Analysis of ASAS-SN Observations of Short-Period Mira Stars

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Abstract We have analyzed observations of a uniform sample of 36 stars in the ASAS-SN variable star catalog, with mean magnitudes between 10 and 12, classified as Mira by the catalog, and with periods of 150 days or less. They presumably represent a transition from Mira type to semiregular type. The stars show a wide variety of light curve shapes, and of deviation from periodicity. The amplitude increases with increasing period, as is well known, but no other properties, including the degree of periodicity, seem to depend on period.

1. Introduction

The All-Sky Automated Survey for Supernovae—ASAS-SN (Jayasinghe *et al.* 2018, 2019)—uses a network of up to 24 telescopes around the world to survey the entire visible sky every night down to about 18th magnitude, and has been doing so for up to 2,000 days. ASAS-SN has identified over 50,000 new variable stars, determined periods and ranges for those that are periodic, classified them using machine learning, and made the information and data publicly available online (asas-sn.osu.edu/variables). It has also used machine learning to uniformly classify 412,000 known variables—many of them also observed by the AAVSO.

We have been using ASAS-SN data to study the complex variability of pulsating red giants (PRGs). Percy and Fenaux (2019) examined the analysis and classification of about 50 red semiregular stars, and identified problems with the ASAS-SN analysis and classification of these. Percy (2020a) used ASAS-SN data to study bimodal PRGs; Percy and Wallace (2020) used them to study PRGs which also had a long secondary period; and Percy (2020b) used them to study several dozen poorly-studied stars previously classified as "irregular" (most of them were non-variable, or microvariable at best). In this paper, we use ASAS-SN data to study 36 stars, classified as Mira stars, having periods less than 150 days, i.e. shorter than the periods of "traditional" Mira stars.

Mira stars, by definition, have visual ranges of 2.5 magnitudes or more. Most have periods of several hundred days; Mira itself has a period of about 330 days. PRGs with smaller ranges would be classified as semiregular (SR) or irregular (L). Note that, in general, the term *range* refers to the difference between the maximum and minimum magnitude; ASAS-SN uses a slightly different definition, as explained below. We wondered: would the short-period Miras be relatively periodic with visual ranges of 2.5 magnitudes or more, or would they be semiregular, with periodic components with full range less than 2.5 magnitudes, or would they represent some sort of smooth transition from typical Mira stars (Willson and Marengo 2012) to typical SR variables (Kiss and Percy 2012)?

2. Data and analysis

We analyzed a uniform sample of 36 stars from the ASAS-SN variable star catalog, with mean magnitudes between 10 and 12, classified by ASAS-SN as Mira stars (visual range greater than 2.5 magnitudes), with periods less than 150 days. The shortest period of the stars in our sample was 87.7 days. The declinations of the stars were +79 to –70 degrees. The datasets were uniform in the sense that they are typically 1,500–2,000 days long—about 15–20 pulsation periods for a typical star in our sample.

The ASAS-SN data were downloaded, the light curves were inspected, and the data were analyzed using the Fourier-analysis routine in the AAVSO VStar time-series package (Benn 2013). Our intention was not just to determine a single period and amplitude, as ASAS-SN does, but also to look for evidence, in the light and phase curves and Fourier spectrum, of more complex behavior such as harmonics, overtones, and long secondary periods (LSPs)—a poorly-understood phenomenon which occurs in about a third of SR variables. Note: in this paper, *overtones* are higher modes of pulsation, the lowest mode being the fundamental. *Harmonics* are non-physical periods which occur in the Fourier spectrum if the phase curve is non-sinusoidal. In that case, the phase curve can be synthesized by the sum of sine curves with the harmonic periods.

Specifically, harmonics have periods which are integral fractions of the pulsation period; the first is exactly half of the actual physical period. The first overtone is most commonly *about* half of the pulsation period, if the dominant pulsation periods are those of the fundamental mode and the first-overtone mode (Xiong and Deng 2007; Percy 2020a). Therefore, overtones can be mistaken for harmonics, and vice versa. The presence of overtones is also evident in the light curve as adjacent pulsation cycles with noticeably different amplitudes. LSPs might show up as slow variations in the light curve, or as low-frequency peaks in the Fourier spectrum. Given that the amplitudes of LSPs are generally 0.5 mag. or less (Percy and Wallace 2020), and that the lengths of our datasets are limited, and that our stars are to some degree non-periodic, and that the total ranges of these stars are greater than 2.5 magnitudes by definition, LSPs might be difficult to detect in these stars, if they are present. There is a similar limitation on our ability to detect overtones and harmonics in the Fourier spectra.

