To Pulsate or to Eclipse? Status of KIC 9832227 variable star

Karen Kinemuchi\textsuperscript{1}

\textsuperscript{1}Apache Point Observatory/New Mexico State University

Abstract

The variable star known as NSVS 5597754 was identified as a short period RRc field star from ground-based photometry. This star happens to fall in the Kepler field of view and has been observed for 3 years with the Kepler spacecraft. Renamed KIC 9832227, this star was re-identified as an eclipsing binary with a periodicity of 0.457970 days. The NSVS ground based photometry yielded a period solution of 0.229 days. The Kepler photometry, which sampled the light cycle every 30 minutes, shows a peculiar behavior that is not purely eclipsing superposed over the primary variation. Follow-up ground based observations were taken in 2010 with the 0.6m MSU Observatory to obtain additional information. I present a summary of the ground based data taken of this perplexing star and conclusions derived thus far.

1. Introduction

The Kepler spacecraft has revolutionized stellar pulsation and asteroseismological studies. Many well known variable stars are now cast in a new light from the monitoring performed by the spacecraft. An example of new discoveries made with Kepler in the realm of RR Lyrae variable stars is the period doubling found in some Blazhko effect affected stars (Szabo et al. 2010). Although a relatively small number of RR Lyrae variable stars are within the Kepler field, each star holds a wealth of information, and puzzles, to keep astronomers busy.

I present one such variable star which was previously identified as an RR Lyrae star, but Kepler has reclassified it and uncovered peculiar behavior never seen from ground based data. This star has multiple nomenclature, but will be mostly referred
KIC 9832227

The position of this star is at $\alpha_{2000.0} = 19^h29^m15.95^s$ and $\delta_{2000.0} = +46^\circ37'19.88"$, and it has $V$ magnitude of 12.369 (Pigulski et al. 2009). I discuss the analysis performed currently on the ground based data, and suggest possible explanations of the peculiar behavior seen from the Kepler light curves.

2. Past ground based observations

The variable star seen in Figure 1 was identified in an all-sky survey (Northern Sky Variability Survey: NSVS) completed with a ground-based, robotic telescope, ROTSE-I (Robotic Optical Transient Search Experiment) (Kinemuchi et al. 2006; Wozniak et al. 2004). Over 300 observations were taken with the robotic telescope over a course of a year. The cadence of observations was two visits per night while that portion of the sky was visible from northern New Mexico. The original robotic telescope collected data without a filter, and hence, the measured magnitudes are in white light. Figure 2 shows the phased light curve of the photometry performed on the star. Kinemuchi et al. 2006 identified this star, dubbed NSVS 5597754, as an RR Lyrae variable star, Bailey type c. The classification was based upon the period solution ($P = 0.229$ days) and the sinusoidal light curve shape.

This variable star was also observed in the All-Sky Automated Survey (ASAS: Pigulski et al. 2009) in the $V$ and $I$-bandpasses. From their observations, this star has a $V - I$ color of 0.719 ($V = 12.369$ and $I = 11.650$) and a $V$ amplitude of 0.22 mag. The star was reported to be an eclipsing binary star (W Ursae Majoris type or EW) with a period of 0.4579480 days.

As demonstrated by the ground based data, the period solution depends upon the interpretation of the phased light curve. The shorter period of 0.229 days appears consistently if one assumes the star is pulsational in nature (see Section 4). The longer period of 0.457 days is derived when the phased light curve shows an eclipsing binary star. Period aliases no longer become an obstacle with the near constant monitoring performed by the Kepler spacecraft, as discussed in the following section.

3. Kepler observations

The Kepler spacecraft, launched in 2009, has been observing KIC 9832227 since the beginning of the mission, and has a total coverage of over 1300 days. KIC 9832227 has been observed in long cadence mode, meaning observations were taken every 29.4 minutes. The exquisite coverage shows detailed luminosity changes in this star that have not been discovered with the ground based data thus far.

