Examination of Time Corrections for RR Lyrae Variables in the Kepler Data

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ABSTRACT

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An investigation into possible effects from the radial relative velocity of observed objects. RR Lyrae type variable stars are chosen as the subjects of the research. Light curves from three stars, taken from Kepler observations, are examined. Data reveals that there is a measurable effect: a shift of 0.01% per 33 km/s velocity. The relevance of this, as well as an anomalous measurement, are discussed.

Keywords: stars: variables, stars: RR Lyrae, Doppler effect, *Kepler*

Contents

Chapter 1

Introduction

In astronomical work extraordinary care is put into accounting for any change caused to measured data. Corrections for things such as the Rømer Delay, the Shapiro Delay, and the Einstein Delay are accounted for in determining the time an observation was taken. Even the site arrival time in which a measurement is taken is sometimes used as a correction (Eastman et al. 2010). The Julian Date (JD) is a universal calender, designed to allow consistent time keeping. The Barycentric Julian Date (BJD) is the same count, but corrects these delays and for slight changes in the Earth's position with respect to the barycenter on the Solar System. While care is taken to correct for the Earth's motion, it seems to be far less common to account for the possible effects of the movement of the observed object. Variable stars are perhaps the most obvious object for which the exact time of observations is critical to our understanding. In order to see if there was any effect on our results for the period of pulsations, I examined a group of RR Lyrae variable from the Kepler Mission. This provided very long data strings that would allow for the accurate determination of periods.

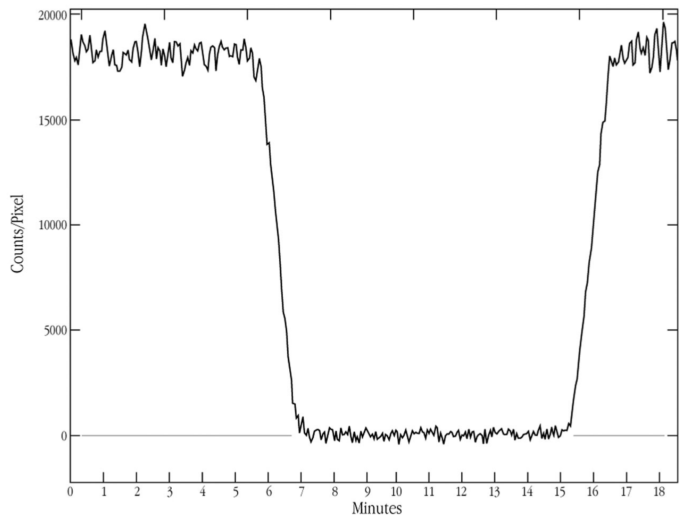

Figure 1.1 This is a typical light curve of an extrinsic variable star. The distinctive flattening is a sign of an object eclipsing the star.

1.1 Variable Stars

Stars that vary in brightness over time are called variable stars. The study of how and why these stars change luminosity can lead to many insights about the star and its surrounding space. There are two different types of variable stars: extrinsic and intrinsic.

Extrinsic variable stars only appear to vary in brightness, as seen from Earth. This is usually caused by other objects blocking some of the light of the star. Planets and other stars are the most common reasons, but clouds of dust or gas can also be possible sources of light change. Study of these stars can lead to more understanding of stellar life cycles and of solar systems.

Intrinsic variable stars vary in brightness due to physical changes within the stars themselves. This can be caused be a change in size, temperature, or a combination of both. The stars also could experience eruptive events, leading to chaotic spikes in brightness.

Figure 1.2 Light travels an additional distance due to the recessional motion of the distant galaxy.

1.2 Movement of Stars

All objects in space move relative to each other. Relative to Earth, an object can move in two types of ways. Tangential movement is orthogonal to line-of-sight. Radial movement is parallel to line-of-sight, or in other words towards or from the observer. As shown in Figure 1.3 the light leaving an object will have a different path length to travel from one observations time to the next.

It is well known that an objects radial velocity can affect how electromagnetic and pressure waves emanating from it are perceived. This is commonly called Doppler shift. Objects moving away from the observer appear to have longer wavelengths (redshift), while those moving towards the observer have shorter (blueshift). We can use this information to try and correct for the path length differences between two separate observations.