3. Results

The results of our analyses are given in Table 1. As well as the names of the stars, Table 1 gives the period PA and range RA from the ASAS-SN catalog, the period P and amplitude A from our analyses, a quantity F, and notes. Our amplitude A is the coefficient of the sine curve with period P. We would expect it to be half the ASAS-SN value, but RA is up to 30 percent greater than 2A, because of the ASAS-SN definition of range—it is the difference between the 5th and 95th percentile of the magnitude distribution (Jayasinghe *et al.* 2019).

We define the quantity F as (R–2A) / R, where R is here defined as the *total* maximum-to-minimum range of the data, i.e. it differs from the ASAS-SN range R, which is defined as indicated above. In the absence of errors, F would be 0 if the star was perfectly periodic, and 1 if the star had no periodicity, and was completely irregular. So F is a measure of the deviation from perfect periodicity. It quantifies the difference between the extreme values of the brightness variation, and the typical values based on the mean period and its amplitude. We hypothesized that F might be closer to 0 for longer-period, larger-amplitude stars.

In the "Notes" column, an asterisk * indicates that there were AAVSO visual data; (*) indicates that the visual data were sparse. We analyzed the visual data in case they could provide additional insight on the star's behavior. Usually they didn't.

Figure 1 shows the relationship between amplitude A and pulsation period P. The average amplitude increases with period—on average from about 0.9 mag. at P = 90 days, to about 1.5 mag. at P = 150 days—as many other studies have shown. The relationship in Figure 1 shows considerable scatter, which is not surprising, given the complexity of the individual stars' variability and the limited time span of the data.

Figure 2 shows the relationship between our parameter F = (R–2A) / R and pulsation period. We hypothesized that the longer-period stars would be more regular (F = 0) and the shorter-period stars would be less regular (F > 0). A very weak trend is seen in Figure 2 (but with much scatter) in the sense that shorter-period stars are very slightly less regular.

Figures 3 and 4 show representative phase or light curves. Figure 3, SS Cas, is almost periodic, and has a sawtooth light and phase curve. Figure 4, RX Lyn, is much more irregular.

Table 1. Analysis of ASAS-SN observations of short-period Mira stars.

Name: ASAS-SN-V	*V* Name*	*PA(d)*	*P(d)*	*RA*	*A*	*F*	*Notes*
J000936.51+513400.7	SS Cas	141.28	141.06	3.31	1.58	0.10	*
J044542.23+750604.9	X Cam	143.29	142.96	5.06	2.31	0.13	*
J053220.76-103721.4	FP Ori	144.99	145.29	2.14	0.91	0.33	
J075403.04-192017.6	ES Pup	138.55	138.03	1.91	0.86	0.31	
J082807.98+382022.8	RX Lyn	145.30	143.91	2.48	1.05	0.42	(*)
J083225.15-570212.9	IZ Car	104.59	104.70	3.42	1.48	0.30	(*)
J083652.88-464344.0	—	108.52	109.48	2.81	1.25	0.26	
J105340.86-531127.8	RU Vel	123.35	123.21	2.35	1.12	0.10	*
J110101.35-542441.4	CI Vel	137.84	138.20	3.44	1.34	0.33	
J111711.74-301051.3	BD Hya	118.46	118.30	3.04	1.29	0.50	
J124401.06-304214.7	V0455 Cen	104.01	103.23	2.98	1.31	0.27	
J150847.62-415948.9	OV Lup	95.15	97.49	2.51	1.15	0.38	*
J153709.22-422104.1	HH Lup	125.08	118.26	2.66	1.28	0.17	
J162313.17+440828.4	AY Her	130.99	129.02	2.38	1.02	0.32	(*)
J163255.65+065129.7	SS Her	108.01	107.81	3.33	1.49	0.40	*
J163302.23-673519.2	KM TrA	126.93	127.34	1.83	0.57	0.61	
J165447.09-651208.0	Z TrA	149.83	149.97	3.52	1.69	0.28	(*)
J170129.45+222838.1	SY Her	116.01	115.66	3.83	1.97	0.16	*
J170457.11-121205.8	UX Oph	115.59	116.29	3.32	1.52	0.24	*
J173705.97+181304.6	FR Her	136.05	134.66	2.79	1.12	0.32	(*)
J180428.19-290814.7	V0795 Sgr	87.70	87.06	2.63	1.13	0.32	
J182117.96-302543.1	V1599 Sgr	137.20	137.82	2.13	0.83	0.34	
J182144.18+040912.3	V0915 Oph	112.24	111.67	3.68	1.62	0.19	(*)
J190008.26-181510.5	V0733 Sgr	102.32	102.26	2.52	1.14	0.26	
J191743.80-172845.0	AL Sgr	92.05	90.02	2.37	0.78	0.61	*
J192008.66+414058.8	HO Lyr	99.75	100.28	3.03	1.36	0.22	*
J193131.25+344217.5	DD Cyg	146.69	146.24	2.50	1.22	0.24	*
J194154.61+544034.2	V0369 Cyg	104.79	104.54	4.05	1.79	0.19	(*)
J195245.97+562050.4	V0392 Cyg	96.47	96.37	1.86	0.66	0.51	*
J200011.10-695254.3	BQ Pav	111.11	109.99	2.79	1.24	0.31	*
J201511.08-060903.8	Z Aql	132.66	128.30	3.97	1.71	0.32	*
J204002.88-284732.6	R Mic	137.62	137.76	4.23	1.93	0.26	*
J210422.53+234918.2	R Vul	136.86	136.59	4.49	2.29	0.26	*
J212305.76+005015.6	RW Aqr	143.53	140.19	3.83	1.84	0.29	*
J215829.19-691236.5	RW Ind	144.86	144.99	4.39	1.96	0.29	
J232114.21+785732.6	RY Cep	149.83	149.63	3.28	1.39	0.22	*

