Abstract

RR Lyrae variables stars are stars with a characteristic relationship between magnitude and phase and whose distances can be easily determined, making them extremely valuable in mapping and analyzing galactic substrates. We present our method for searching for RR Lyrae variable stars using data extracted from the Dark Energy Survey (DES). The DES probes for stars as faint as $i = 24.3$. Finding such distant RR Lyrae allows for the discovery of objects such as dwarf spheroidal tidal streams and dwarf galaxies; in fact, at least one RR Lyrae has been discovered in each of the probed dwarf spheroidal galaxies orbiting the Milky Way (Baker & Willman 2015). In turn, these discoveries may ultimately resolve the well-known missing satellite problem, in which theoretical simulations predict many more dwarf satellites than are observed in the local Universe. Using the Lomb-Scargle periodogram to determine the period of the star being analyzed, we could display the relationship between magnitude and phase and visually determine if the star being analyzed was an RR Lyrae. We began the search in frequently observed regions of the DES footprint, known as the supernova fields. We then moved our search to known dwarf galaxies found during the second year of the DES. Unfortunately, we did not discover RR Lyrae in the probed dwarf galaxies; this method should be tried again once more observations are taken in the DES.

Introduction

The first, obvious question to consider when locating RR Lyrae is how one can distinguish RR Lyrae variable stars from the thousands of other stars one may find when probing a small area of the DES. In general, RR Lyrae lie in a relatively well-defined region on color-color plots, and Sesar et al. 2010 determined these color cuts to be effective:

$$-0.15 < g - r < 0.40$$
$$-0.15 < r - i < 0.22$$
$$-0.21 < i - z < 0.25$$

The variability cuts were determined based on the following low order statistics and the bounds on these statistics (Sesar et al. 2010):

$$\chi^2 = \frac{1}{n-1} \sum (y_i - \text{mean}(y))^2$$

$$\sigma = \left[\sum (y_i - \text{mean}(y))^2 / (n-1)\right]^{1/2}$$

Where

$$\mu_i = \frac{1}{R} \sum_{j=1}^{R} (y_{ij} - \text{mean}(y))^2$$

Finally, we required $\chi^2(g) > 3$, $\chi^2(r) > 3$, and $\chi^2(i) > 0.05$, $\sigma(i) > 0.05$.

Looking for RR Lyrae in Supernova Fields

With the periodogram functioning as desired (see right-hand plot), we then moved our focus on actually finding RR Lyrae in the Dark Energy Survey. The Dark Energy Survey consists of two different methods of probing the sky: the wide-area and the time-domain surveys. The wide-area survey intends to cover a large area of the sky below the color the equation $(5000 \text{ square degrees of sky, to be exact})$. To begin our search, we analyzed data from the Supernova fields within the DES Survey (these fields are circled in yellow in plot below), as these fields have a much higher number of observations in the DES Survey. A typical number of observations in the Supernova Fields is 100 or more, whereas the Y1 and Y2 data typically have a maximum of twenty observations per object, and these areas of the survey do not overlap.

Other problems were encountered while searching for RR Lyrae variables. One such problem is aliasing. The DES Survey has an observing cadence of approximately one day, and the frequency with which we took measurements may lead the periodogram to conclude that the period is different than the true period of the object. In particular, the periodogram would return periods that are harmonics of one day (1/2 day, 1/3 day, ...). While these stars are far more rare than RRab type stars, we could not rule out a potential detection. Unfortunately, however, these stars have light curves very similar to eclipsing binary stars, and these were specifically cut using the condition $y_r > 1$. One such ambiguous case is displayed below:

![Image of a ground truth RR Lyrae variable star with its unfolded light curve.](image)

Figure 1: An example of a “ground truth” RR Lyrae variable star with its unfolded light curve.

Galaxy Matching

Determining the property of the galaxy the RR Lyrae are in is extremely important, as theory predicts far more satellite galaxies than are observed. One RR Lyrae has been found in every dwarf satellite discovered, so it is scientifically significant to discover such RR Lyrae in such a dwarf galaxy.

Galaxies

Unfortunately, none of the identified candidate dwarf galaxies can be found in the Supernova Fields, so the number of observations for a field containing a dwarf galaxy is extremely limited. While the Supernova Fields may have 400 or more observations per object, the stars of a dwarf galaxy typically have between 38 and 25 observations. To test the Lomb-Scargle Periodogram, we found a star with a similar number of observations to those stars in a dwarf galaxy. The results were less than satisfactory:

![Image of the Lomb-Scargle Periodogram with periods from Sesar et al. 2010 as “ground truth”.](image)

Figure 2: Demonstration of the functionality of the Lomb-Scargle Multiband Periodogram with periods from Sesar et al. 2010 as “ground truth”.

Conclusions

We have described our method of identifying RR Lyrae variable stars in the Dark Energy Survey. We demonstrated the ability of Vanderplas’ implementation of the Lomb-Scargle Periodogram to correctly identify periods, showed that RR Lyrae can be identified in the DES, and described some of the caveats of utilizing this method for the purpose of identifying RR Lyrae. Unfortunately, we did not have the opportunity to analyze the dwarf galaxies in the DES for RR Lyrae; yet, once the survey is complete, there will be a sufficient number of observations to employ this method and obtain important scientific results. Namely, we will be able to measure the distance to such galaxies very accurately.

Acknowledgments

Texas A&M University thanks Charles R. B. 82 and Judith G. Munnerlyn, George L. 90, and Cynthia Woods Mitchell, and their families for support of astronomical instrumentation activities in the Department of Physics and Astronomy. This work was supported by NSF grant AST-1263034, "REE! Site: Research and Instrumentation at Texas A&M University."