Abstract
The Kepler Mission is a Discovery mission supported by NASA’s Science Mission Directorate, and its primary aim is to discover Earth-like planets in the habitable zone of solar-type stars. The space telescope was designed with a photometer that monitors the Kepler field in a near continuous manner in order to achieve this goal. With this mission, the asteroseismology community also benefits from the Kepler data via the abundant time-series photometry. With a short cadence of 1 minute and long cadence of 30 minute observations, the time coverage for many variable stars is unprecedentedly complete. The Kepler field also contains the archetype RR Lyr, and the Kepler Asteroseismic Science Consortium (KASC) Working Group for RR Lyrae stars have been working to uncover the mysteries surrounding these stars. I will provide an overview of the Kepler program in relation to RR Lyrae research.

1. Introduction
The Kepler project, NASA’s 10th Discovery Mission, was launched in March 2009 with the primary objective of finding Earth-sized planets in the habitable zone of solar-type stars. While the exoplanet search is ongoing, the impact to asteroseismology projects is enormous. The high precision time-series photometry provided by Kepler is unprecedented for many areas of variable star research. For the celebration conference for George W. Preston, it is fitting to present the light curve of the eponym RR Lyr from Kepler.

This proceeding is divided as follows: Section 2 covers the data acquisition of the Kepler data and processing; Section 3 focuses on some published results of work done of RR Lyrae variable stars found in the Kepler field of view as well resources available from the Kepler Guest Observer Office; and Section 4 describes some NASA programs and opportunities to analyze Kepler data.

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2. Kepler Observations

The Kepler field of view is centered at $\alpha_{2000} = 19 : 22 : 40$ and $\delta_{2000} = +44 : 30 : 00$ and is $\sim 13.5$ degrees above the Galactic plane. Fortunately, the archetype RR Lyr ($\alpha_{2000} = 19 : 25 : 27.91$, $\delta_{2000} = +42 : 47 : 03.7$) is within the field of view. The Kepler photometer has two observational modes, long and short cadence. Long cadence observations are 270 coadded images with a combined exposure time of 30 minutes. The short cadence, which are 1 minute observations, is only 9 coadds. The bandpass of Kepler is wide in the optical regime (4200-9000 Å). This bandpass avoids the calcium H and K lines in the blue end and the fringing effects for the red end. The Kepler magnitude is approximately 0.1 magnitudes off of the $R$ magnitude for almost all stars (Koch et al. 2010).

Almost 100 years ago, time-series photometry was performed on RR Lyr with photographic plates. Figure 1 shows the light curve of RR Lyr from data reported in Tucker (1913) that covers 13 days. The total number of data points is 701 observations to create this light curve. Even in this data set, one can see the Blazhko effect modulates the amplitude in RR Lyr. The Blazhko effect (Blazhko 1907) has a periodicity between tens to hundreds of days, and it is characterized by a change in amplitude and pulsational period. Not all RR Lyrae variable stars exhibit Blazhko, but most surveys are estimating about 40-50% of all of these stars have this effect (Jurcsik et al. 2009, Kolenberg et al. 2010). Even to this day, the Blazhko effect still does not have a satisfactory explanation, but with Kepler, we can begin to discover more about this mysterious phenomenon. More in-depth discussions of the Blazhko effect of RR Lyr can be found in this conference proceeding series by K. Kolenberg or in Kolenberg et al. (2011).

Compared to the photographic work done by Tucker (1913), Kepler can obtain over 100 times more data points with short cadence mode. The cadence coverage allows us to observe nearly continuously the pulsation cycle of RR Lyr, but also many short period variable stars. Under the Director’s Discretionary Target program \(^2\), short cadence data were obtained for RR Lyr during Quarter 5 (March-May 2010). Since RR Lyr is a bright star ($V = 7.1$ magnitude), a special custom optimal aperture was created. This optimal aperture takes into account the bleed columns and essentially recovers all the photons from RR Lyr. Figure 2 shows the custom aperture (in green) used for RR Lyr. In Figure 2, a 10 × 10 arcminute region around the star is shown with the axes in units of pixels. The pixel scale of the Kepler photometer is 3.98 arcseconds per pixel. From the optimal aperture, the photons were summed from all the pixels assigned for the aperture. Even with such a star saturating on the CCD, we are able to conserve all the flux in the bleed columns in order to measure the brightness of the star. With the 1-minute short cadence over three months, this yielded over 130,000 observations. The light curve of RR Lyr is presented in Figures 3, 4, and 5.\(^2\)