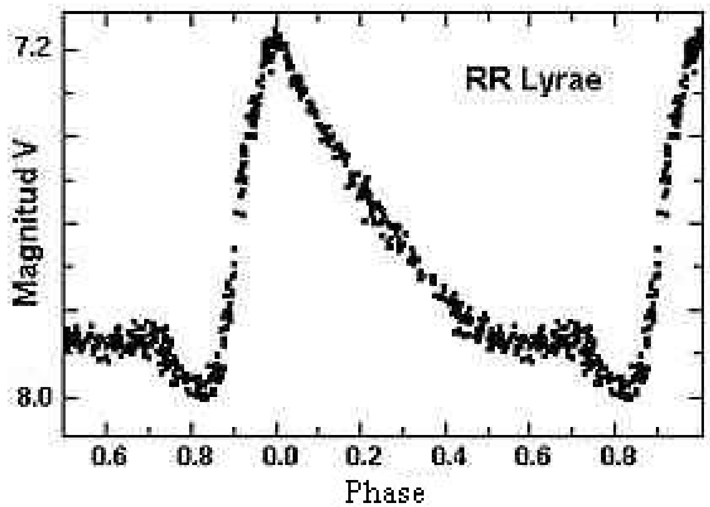

Figure 1.3 This is a typical light curve of an RR Lyr variable star. The changes are continuous, and the increases sudden.

1.3 RR Lyrae Stars

Since a number of RR Lyrae were included in the Kepler field, I decided to look at RR Lyrae type variable stars for this project. They have a well-established period-luminosity relationship, and so are used as standard candles. They most often appear in globular clusters, and are generally of spectral class A. They are low mass, usually about 0.5 solar masses.

RR Lyrae are pulsating variables. This means that the entire star expands and shrinks at a regular beat. The fundamental frequency of this beating determines the period of the star. They can beat with multiple, interfering frequencies. Care must be taken to separate these.

Because of their importance as standard candles in globular clusters, and the need for accuracy in the measurement of their period in order to use them as such, RR Lyrae type stars seemed a good candidate to investigate my theory. If their space motion significantly changed the measured period we would determine a wrong value for the luminosity. The absolute luminosity is then used as a distance indicator. Therefore it is critical we have the true period of the star.

Chapter 2

Setup

2.1 Kepler Observations

The Kepler space observatory (see Figure 2.1) was launched in March 2009. This NASA operated satellite was designed to discover Earth-sized exoplanets. To do this, it continuously monitors the brightness over 100,000 stars in a fixed field. Because of the sensitive nature of the search, the photometer aboard Kepler is made of 42 2200x1024 pixel CCDs, for a total resolution of 95 megapixels. The long cadence observations are readout every 29.4 minutes.

Although it was designed for exoplanet searches, due to its fixed field nature, Kepler also observed many more stars, including quite a few RR Lyrae type variables. The very precise data from these observations are available for public use, and this is what I used for this project.

2.2 Process

I decided to look at three different stars; AW Draconis, NR Lyrae, and V839 Cygni, whose characteristics are shown in Table 2.1. These were selected because of the quality of their light curves from Kepler. Each had many quarters of near complete data from long cadence observations, and