During the commissioning period, known as Quarter 0 (Q0), this star was observed for 10 days at long cadence mode. The light curve from this time period shows a clear eclipsing nature (see Figure 3). The star was observed during Quarter 1 (Q1),
Figure 1.— Digital Sky Survey image of NSVS 5597754/KIC 9832227. North is up and East is to the right. The image covers $\sim$ 1 arcminute in right ascension and $\sim$ 10 arcminutes in declination.
Figure 2.— Phased light curve for NSVS 5597754. The photometry is based on the original ROTSE magnitude system which is white light.

which lasted 34 days, and a curious behavior appeared that was not seen in the 10 day coverage of Q0. A secondary variation can be clearly seen over the primary variation. This “envelope” variation continues into subsequent quarters. Figure 4 shows Q1, Quarter 2 (Q2), and Quarter 3 (Q3) data of KIC 9832227 and an overall view of the secondary variation. Note that Q2 and Q3 have 93 days of coverage per quarter.

The Kepler Eclipsing Binary Working Group analyzed the data and determined this star to be an “uncertain” classification (Matijević et al. 2012). They determined the variation period to be 0.457950 days, which is nearly double the period value determined from the NSVS photometry.

A recent update of the stellar parameters in the Kepler Input Catalog (Pinsonneault et al. 2012) shows that KIC 9832227 had an effective temperature of 5854K and a log $g$ value of 4.45. The effective temperature indicates this star is too cool to be a c-type RR Lyrae, which typically is much warmer as the blue edge of the instability strip has an effective temperature of 7400K (Smith 1994). The log $g$ value also shows that this star is a dwarf. With the addition of the stellar parameter information, we can conclusively say that this star is not an RR Lyrae star.

1 [http://keplerels.villanova.edu/](http://keplerels.villanova.edu/)
Figure 3.— Kepler light curve of KIC 9832227 during Quarter 0. Observations were taken in long cadence mode (every 29.4 minutes). The y-axis is the Pre-Data Conditioned Simple Aperture Photometry Flux in the units of electrons per second. The x-axis is the Barycentric Julian Date in days.

Figure 4.— Kepler light curve of KIC 9832227 during Quarter 1 (34 days). Data were collected in long cadence mode. The units on the x and y-axis are the same as in Figure 3.

The entire data set collected for this star are currently available through the Mikulski Archive for Space Telescopes\(^2\). Figure 7 shows the light curve from 2009 to 2012 (Q0-Q15). The data from each quarter were offset by a mean amount in flux units with respect to Quarter 5 data to stitch multiple quarters together. No scaling correction was applied to the quarter datasets. Using the first 500 Kepler observations, we recalculated the primary periodicity using the Supersmoother algorithm (Reimann 1994), and we arrive at \(P = 0.45797\) days for an eclipsing binary. This solution agrees with the findings of the Eclipsing Binary Working Group. We note the long term “envelope” variation seen over the primary is not periodic, and at Quarter 13, it appears to disappear for about 36 days. The nature of this envelope feature is currently being investigated. Suggestions for this phenomenon are discussed in Section 5.

\(^2\) http://archive.stsci.edu/kepler/
4. Follow-up Photometry and Analysis

During Quarter 7 and 10 Kepler monitoring, follow-up ground based observations of this star were collected at the Michigan State University 0.6m telescope in multiple bandpasses (Johnson $BVI$ and Sloan $g'r'i'$ filters). Figure 5 shows the phase-folded light curve from the MSU observations. We see a notable “peakiness” at the maximum and minimum of the variation rather than a more rounded feature. A periodicity of 0.22898 days was determined for these datasets, but it is clear that with this period the light curve did not repeat precisely from cycle-to-cycle.

Further period analysis was done on the Kepler photometry from Q0-Q5. The light curve was synthesized by R. Stellingwerf with Period Dispersion Minimization (PDM) (Stellingwerf 1978). A primary period of 0.22898 days was also found, and a secondary period of 0.4601 days was discovered. The secondary variation was modelled, but the results yielded no clear picture as to what the phenomenon is.
Under the premise that this star had pulsations like a c-type RR Lyrae star, Fourier Decomposition techniques were applied to both NSVS and Kepler data. This work was completed by S. Morgan at University of Northern Iowa. In Table 1, we list the resultant Fourier decomposition parameters for the light curves developed from the NSVS data (300 epochs) and Kepler data (23000 observations). We list only the Fourier decomposition parameters for $n = 2$ and $n = 3$. The NSVS data produced a period solution of 0.228958 days, and the Kepler data had a period of 0.228975 days. From the analysis of the Kepler data, a secondary period of 0.4598 days appeared, but has a power 30 times smaller than the primary period. The discrepancy on the Fourier parameters from the two datasets could come from analyzing light curves from a non-standard bandpass (i.e. usually Fourier decomposition analysis is done on broad-band Johnson V data). The NSVS dataset was obtained from white light, and the Kepler data were taken from a broad optical filter ($\lambda = 4300 - 9000\text{Å}$). The Fourier decomposition parameter discrepancy between data sets could also be explained that with the Kepler data, the binarity is more clear than any pulsational feature.
Figure 8.— Ground-based photometry of KIC 9832227 from the Michigan State University Observatory 0.6m telescope. Data were collected by H.A. Smith during the fall of 2010 (red points) and summer of 2011 (blue points).