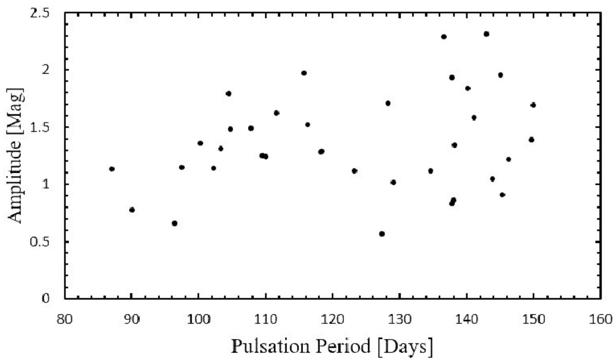

Figure 1. The relationship between V amplitude and period in days. On average, the amplitude increases with increasing period—a well-known result.

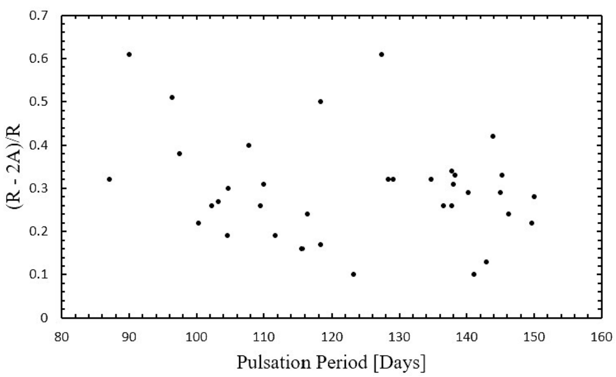

Figure 2. The relationship between the quantity F (see text) and the period in days. F is a measure of deviation from perfect periodicity. There is a very slight downward trend between F and period, with much scatter.

Fourteen of the 36 stars have 2A less than 2.5 magnitudes, so they would not be classified as Mira if they were perfectly periodic; the larger ASAS-SN range and the Mira classification is presumably a result of deviations from perfect periodicity. Nine of the stars have an ASAS-SN range RA which is less than 2.5 magnitudes.

4. Discussion

The periods that we derive are slightly different from the ASAS-SN periods, presumably because the latter were derived from a shorter dataset, and the periods of PRGs are known to be slightly unstable, and the variability complex. As mentioned above, the ASAS-SN ranges RA are up to 30 percent greater than 2A, presumably due to the ASAS-SN definition of range.

Hence our quantity F. In the absence of errors, F = 0 if the variability was perfectly periodic, and F = 1 if it was perfectly non-periodic. As it is, F ranges from 0.10 to 0.61. There is a very weak tendency for the longer-period stars to be more periodic and less irregular, but the tendency is not strong enough to call a correlation. There is certainly not a smooth transition from the longer-period Mira stars to the shorter-period ones.

