More Surprises from the Eclipsing Cepheid TYC 1031 1262 1

T.W. Kirkman, B. Demarais, M. Ellis, D. Byrne, J. Benson, J. Hoppert, A. Lusty

College of Saint Benedict
Saint John's University

Introduction

TYC 1031 1262 1 (aka ASAS J182611+1212.6, hereafter ASAS182612) was the first reported eclipsing Cepheid in the Galaxy (Antipin 2007). In June 2007 AAVSO initiated a campaign to monitor the star and for the past decade College of St. Benedict and St. John's University (CSB/SJU) undergraduates have continued to monitor this star. The star has proven to be a bit of a puzzle. The Cepheid component has been classified as type II (Antipin, 2007), classical (Schmidt, 2009), and anomalous (Sipahi, 2013). Sipahi et al. measured its radial velocities, found it was a double-lined eclipsing binary, and concluded it consisted of two bright giant stars: F8II+G6II (masses: 1.64 $M_\odot$ and .93 $M_\odot$) in the thick-disc population of our Galaxy. They measured a pulse period *increase* of about 2.5 min yr^{-1} which they associated with mass loss as the Cepheid almost fills its Roche lobe.

Observations

AAVSO's Alert 351 seemed to be an ideal project for our undergraduates. Up in the early evening during fall semesters and at $V \sim 11.5$, ASAS182612 was easily within reach of our 12" Meade telescope, using cameras and filters ($BVRI$) from SBIG. Most every night nearby IC 4665 was used to check color correction coefficients, and AAVSO supplied several standard stars with colors and magnitudes similar to ASAS182612 easily within the same frame as ASAS182612. Aperture photometry was performed using GAIA, a part of the UK STARLINK Project keep alive through the decade by the Joint Astronomy Centre and the East Asian Observatory. The SJU observatory is located in relatively dark rural central Minnesota. Typically there were about a dozen photometric nights per semester.

Methods

All $BVRI$ observations of ASAS182612 available from AAVSO were downloaded. Near simultaneous observations from a single observer were averaged. Often a sequence of observations from an observer would show a statistically significant linear trend. Each such linear trend was examined as a possible in-progress eclipse. In the end AAVSO provided 402 V measurements, 295 B, 263 I, and 161 R. BVI measurements spanned $\gtrsim$2700 d, but R measurements spanned only $\sim$1000 d. As a result of this shortened span, pulse acceleration in the AAVSO R filter data was not statistically significant. CSB/SJU $BVRI$ measurements were reduced as $B-V, V, R-I, I$ values. Deviations in magnitudes are, on a given night, correlated between different filters, so color indices actually show less scatter than individual magnitude measurements. The CSB/SJU data spans $\sim$3400 d and includes 163 nights. With very few exceptions nearly simultaneous observations through all four filters were obtained each night.
Time for all observations were converted to heliocentric JD.