\(^2\) http://keplergo.arc.nasa.gov/GOProgramDDT.shtml
Due to RR Lyr being such a bright target and the use of a custom aperture, the data were not processed through the entire Kepler data pipeline, housed at NASA-Ames Research Center. Basic data reduction steps were applied, but the aperture photometry was carefully done outside of the pipeline in order to produce the light curve information. Instrumental signatures from the spacecraft are minimal for the light curve of RR Lyr since it is such a bright star. However, Kepler users are advised to consult the Data Release Notes in order to identify any known instrumental artifacts in the aperture photometry. For example, some features include a three-day cycle of the desaturation of angular momentum of the reaction wheels, initiation of the long cadence observations, and thermal instabilities, which affects focus.

In general, the short cadence data are used for transit timing measurements for planets, but also for asteroseismology. In the binary FITS table files, which can be downloaded from the Multi-Mission Archive at STScI\(^3\) (MAST), there are two data columns used for producing light curves. The column labeled “ap_raw_flux”\(^4\) contains the data pipeline product known as Photometric Analysis or PA. The data have been processed with the standard data reductions steps (bias, dark, and flat fielding) along

\(^3\) http://archive.stsci.edu/kepler/

\(^4\) In future releases of the data, this column of data will be renamed to “SAP_FLUX”.

Figure 1.— Photographic plate measurements of RR Lyr. Data taken from table 1 of Tucker (1913).
Figure 2.— Custom optimal aperture for RR Lyr used by Kepler spacecraft. The green area is the custom, optimal aperture. The axes mark the location within the CCD chip and are in units of pixels.

with Kepler specific calibrations (cosmic ray removal, gain and nonlinearity, smear, and local detector undershoot effects). When this calibrated data goes through the PA pipeline module, the sky background level is removed and simple aperture photometry is performed. The sky background level is determined from pixels from the long cadence observations and is extrapolated for short cadence data.

The column with data labeled as “ap_corr_flux”\(^5\) contains data that has calibrated data (bias, dark, flat fielding, etc has been applied), PA aperture photometry, and then the Pre-search Data Conditioning or “PDC” processing. This column contains data

\(^5\) ap_corr_flux will be renamed in future releases of data as “PDCSAP_FLUX”
Figure 3.— Quarter 5 short cadence time-series data of RR Lyr. This data spans March-May 2010. In this figure, the Blazhko effect of RR Lyr can be clearly seen. The Blazhko period is $\sim 39$ days (Kolenberg et al. 2011).

where most of instrumental artifacts have been removed, and the data have been prepared for planet transit searching. However, the PDC data or ap\_corr\_flux values may have much of the astrophysical signatures removed, and the astronomical community is cautioned in using this data column. More details regarding the Kepler pipeline processed data are described in the Kepler Data Processing Handbook\(^6\).

3. RR Lyrae research

Currently, there are 37 known RR Lyrae variable stars in the Kepler field of view, and a majority of them are observed in long cadence. The Kepler Asteroseismic Science Consortium\(^7\) (KASC) has a working group devoted to the study of RR Lyrae variable stars. Recent results are presented in this conference.

The first Kepler results of RR Lyrae variable stars are published in Kolenberg et al. (2010). As more data are becoming available to the working group, unique phenomena have been uncovered. Of the small sample of RR Lyrae variable stars, 11 exhibit the

\(^6\) can be found at MAST [http://archive.stsci.edu/kepler/] or http://kepler.go.arc.nasa.gov/Documentation.shtml

\(^7\) http://astro.phys.au.dk/KASC/
amplitude and period modulation known as the Blazhko effect. Even with the small sample of RR Lyrae stars, we are finding at least 40% of the stars are experiencing the Blazhko effect (Kolenberg et al. 2010). A few stars with Blazhko also show a secondary, transient effect previously seen only in RV Tauri type variable stars. The period doubling effect (Szabo et al. 2010, Benko et al. 2010) was observed in 3 Blazhko RR Lyrae stars. This effect is characterized by alternating maxima in the Kepler light curves and the discovery of half-integer frequencies in the frequency spectra.

To expand the studies of Kepler RR Lyrae stars, we need to find unknown, fainter candidates. The confusion limit for Kepler is approximately $K_P = 21$ magnitude. The Kepler Input Catalog (Brown et al. 2011) contains pre-launch ground based information for objects down to $K_P = 17$. Therefore, there may be a plethora of unknown variable stars that Kepler could observe.

