Periodicity Analysis of the Semiregular Variable Star EV Aquarii

Emil Terziev
John R. Percy
Department of Astronomy and Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada; address correspondence to john.percy@utoronto.ca

Arne A. Henden
AAVSO, 49 Bay State Road, Cambridge, MA 02138; arne@aavso.org

Received May 5, 2011; revised September 8, 2011; accepted September 13, 2011

Abstract EV Aquarii is a variable star which was formerly misclassified as a cataclysmic variable, but photometric observations and colour indices have since indicated that it is most likely a semiregular M giant. The authors of this paper have used self-correlation analysis and Fourier analysis to determine the variability profile of the star. Data from the AAVSO International Database, the All-Sky Automated Survey, The Amateur Sky Survey, and co-author Arne Henden were used. The period of variation has been found to be 123.6 days ± 2.1 days. The amplitude of this variation is not constant; it changes with time between approximately 0.4 and 1.0 magnitude. There were no indications of a longer secondary period, though there has been observed an instance of a transient period of variation on a shorter timescale of about 40 days. There was no evidence found of periodic variation of the color differences.

1. Introduction

This paper arose as a result of a message, on the Citizen Sky distribution list, from co-author Henden, who is Director of the AAVSO. Over the course of his many years as an observer, he had accumulated a list of about forty projects which would be suitable for an experienced amateur astronomer or student. Co-author Terziev, who is an undergraduate Astronomy and Physics major, was looking for such a project. Since he had some experience in analyzing red semiregular variables, this project on EV Aquarii (R. A. 21^{h} 06^{m} 17.87^{s}, Dec. +00° 52' 43.9" (J2000)) seemed promising. Henden's file on this star (Henden 2011) included over a decade of email correspondence and observations.

This variable was initially called CSV 5342 and a finding chart was published in 1971 (Tsesevich and Kazanasamas 1971). There followed a series of confusions that often arise in variable star research, including a rather small and complex finder chart that may have led to a misidentification and inclusion in the second edition of the *Catalog and Atlas of Cataclysmic Variables* (Downes *et al.* 1997). Finally in 1999, Henden obtained observations which confirmed that the star was a red (*B–V* = +1.5) variable with a small amplitude and a longish period. He also provided a comparison star sequence for other observers to use.

Several sources of observational data were used in order to determine the variability profile and calculate the period of the star. One set of observations came from the American Association of Variable Star Observers (AAVSO), containing both Visual and *V*-band measurements. Another was obtained from the All Sky Automated Survey (ASAS), and was imaged in the *V* band. Observations of *V–I* color indices from The Amateur Sky Survey (TASS) were also used. Finally, we used Henden's personal observations, which were of the *V*-band magnitude and of color indices. Figure 1 shows light curves constructed from these datasets.

2. Discussion

We used two methods to analyze the data. The first was standard Fourier analysis of the data to produce frequency spectra of each dataset, using Period04 (Lenz and Breger 2005). The second was self-correlation analysis, which involves calculating the average differences in magnitude between all pairs of points in the dataset, and grouping them into bins according to the separation in time between the points. Points that are separated by multiples of the period manifest as minima in a self-correlation diagram. For a more detailed description of self-correlation analysis, consult Percy and Mohammed (2004).

To determine the period, we combined all of the *V*-band datasets, and performed Fourier analysis of the *V*-band and Visual observations. The spectra are presented in Figure 2.

The frequency of the most prominent peak in the Fourier transforms of each band gave us estimates of the period of 123.5 days ± 3.6 days (*V* band) and 123.7 days ± 2.6 days (Visual). The errors in frequency were calculated as the Half Width Half Max of the main peak, expressed as percentage errors in terms of the frequency of maximum amplitude, and the same percentage errors were applied to the corresponding period lengths. We calculated an average period, weighing each of the values we obtained by the inverse of their error. The average period was 123.6 days ± 2.1 days. Note that there are additional peaks of considerable amplitude on either side of the main frequency. However, they are separated from the main frequency by approximately 0.0027 (1/365) cycle per day. They are, in all likelihood, 1 cycle per year aliases of the main frequency. The alias structure responsible for the additional peaks can be seen in the spectral windows included in the same figure. Additionally, the frequency of maximum amplitude is actually double-peaked in the transforms of both the *V* band and Visual data. The companion peaks are at periods of 131.2 days ± 3.4 days (*V* band) and 129.7 days ± 3.1 days (Visual).