Figure 1: AAVSO Pulse V

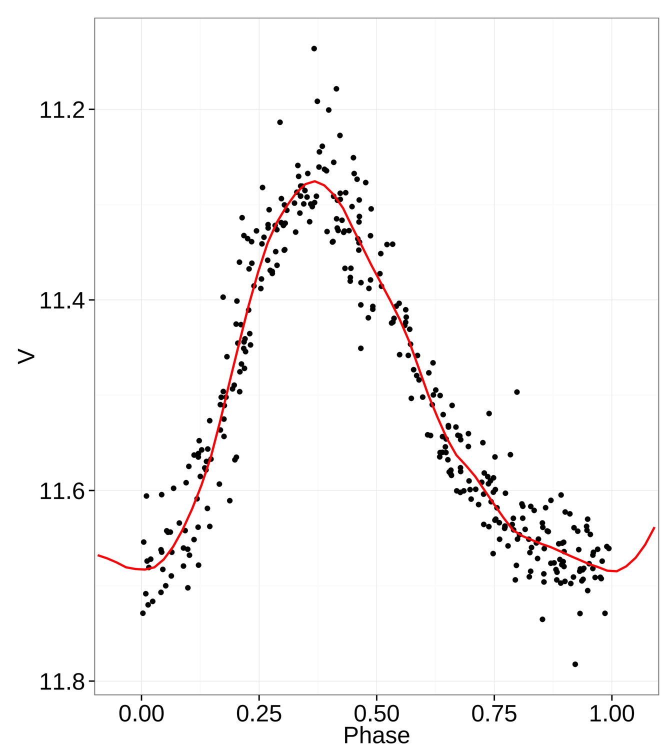


Figure 2: AAVSO Orbit V

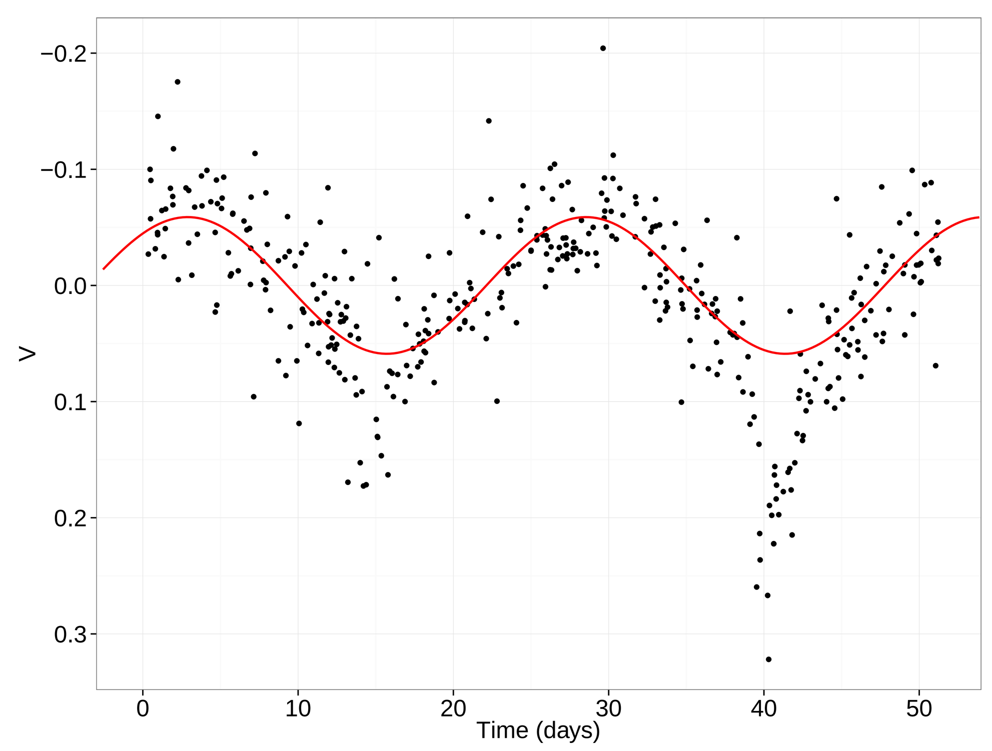


Figure 3: CSB/SJU Pulse V

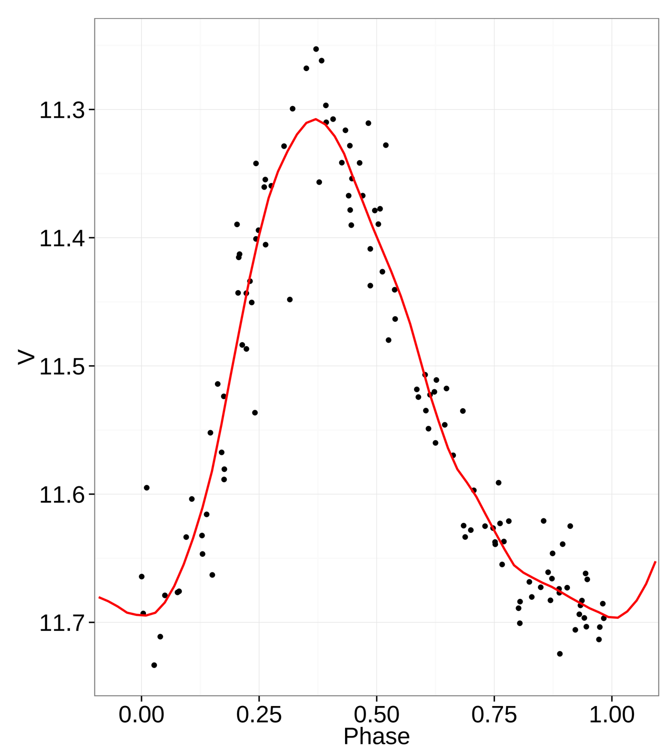


Figure 4: CSB/SJU Orbit V

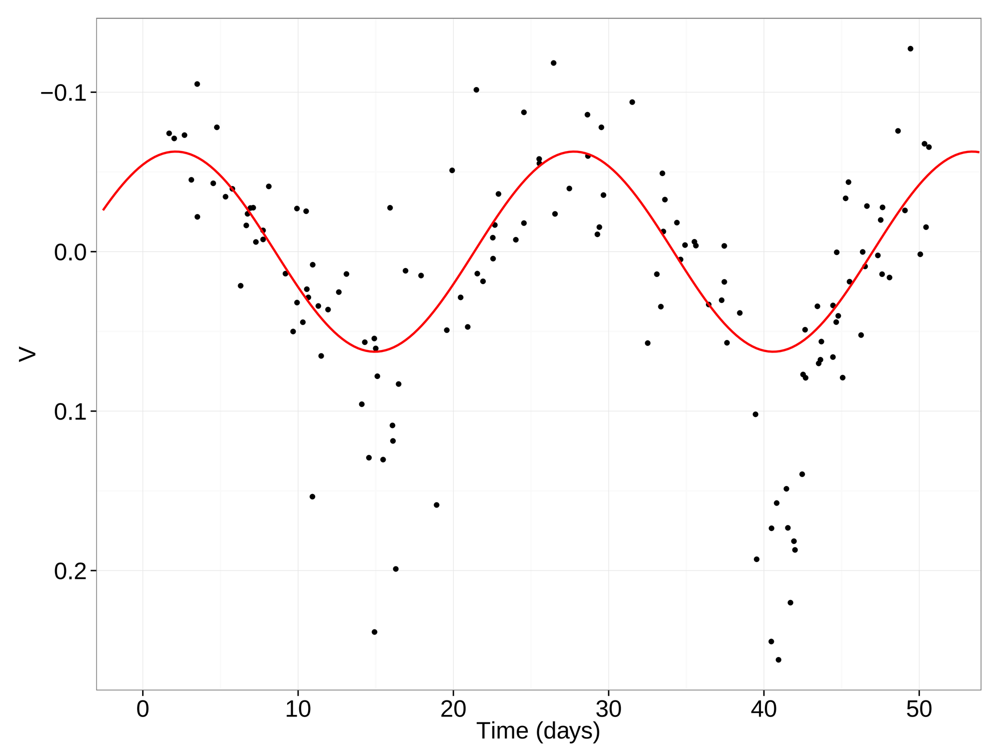


Figure 5: Fit with No Acceleration

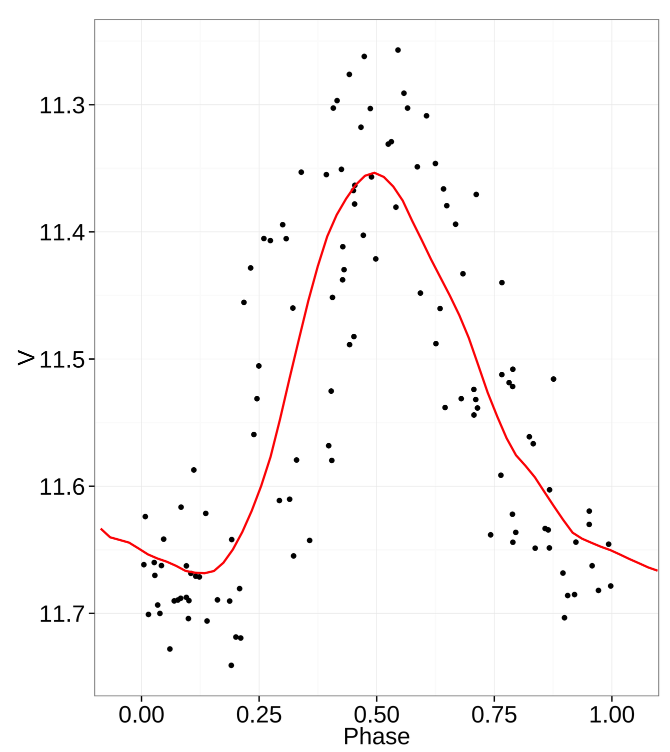


Figure 6: Pulse Period Deacceleration/Acceleration

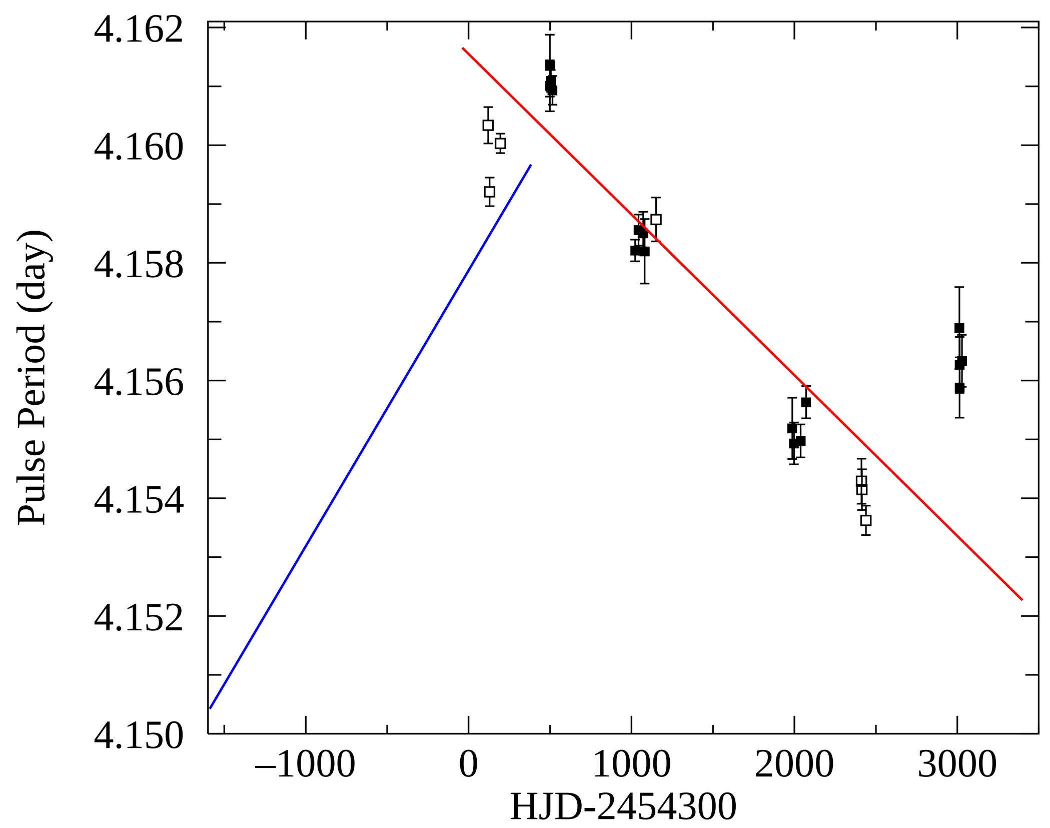


Figure 7: Pulse Period

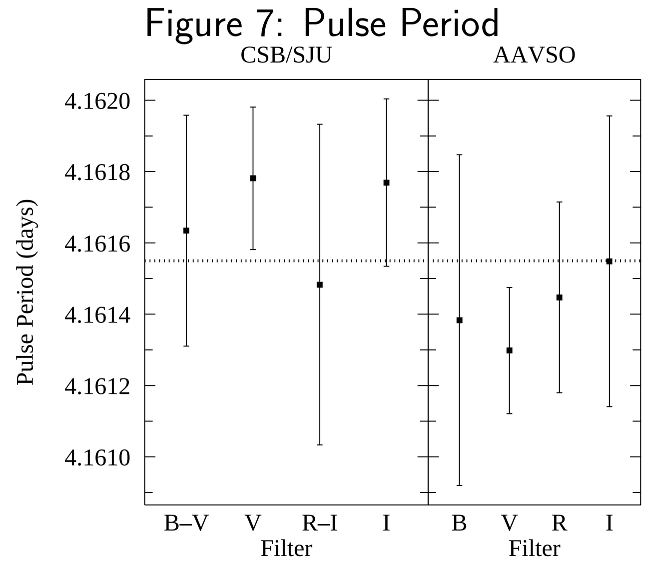


Figure 8: Pulse Acceleration

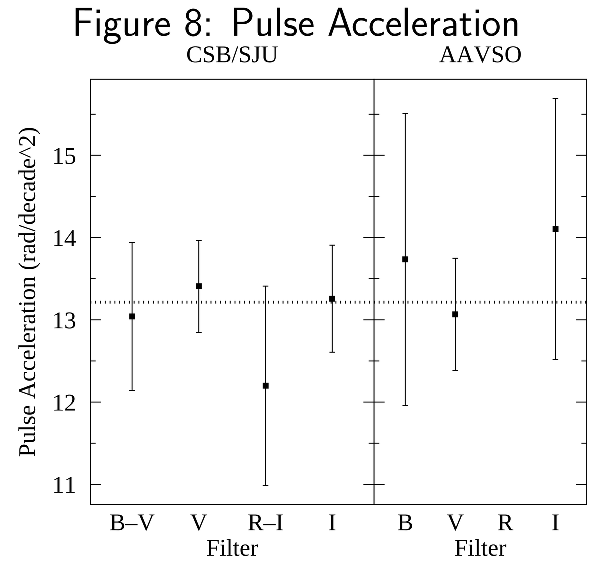
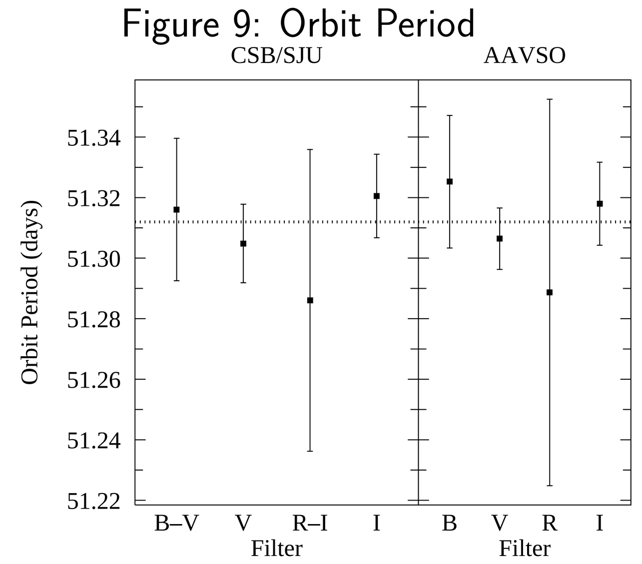


Figure 9: Orbit Period



Results

Figs. 1 & 2 show the V filter observations from AAVSO. Similar results were obtained for data in B, R, I filters, but the V observations are the most numerous of those reported by AAVSO observers and show the least scatter. Figs. 3 & 4 show our V observations