| Dataset | Period (days) | $R_{21}$ | $\phi_{21}$ | $R_{31}$ | $\phi_{31}$ |
|---------|---------------|----------|-------------|----------|-------------|
| NSVS    | 0.228958      | 0.130    | 6.113       | 0.0366   | 1.857       |
| Kepler  | 0.228975      | 0.081    | 3.118       | 0.030    | 6.245       |

5. Conclusions

KIC 9832227, or NSVS 5597754, is not a short period c-type RR Lyrae star, but most likely a complicated W Ursa Majoris type eclipsing binary. The photometry, coupled with the derived stellar parameters from Pinsonneault et al. 2012, shows
this star is too cool to be an RR Lyrae, and is characterized as a dwarf star from its log \( g \) value. Ground based observations do not show the secondary variation that appears on top of the primary 0.456 day periodicity. Only through Kepler long cadence observations were we able to see this additional behavior.

As to what could cause the secondary variation, a couple of suggestions have been proposed. If we use the period solution from the PDM and Fourier decomposition of the light curve, the periodicity is on the short end of the RR Lyrae regime. If this star was a true pulsator, it could be reclassified as an unusual delta Scuti variable star. Another explanation is that this star is an exotic binary star system. The secondary variation is not completely periodic, and in the case of Quarter 13, the variation disappears for approximately 36 days.

Combining additional spectroscopic information with the accumulated photometry can help illuminate the nature of this object. Since August 2012, I have collected 6 epochs worth of echelle spectra on this object at the ARC 3.5m telescope in an effort to obtain radial velocities and metal abundances. With these additional pieces of information, we hope to get a better idea of the composition of the primary star and the dynamics of the system.

6. Acknowledgements

I would like to thank Horace A. Smith for being my Ph.D advisor at Michigan State University. He originally brought the NSVS project to my attention as a possible thesis project. It is through that work I first discovered this variable star, and while it is not an RR Lyrae, it has proven to be a very interesting object.

I would also like to thank all the collaborators who have provided very useful discussions and head scratching over this star: Robert Stellingwerf for doing a careful period analysis of five quarters of Kepler data; Siobahn Morgan for her Fourier decomposition work on both the NSVS and Kepler data; Doug Welch, Peter Stetson, and Michel Breger for delightful conversation and musing over this peculiar star.

Kepler data collected during Quarters 10,11,12 and 13 was made possible via the Kepler Guest Observer Cycle 3 Program, ID# 30024. This paper includes data collected by the Kepler mission. Funding for the Kepler mission is provided by the NASA Science Mission directorate. Some/all of the data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX09AF08G and by other grants and contracts.

References

Kinemuchi, K., Smith, H. A., Woźniak, P. R., McKay, T. A., & ROTSE Collaboration 2006, AJ, 132, 1202
Matijević, G., Prša, A., Orosz, J. A., et al. 2012, AJ, 143, 123
Pigulski, A., Pojmański, G., Pilecki, B., & Szczygieł, D. M. 2009, AcA, 59, 33
Pinsonneault, M. H., An, D., Molenda-Żakowicz, J., et al. 2012, ApJS, 199, 30
Reimann, J. D. 1994, Ph.D. Thesis: University of California, Berkeley
Smith, H. A. 1995, Cambridge Astrophysics Series, 27,
Stellingwerf, R. F. 1978, ApJ, 224, 953
Szabó, R., Kolláth, Z., Molnár, L., et al. 2010, MNRAS, 409, 1244
Woźniak, P. R., Vestrand, W. T., Akerlof, C. W., et al. 2004, AJ, 127, 2436