It can be seen in the light curves (Figure 1) that, while the star remains mostly periodic over the span of the observations, the amplitude of the brightness variations is not constant in time, and neither is the median magnitude around which the brightness oscillates. This implies that there could possibly be a longer period which governs these factors. Typically, the longer (secondary) period would be of the order of 10 times the shorter period (Nicholls *et al.* 2009). However, there are no prominent peaks in the Fourier transforms (Figure 2) at such low frequencies. We also performed self-correlation analysis looking for such secondary periods, and found none (Figure 3).

Since the amplitude of variation does not appear constant (it varies between approximately 0.5 magnitude and 1.0 magnitude in the light curves), we split the data into intervals of about 1,000 days (based on observational gaps), and calculated the amplitude in each interval separately. We were unable to use the AAVSO Visual data for amplitude determination, since the spacing of observations left gaps in the self-correlation diagrams, making the extrema hard to distinguish. The self-correlation diagrams of the *V*-band data can be seen in Figure 4. The repeating minima show that the periodic component of variation is very coherent. It is also possible to determine the average observation error of each dataset using self-correlation. Extrapolating the delta magnitudes to a delta time of 0 day would give us an approximation for the measurement error. We discovered that the AAVSO *V*-band data were accurate to about 0.05 magnitude, the AAVSO Visual data to about 0.15 magnitude, the ASAS *V*-band data to about 0.07 magnitude, and Henden's *V*-band data to about 0.01 magnitude.

To determine the amplitude from a self-correlation diagram, we took the average value of the maxima in the diagram and subtracted the average value of the minima. This difference is approximately 0.9 of the full amplitude of variation of the star. The values for the amplitude we obtained are summarized in Table 1.

We created phase diagrams using the average period we calculated (Figure 5). Again, the data were split into intervals of about 1,000 days to avoid excessive amplitude changes within each interval. The phase diagrams of each segment of observations show amplitudes similar to those obtained from self-correlation.

It should be noted that we found an instance of EV Aqr exhibiting transient periodic behavior on a shorter timescale. Figure 6 presents a light curve of a single observation season lasting approximately 250 days. During this season, there is an obvious cyclic behavior with a period of about 40 days. The self-correlation diagram in the same figure confirms this. The shorter period cannot be found in either the previous or the next observation season, so it must have been short lived.

We used 2MASS multiband observations (Skrutskie *et al.* 2006) and Henden's data to determine the star's colors. From Henden's data, we determined that the star's approximate colors are: $U–B = +1.2$, $B–V = +1.5$, $V–R = +1.4$ and $R–I = +1.9$. The 2MASS observations with A-quality flags revealed that the average $J–K$ color is +0.7. These values are typical of stars of this type; it is almost certainly an M giant. Henden had also taken time series *B–V* data, and we used *V–I* data from TASS. In Figure 7, we have plotted a phase diagram of Henden's observations from JD 2451810 to 2452172, comprising about three cycles of the main period. The observations are phased to our calculated average period of 123.6 days. The *V–I* phase diagram (phased to the same period) is also shown. The *V–I* colors were observed between JD 2452870 and 2453322, which is a length of time equal to about 3.7 cycles of variation. As Figure 7 reveals, the color differences are most likely random and do not vary systematically like the brightness does.

3. Conclusion

In summary, we found EV Aqr to be variable with a strong periodic component. The period of variation is 123.6 days ± 2.1 days. The amplitude of variation changes with time between about 0.4 and 1.0 magnitude. We found no conclusive indication of a longer secondary period. Such a period could potentially exist, but may be longer than the span of our data. We found that the star sometimes exhibits shorter transient periodic behavior. The star varies by about 0.1 in (*B–V*), but does not do so periodically.

4. Acknowledgements

We would like to thank T. Kato, M. Morel, G. Poyner, P. Schmeer, L. Shaw, and B. Sumner for private communications about this star, and the Ontario Work-Study Program for support. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation.

References

Downes, R., Webbink, R. F., and Shara, M. M. 1997, *Publ. Astron. Soc. Pacific*, **109**, 345.

Henden, A. A. 2011, http://www.aavso.org/sites/default/files/arne_projects/p024.evaqr.txt.

Lenz, P., and Breger, M. 2005, *Commun. Asteroseismology*, **146**, 53.

Nicholls, C. P., Wood, P. R., Cioni, M.-R. L., and Soszynski, I. 2009, *Mon. Not. Roy. Astron. Soc.*, **399**, 2063.

Percy, J. R., and Mohammed, F. 2004, *J. Amer. Assoc. Var. Star Obs.*, **32**, 9.

Skrutskie, M. F., *et al.* 2006, Astron. J., **131**, 1163.