The most interesting result of this study is the wide range of behavior in this sample of stars. Some stars (e.g. SS Cas (Figure 3), HO Lyr, DD Cyg, V915 Oph, and R Vul) are nearly periodic; others (e.g. RX Lyn (Figure 4), Z Aql, and KM TrA) are noticeably irregular. Most have reasonably sinusoidal light and phase curves, but V369 Cyg, SS Cas, FP Ori, and UX Oph

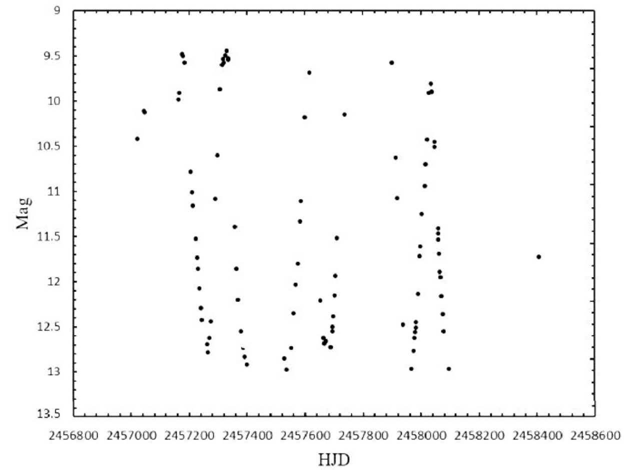

Figure 3. The light curve for SS Cas, from ASAS-SN data. The variability is close to periodic, but the phase curve is saw-toothed.

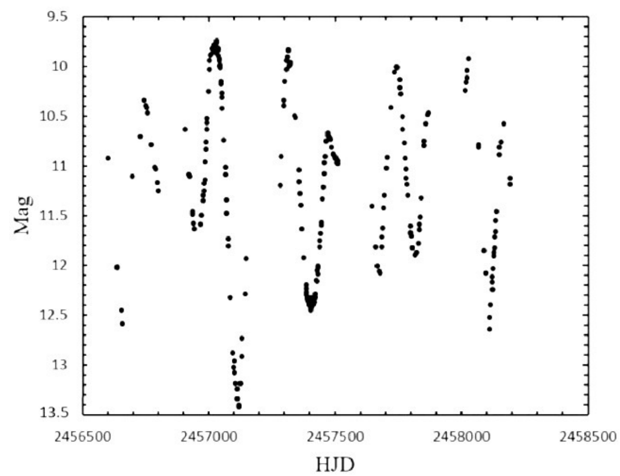

Figure 4. The light curve of RX Lyn, from ASAS-SN data. Note the large deviations from monoperiodicity.

have sawtooth phase curves; RY Cep has rounded maxima and sharp minima; FP Ori has a faster rise to maximum and a slower decrease; V733 Sgr has the opposite; RU Vel has a sharp maximum. Several of these stars show harmonics in their spectra, confirming that the light curve is non-sinusoidal. V794 Sgr, AL Sgr, IZ Car, and Z TrA have slow variations in pulsation *amplitudes*, which are found in many PRGs (Percy and Abachi 2013). BD Hya has a sudden transition from shallow minima to deep ones. Most of the stars have small cycle-to-cycle fluctuations in amplitude which could be due to overtones, but only SY Her, V1599 Sgr, and RW Ind seem to show possible overtones in the Fourier spectrum. KM TrA, R Mic, and V1599 Sgr show possible evidence of an LSP in the light curve; others may have LSPs, but these probably have amplitudes of 0.5 or less, and may not show up in the light curve or Fourier spectrum. The data for X Cam, RW Aqr, HH Lup, and CI Vel are somewhat sparse. Light curves of all of these variables are freely available on the ASAS-SN website: https://asas-sn.osu.edu/variables.

This project was carried out by an undergraduate student majoring in astronomy and physics. Projects such as this are an excellent way for students to develop and integrate their science, math, and computer skills, and to be introduced to the research process—motivated by knowing that they are doing real science, with real data.

5. Conclusions

We have shown that our uniform sample of 36 Mira stars with periods less than 150 days shows a wide range of light and phase curve shapes, and degrees of periodicity. Other than a positive correlation between amplitude and period, this variety of behavior does not seem to correlate with period, though there is a very weak tendency for the longer-period stars to be slightly more periodic.

6. Acknowledgements

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