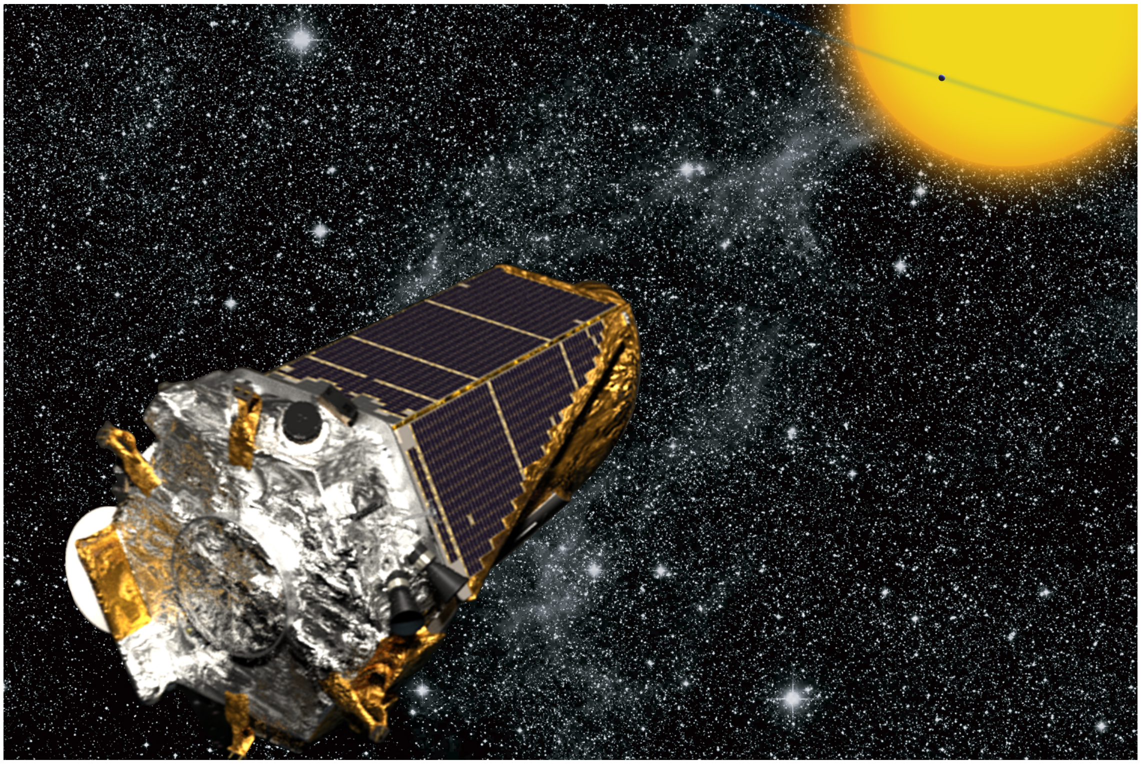

Figure 2.1 The Kepler Satellite.

each had a fairly smooth curve. I wanted the most basic light curves in order to focus on the theory being tested, the effect of velocity on observed frequencies, and not worry about possible interfering data. Some of the chosen stars did also have short cadence light curves available, although these were not used in the determination of frequencies.

Targets				
Name	K_p	P_{pul}	Frequency	Amplitude
AW Dra	13.053	0.6872160	1.455146	0.892
NR Lyr	12.684	0.6820264	1.466219	0.767
V839 Cyg	14.066	0.4337747	2.305344	0.793

Table 2.1 Characteristics of three target stars.

After deciding on the three stars to study, I requested their data from the Kepler database. Although each quarterly observation was done with the same instrument, there were many factors to the observed brightness. As such, each quarter had to be adjusted for observational differences. For each quarter, the average brightness was found, and this was subtracted from each data point, so that the average was 0. This way, each quarter was aligned with the others. The various quarters were then combined so that there was one complete light curve for each star.

As the idea of the research was to discover the effect of velocity on the light curves observed, I took the base data from Kepler, and adjusted it for arbitrary velocities. I used -100 km/s, -50 km/s, +50 km/s, and +100 km/s. For each of these velocities, I added to the reported observation times an adjustment of where the observation would have come, if the star had the relative velocity, as per equation 1, where HJD is the adjusted time of observation, HJD_0 is the original, v is the relative velocity being added to the star, Δt_i is the difference in time from this specific observation to the beginning of the observations, and c is the speed of light.

$$HJD = HJD_0 + \frac{v\Delta t_i}{c} \tag{2.1}$$

By doing this process for each of the chosen velocities, I ended up with five data sets for each star; the original base curve and one each for -100 km/s, -50 km/s, 50km/s, and 100 km/s.

For each data set I used Period04 to calculate the frequencies of the variable stars fluctuations. Period04 (Lenz & Breger 2005) is a Fourier Transform package which determines the best sine wave to fit the data, including amplitude and phase. Once determined this curve is removed from the data. Then the next period can be determined. I found the first ten frequencies of each data set.

Chapter 3

Results

3.1 Data

Appendix A shows the frequencies obtained for each of the data sets. Each shows a measurable change to the frequencies when velocity is taken into account. For every 50 km/s deviation from the base, there is a shift of a few thousandths in the frequencies. This amount does increase slightly with subsequent frequencies. While this is not large, it is present.

I also wanted to know how much the variation was as a percentage of the original frequencies. These values are shown in Appendix B. This shows a very interesting result. The changes are very linear, each 33.3 km/s causing 0.01% change to the frequency. This is the same for each star, and for each level of frequency.

The above is all true except for a single velocity change for one of the stars. When V839 Cyg was given a 50 km/s change to its velocity, the frequencies changed drastically. They instead fell into half frequencies. Other than this, the star behaved the same as the rest.

3.2 What this means

The fact that the changes to frequency are so small means that this phenomenon can most likely be ignored for most cases. However, it is a measurable shift, and so if complete accuracy is desired, must be taken into account. As astronomical research continues to become increasingly accurate, these shifts will become more concerning.

Fortunately, the consistent nature of the shift, exactly 0.01% per 33.3 km/s, means that it is a simple correction to account for.

The strange result of the V839 Cyg frequencies when 50 km/s were added to it is important. If this is a possible result for different speeds and different stars, it is possible that by ignoring the actual velocity of the star, frequencies determined could actually be half frequencies.