Tsesevich, V. P., and Kazanasmas, M. S. 1971, *Atlas of Finding Charts of Variable Stars*, "Nauka," Moscow.

Table 1. Summary of measured amplitudes of variation of EV Aqr.

Observation Period (JD)	*Amplitude (d)*
2451800–2453000	0.99
2453100–2454100	0.51
2454200–2455200	0.45

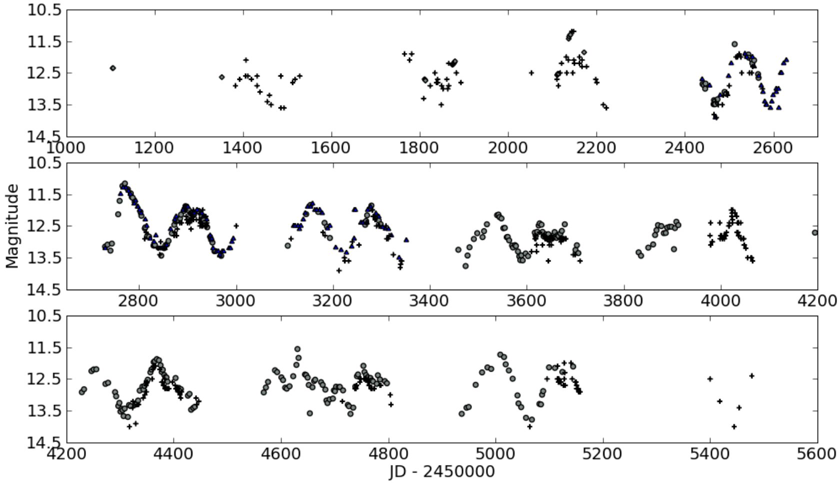

Figure 1. EV Aqr light curves: ASAS *V*-band data (open circles); AAVSO *V*-band data (triangles); Henden data (diamonds); AAVSO Visual data (plus-signs).

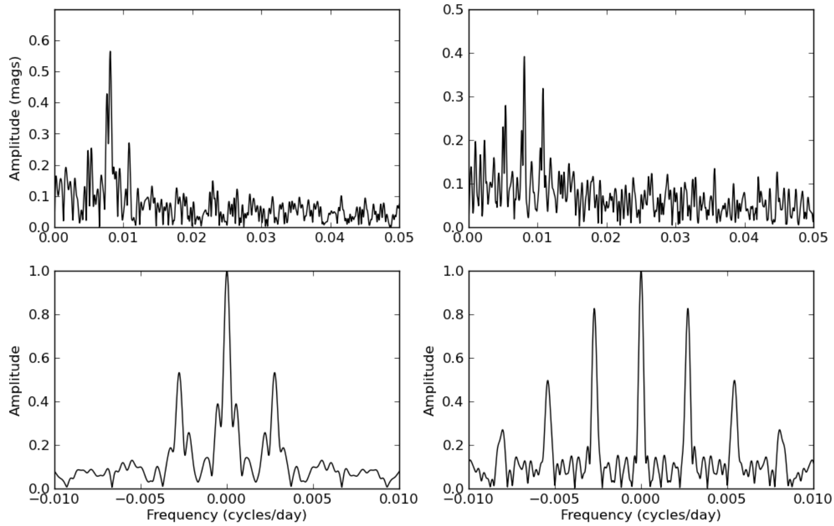

Figure 2. EV Aqr Fourier transforms: (top) and spectral windows (bottom) of *V*-band data (left) and Visual data (right).

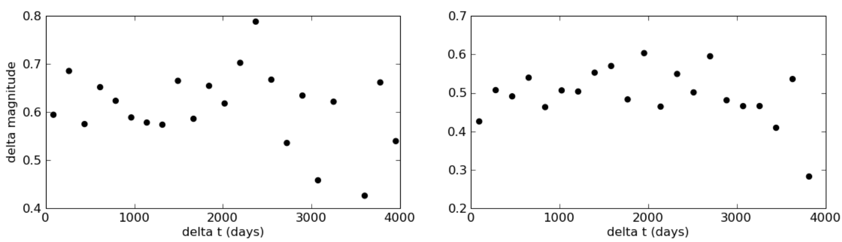

Figure 3. Self-correlation diagrams of EV Aqr *V*-band data (left) and Visual data (right).