A new resource which takes advantage of the monthly full frame images of the entire Kepler field should list potentially new and unknown variable stars. The full frame images are taken by Kepler each month in order to check the health of the photometer. These publicly available images can have aperture photometry performed on them, and thus create light curves with a much lower cadence.

To determine which stars are potential variable stars, a difference image was produced. Those stars with a large (at least $5\sigma$) residual were considered to be variable.
Figure 5.— Quarter 5 short cadence data of RR Lyr. A little more than 9 pulsational cycles are seen in 5 days. A hint of the alternating maxima can be seen here, which is described as the period doubling effect (Szabo et al. 2010).

Over the entire Kepler field of view, over 260,000 stars were found to be variable star candidates. This catalog of variable star candidates can be used to identify new targets for Kepler to observe. For all of these candidates, light curves were produced from Quarter 0 commissioning full frame images. This set of eight full frame images were taken when the spacecraft was at optimal pointing and thermally stable, thus the photometry is not as impacted by many of the instrumental artifacts which appear in later quarters of data.

An example of a light curve of a variable star candidate is shown in Figure 6. These eight data points were not taken consecutively during the commissioning phase but over a 30 hour period. The aperture photometry done on the full frame images was completed with the IRAF package apphot, thus the uncertainties are due to the assumption of a Gaussian profile of the star. The Kepler aperture photometry uses a more exact pixel response function to maximize the flux of a target in order to do the photometry (Jenkins et al. 2010). This star, identified as Kepler ID 8332007, was also observed during Quarter 1 and with a 30 day coverage in long cadence. This star appears to be a bona fide variable star as seen in Figure 7.

Almost 75% of the variable star candidates that make up this catalog are not currently being observed by Kepler. This catalog of variable stars will provide many areas
Figure 6.— Variable star candidate Quarter 0 light curve. The light curve was created from aperture photometry done with the IRAF package apphot on the 8 full frame images taken during Kepler's commissioning phase. The y-axis is a relative Kepler magnitude.

of asteroseismology more candidates and better statistics for their variable star studies. This variable star candidate catalog is slated to be released later in 2011 at the MAST.

4. Opportunities with Kepler

The Kepler mission is a resource available to the astronomical community. The spacecraft stares nearly continuously at its field of view, but is travelling in an Earth-trailing orbit. In the time while we can still communicate with the satellite, we need to take advantage of Kepler's high precision photometry. As of this writing, three quarters of data (138 days) are available to the public for both exoplanet and astrophysical research. All public data can be retrieved from the MAST through their various webforms, and the data files are in binary FITS file format.

Opportunities exist for the astronomical community to become involved with Kepler data. The Guest Observer Program\(^8\) will allow investigators to obtain data on new

\(^8\) http://keplergo.arc.nasa.gov/
targets in the Kepler field of view for astrophysical studies. The Astrophysics Data Analysis Program supports archival research of publicly available data. Both of these NASA programs provide funding on a yearly basis. Guest Observer proposal deadlines occur mid-December of each year of the mission, and the Astrophysics Data Analysis Program deadlines are mid-May of each year. Another avenue to obtain data is through the Kepler Asteroseismic Science Consortium\(^9\), which is open to all astronomers. On the shorter time scale, Director’s Discretionary Target Program\(^10\) allows the astronomical community to propose new targets to be observed on a quarterly basis (every 3 months) in either short or long cadence mode. This program is excellent for pilot studies in preparation for either a Guest Observer or Astrophysics Data Analysis Program proposal. Deadlines for the Director’s Discretionary Target Program are by the 24th of January, April, July and October.

The main mission statement of the Kepler Guest Observer Office is to help the astronomical community exploit the resources Kepler provides through its high precision photometry. As more quarters of data are made public, the Office is dedicated in providing support to the astronomical community through instrument and data expertise. We provide access to contributed software\(^11\) which will help the community analyze the Kepler data. Not only can RR Lyrae stars be studied through Kepler, as shown in this proceeding and others from this conference, but other types of variable stars. Kepler is expected to expand not only exoplanet investigations but many areas of astrophysics research.

\(^9\) http://astro.phys.au.dk/KASC/
\(^10\) http://kepler.go.arc.nasa.gov/G0programDDT.shtml
\(^11\) http://kepler.go.arc.nasa.gov/ContributedSoftware.shtml
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