results. Similar results were obtained for I and the color indices $B-V$ and $R-I$. We fit the observations (except the AAVSO R observations) to a simple model where the magnitude (or color index) was the sum of a term corresponding to a potentially accelerating Cepheid pulse and a term due to ellipsoidal variation:

$$\text{mag} = a_1 \cdot \text{pulse}((t + Kt^2)/T_p - a_2 \ \%\%\ 1) + b_1 \cdot \sin(4\pi t/T_o - b_2) + C$$

where a_1, a_2 (b_1, b_2) determine the amplitude and phase of the Cepheid pulse (ellipsoidal variation), T_p (T_o) is the pulse (orbital) period, K is related to pulse acceleration, and C is the average magnitude. The fits found that all of these parameters (with the occasional exception of a_2, which was generally small—i.e., $BVRI$ nearly in phase) were highly statistically significant and consistent across datasets and filters. Some of these results are displayed in Figs. 7–9. A simple sinusoidal was an adequate fit for the ellipsoidal variation. Initially the pulse was modeled with a truncated Fourier series. However since truncated Fourier series are bandwidth limited they pay particular attention to high slope regions at the expense of low slope regions (e.g., Gibbs phenomena). Best results were obtained using a fixed (for all filters) pulse template derived by loess regression to the well populated AAVSO V observations. Figs. 1–5 display 'pre-whitened' data/curve where the model for one frequency has been subtracted from the data and plotted with the model for the other frequency. Fig. 5 shows degradation of the fit if one attempts to fit the observations with a unchanging pulse period (i.e., $K = 0$). Fig. 6 shows the main result of this work in a different way. The blue line displays the pulse period *increase* found by Sipahi et al. (2013) plotted during the times of the observations they used to determine this period increase. The red line displays the corresponding result of our fits in the time frame of our data. The data points display a best fit constant pulse period for sequential three-season subsets of our data plotted at the mean time of those subsets. The filled boxes display CSB/SJU results in four filters, the unfilled boxes display AAVSO data in four filters (when available). Clearly the secular behavior suggested by Sipahi et al. is inconsistent with our results. Combining the two results suggests periodic or nonperiodic variation of the pulse period at the 0.1% level over a time scale of about a decade. At least another decade of data is needed to resolve the behavior.

References

Antipin S. V., Sokolovsky K. V., Ignatieva T. I., 2007, MNRAS, 379, L60

Schmidt E. G., Hemen B., Rogalla D., Thacker-Lynn L., 2009, AJ, 137, 4598

E. Sipahi, C. İbanoğlu, Ö. Çakırlı, S. Evren, 2013, MNRAS, 429, 757