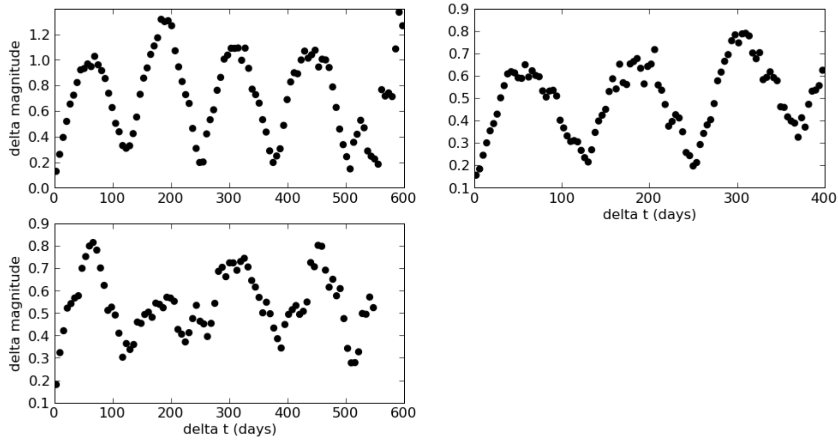

Figure 4. Self-correlation diagrams of EV Aqr *V*-band data: JD 2451800–2453000 (top left); JD 2453100–2454100 (top right); and JD 2454200–2455200 (bottom left).

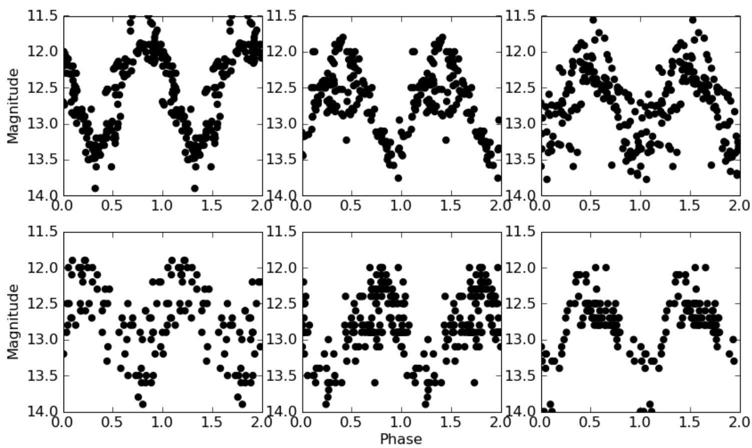

Figure 5. EV Aqr phase diagrams. Top row: *V*–band data, JD 2451800–2453000 (left), JD 2453100–2454100 (center), JD 2454200–2455200 (right). Bottom row: Visual data, JD 2451350–2452600 (left), JD 2452800–2454100 (center), JD 2454300–2455500 (right).

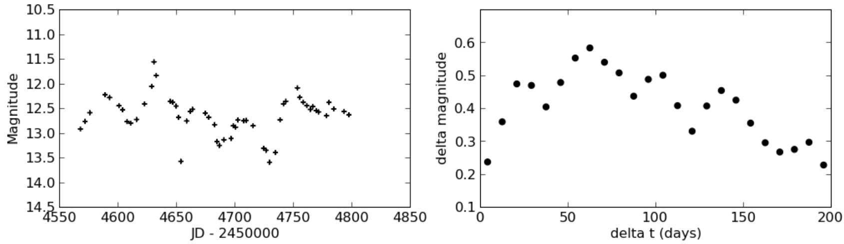

Figure 6. EV Aqr light curve of *V*-band data, JD 2454550–2454800 (left), and self-correlation diagram of the same observation season (right).

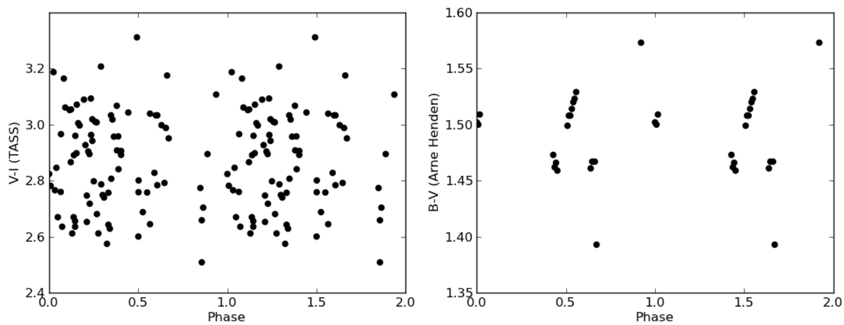

Figure 7. EV Aqr phase diagrams of *B–V* color indices from Henden data (left) and *V–I* color indices from TASS (right).