more accurate measurements of Cepheid period changes can be taken by comparing the observations to the stellar evolution predictions
- The variation in a Cepheid's period is one of the main contributors to its usefulness for cosmic distance measurements

Theory

- Different Stars are visible at different times of year
  - Altitude of Star

$$\sin(a) = \sin(\delta)\sin(\phi) + \cos(\delta)\cos(h)\cos(\phi)$$

a=altitude
δ=declination
ϕ=observer's latitude
h=local sidereal time-right ascension

  - Local Sidereal Time = $GST - \lambda$

λ=observer's longitude

Theory Cont.

- Greenwich Sidereal Time (GST)

$$\text{GST} \approx (360^o \text{ (months since March 21)}(30.4333))/365.25$$

- Number of hours per night during which data can be taken
  - calculate duration of nighttime using sunset/sunrise times

Methodology

The current simulation produces an ideal light curve that does not account for the data quality effects that occur when the ROTSE III telescope takes observations. An example of the original simulation output is shown in Fig. 1.

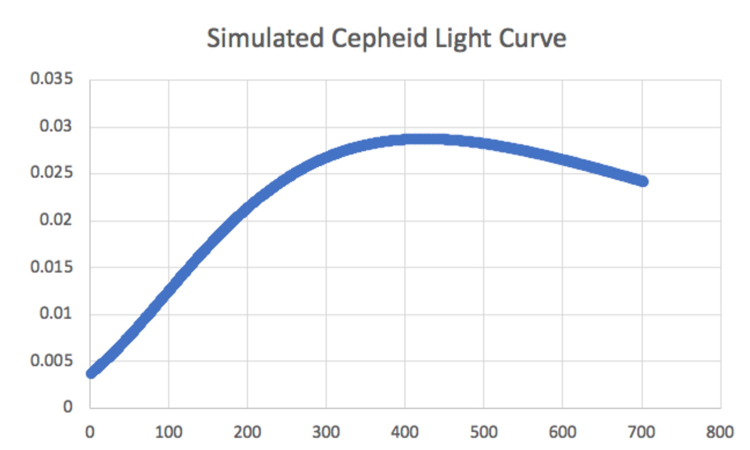

Fig. 1. An example a simulated light curve (luminosity vs. time) output by the current simulation.

The current simulation uses MESA, a code that simulates the stellar evolution of the Cepheid. This simulation will be improved upon to simulate a realistic light curve that accounts for data quality effects through the creation of a secondary code in Python that will filter out the data points that would not be observed by the ROTSE III telescope. This code will produce a simulated light curve that resembles a real Cepheid light curve as shown in Fig. 2.

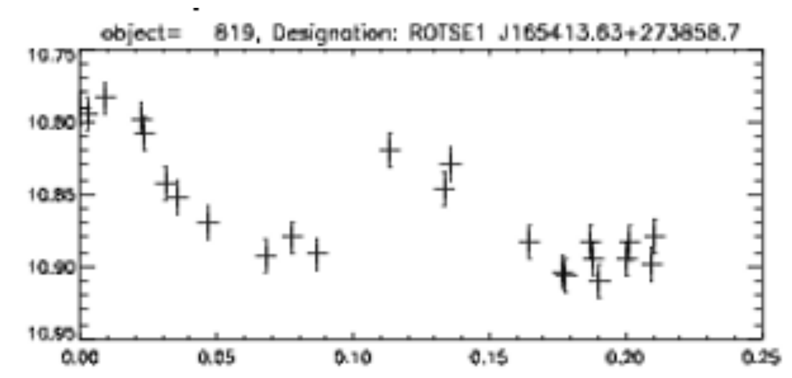

Fig. 2 An example of a real Cepheid light curve observed by a ROTSE telescope.

Results

The main functions of the software design are described below and a flow chart including the outputs and inputs of each module and function is shown in Fig. 3.