3.3 Future Research

Although the results of this research were straight forward, the sample size was very limited. This means that large scale verification is important. Also, because I wanted to simplify the results, only very simple light curves were used. Are there changes if more complex light curves are the subject of shifts?

As mentioned above, there is the one case in this investigation were the frequencies found were the half frequencies, compared to the other velocities of the star. It must be investigated as to whether this is a common occurrence.

Appendix A

Frequencies

Top 7 Frequencies for NR Lyr					
Frequency	-100	-50	Base	+50	+100
F1	1.466722	1.466477	1.466232	1.465988	1.465744
F2	2.933409	2.932920	2.932431	2.931942	2.931453
F3	4.400131	4.399397	4.398663	4.397930	4.397196
F4	5.866818	5.865840	5.864861	5.863883	5.862906
F5	7.333540	7.332317	7.331094	7.329871	7.328649
F6	8.800262	8.798794	8.797326	8.795859	8.794393
F7	10.266949	10.265236	10.263524	10.261813	10.260102

Table A.1 Frequencies determined for NR Lyrae with 4 different recessional velocities

Top 7 Frequencies for AW Dra					
Frequency	-100	-50	Base	+50	+100
F1	1.455640	1.455397	1.455154	1.454912	1.454669
F2	2.911246	2.910760	2.910275	2.909789	2.909304
F3	4.366886	4.366157	4.365429	4.364701	4.363973
F4	5.822492	5.821520	5.820550	5.819579	5.818609
F5	7.278132	7.276918	7.275704	7.274490	7.273278
F6	8.733772	8.732315	8.730858	8.729402	8.727947
F7	10.189377	10.187678	10.185979	10.184280	10.182582

Table A.2 Frequencies determined for AW Draconis with 4 different recessional velocities

Top 7 Frequencies for V839 Cyg					
Frequency	-100	-50	Base	+50	+100
F1	2.306116	2.305731	2.305347	1.152673	2.304578
F2	4.612230	4.611461	4.610692	2.305346	4.609154
F3	6.918347	6.917193	6.916040	3.458020	6.913734
F4	9.224463	9.222925	9.221387	4.610693	9.218312
F5	11.530579	11.528656	11.526733	5.763367	11.522890
F6	13.836695	13.834387	13.832080	6.916040	13.827468
F7	16.142811	16.140118	16.137426	8.068713	16.132045

Table A.3 Frequencies determined NR Lyrae with 4 different recessional velocities

Appendix B

Percentile

Percent Differences for NR Lyr					
Frequency	-100	-50	Base	+50	+100
F1	0.0334	0.0167	0.0000	-0.0167	-0.0333
F2	0.0334	0.0167	0.0000	-0.0167	-0.0333
F3	0.0334	0.0167	0.0000	-0.0167	-0.0333
F4	0.0334	0.0167	0.0000	-0.0167	-0.0333
F5	0.0334	0.0167	0.0000	-0.0167	-0.0333
F6	0.0334	0.0167	0.0000	-0.0167	-0.0333
F7	0.0334	0.0167	0.0000	-0.0167	-0.0333

Table B.1 Percentile period changes for V839 Cygni with 4 different recessional velocities

(check the last table for the +50 column)

Percent Differences for AW Dra					
Frequency	-100	-50	Base	+50	+100
F1	0.0334	0.0167	0.0000	-0.0167	-0.0333
F2	0.0334	0.0167	0.0000	-0.0167	-0.0333
F3	0.0334	0.0167	0.0000	-0.0167	-0.0333
F4	0.0334	0.0167	0.0000	-0.0167	-0.0334
F5	0.0334	0.0167	0.0000	-0.0167	-0.0333
F6	0.0334	0.0167	0.0000	-0.0167	-0.0333
F7	0.0334	0.0167	0.0000	-0.0167	-0.0333

Table B.2 Percentile period changes for AW Draconis with 4 different recessional velocities

Percent Differences for V839 Cyg					
Frequency	-100	-50	Base	+50	+100
F1	0.0334	0.0167	0.0000	-50.0000	-0.0333
F2	0.0334	0.0167	0.0000	-50.0000	-0.0333
F3	0.0334	0.0167	0.0000	-50.0000	-0.0333
F4	0.0334	0.0167	0.0000	-50.0000	-0.0333
F5	0.0334	0.0167	0.0000	-50.0000	-0.0333
F6	0.0334	0.0167	0.0000	-50.0000	-0.0333
F7	0.0334	0.0167	0.0000	-50.0000	-0.0333

Table B.3 Percentile period changes for V839 Cygni with 4 different recessional velocities

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