- Function: **weather**
  - Simulates bad weather by using one random number generator to select the instances of bad weather and a second one to choose the duration of the bad weather
  - Flags these selected data points
- Function: **daynight**
  - Calculates duration of darkness per night during different times of year
  - Flag fraction of data points that would correspond to daylight
- Function: **abovehorizon**
  - Calculates when the star was visible to the telescope
  - Flags points corresponding to times of year when star is below horizon

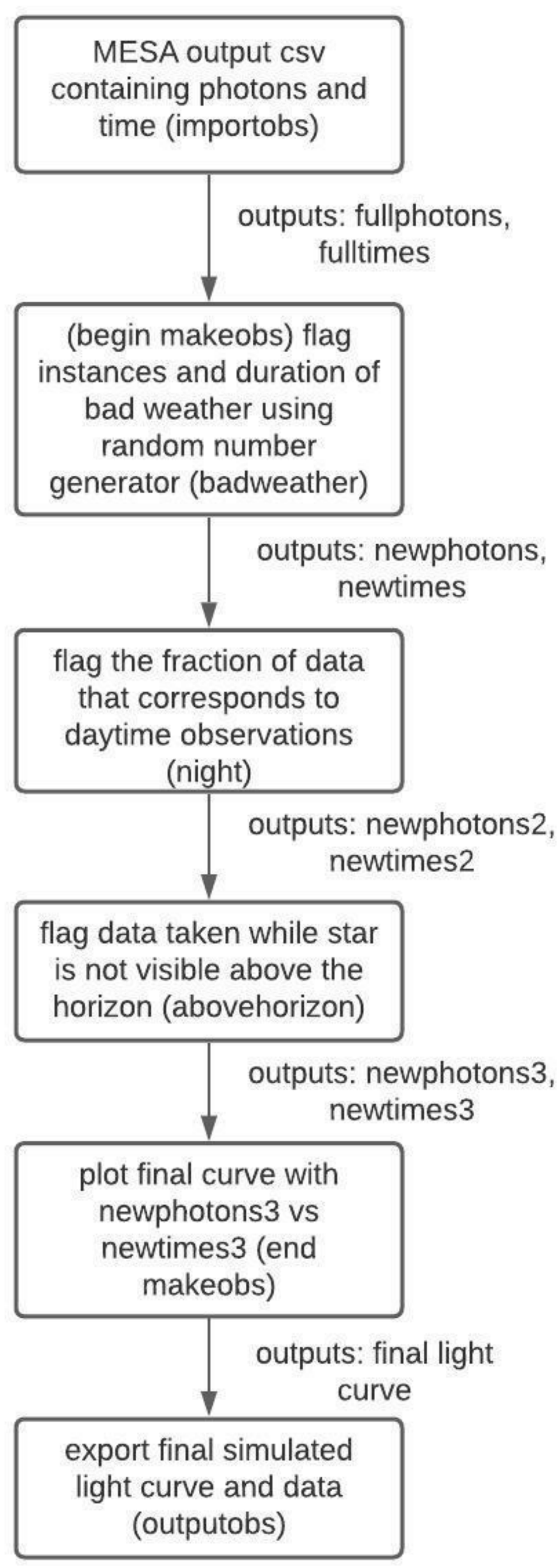

Fig. 3. Summary of main purpose, inputs and outputs of each module and function for the software design

Discussion

- Once coded: simulation will produce theoretical models for a certain Cepheid that will allow the analysis of variations between theory and observations.
- These differences could help understand the behavioral physics behind these stars that are so vital to decoding the mysteries of outer space. These differences might hold the key to fully understanding Cepheids and their role in the universe.

Conclusions

- In replicating the telescope results, we can find insight as to what happens to the light as it travels from the star by comparing it to real observations
- This simulation is not extensive– leaves room for additional modules if these three are found to be insufficient
- The bulk of data quality effects are accounted for
- Two further modules that might be needed to:
  - Factor in how many exposures ROTSE III took per night per area
  - simulate the effects of using a CCD camera for observations.

References and Acknowledgements

[1]H. Singh, S. Das and A. Bhardwaj et al., Light Curve Parameters of Cepheid and RR Lyrae Variables at Multiple Wavelengths – Models vs. Observations, (arXiv, 2019).

[2]A. Bhardwaj, S. Kanbur and M. Marconi et al., A comparative study of multiwavelength theoretical and observed light curves of Cepheid variables, (Monthly Notices of the Royal Astronomical Society, 2017) Vol. 466, Issue 3, p. 2805–2824.

A special thanks to Dr. Robert Kehoe from Southern Methodist University, Dr. Danielle Kara and the John Carroll University Physics Department, and the Colleran-Weaver Summer Research Fellowship for this opportunity and all the help.

Thank you also to the members of the Variable Star Project who have helped me complete this software design.