Period Analysis of All-Sky Automated Survey for Supernovae (ASAS-SN) Data on a Sample of "Irregular" Pulsating Red Giants

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Received January 22, 2020; revised March 13, 2020; accepted March 17, 2020

Abstract All-Sky Automated Survey for Supernovae (ASAS-SN) data and, for some stars, AAVSO visual and V data have been used to study the possible periodicity of 74 "irregular" pulsating red giants (PRGs) in the AAVSO observing program. Results have been obtained and tabulated for 41 of them. For most of the tabulated stars, the new data provide more and/or better results than AAVSO data alone. All have small amplitudes. Several of the stars appear to have a long secondary period, as well as a pulsation period. A very few may be bimodal. Only about half of the periods that we derive are consistent with the periods in the VSX catalogue. We recommend that the AAVSO consider which of these small-amplitude "irregular" stars should continue to be observed, and how.

1. Introduction

Red giant stars are unstable to pulsation. In the *General Catalogue of Variable Stars* (GCVS; Samus *et al.* 2017), pulsating red giants (PRGs) are classified according to their light curves. Mira (M) stars have reasonably regular light curves, with visual ranges greater than 2.5 magnitudes. Semiregular (SR) stars are classified as SRa if there is appreciable periodicity, and SRb if there is little periodicity. Irregular (L) stars have very little or no periodicity. These divisions are arbitrary; there is a smooth spectrum of behavior in these stars, in amplitude, in period, and in degree of periodicity or irregularity. This paper deals with the "irregular" end of the spectrum.

There are hundreds of PRGs in the AAVSO visual observing program which are classified as SR or L type, but which have not been well-analyzed—usually because the number and distribution of measurements is insufficient. Percy and Terziev (2011), following on the work of Percy and Long (2010), analyzed data on "neglected" L-type stars in the AAVSO International Database (Kafka 2020) and, in their Table 2, recommended which stars might benefit from further observations—preferably photoelectric or CCD—and which would not.

Data from the All-Sky Automated Survey for Supernovae (ASAS-SN: Jayasinghe *et al.* 2018, 2019) is now available for almost all of these L-type stars, and can potentially provide additional information about their variability and periodicity. In the present paper, we use the ASAS-SN data and the AAVSO time-series package VSTAR (Benn 2013) to study the periods and amplitudes of as many of these stars as possible. We also analyze AAVSO visual and PEP/CCD data on these stars where available, to complement the ASAS-SN data. The purposes of this project are (1) to determine whether any of these "irregular" variables show sufficient periodicity to be reclassified as semiregular, (2) to determine the amplitudes of variability and, based on these and the degree of periodicity, recommend whether they should continue to be observed by the AAVSO and, if so, how, and (3) to compare our results with those given by the AAVSO VSX catalogue (Watson *et al.* 2014). The purpose was not to undertake astrophysical analysis of these stars; they are not suited for that purpose.

2. Data and analysis

Data were downloaded from the ASAS-SN website, and Fourier-analyzed using the AAVSO time-series analysis package vstar (Benn 2013). Where possible, AAVSO visual or Johnson V data (Kafka 2020) were analyzed also, though this paper reports only on stars which had usable ASAS-SN data. Note that ASAS-SN data are not suitable for stars brighter than V = 7 or fainter than V = 17. The precision of the period(s) that we determined was limited by the length of the dataset which, in the case of the ASAS-SN data, was about 2,000 days, so the uncertainty in the periods was typically about one percent. Pulsation periods of red giants are also known to "wander" by a few percent (Eddington and Plakadis 1929). The data available to us were often sparse, especially in the case of the AAVSO data. These limitations must be kept in mind when comparing results from ASAS-SN and AAVSO data with each other, and with results from the VSX catalogue and other results in the literature. As usual, we had to be alert for alias and harmonic periods, to distinguish them from overtone periods, which can be astrophysically useful (Percy and Huang 2015). Percy and Fenaux (2019) have discussed some other problems with ASAS-SN automated analysis and classification of pulsating red giants.

3. Results

The initial sample of stars was taken from Table 2 in Percy and Terziev (2011). There were some stars which were not observed by ASAS-SN, usually because they were too bright. For others, the ASAS-SN data were too sparse or scattered for analysis. For yet others, the combined ASAS-SN and AAVSO data did not produce any meaningful period results, either because the data were insufficient, or because the star's amplitude was too small, or because the star was truly irregular. In this paper, amplitude refers to the coefficient of the best-fit sine curve with the period under discussion; the peak-to-peak range would be twice this.

WY Gem, BU Gem, KK Per, and PR Per are actually classified as red supergiants, but it is still important to know

Table 1. Analysis of ASAS-SN data on irregular pulsating red giants.

Star Name	*P(days)*	*A (mag.)*	*PVSX (days)*	*Notes*
V338 Aql	47 ± 3	0.09	75.499374	LSP 760 d, A 0.1
HM Aur	270 ± 5	0.34	—	also 742 d, A 0.28
DK Boo	63	0.05	60.23	
UX Cam	94	0.11	—	LSP 920 ± 20 d, A 0.22
AA Cam	75 ± 25	0.08	—	LSP 650 d, A 0.13
UV Cnc	150 ± 50	0.16	148.520266	
RU Car	111	0.06	359	
BO Car	145	0.19	130.7	
WW Cas	400	0.13	—	also 233 d, A 0.11
AA Cas	80	0.14	—	LSP 800 d, A 0.15
PY Cas	55:	0.10	111	possible LSP 566 d, A 0.13
V396 Cen	220 ± 10	0.18	230.769226	also P 400 d, A 0.18?
SW Cet	80.5	0.19	53.93228	possible LSP 1150 ± 100 d, A 0.20
AO Cru	290	0.12	—	results uncertain
SV Cyg	410 ± 10	0.20:	196	also P 200 ± 10 d, A 0.15
AX Cyg	370 ± 10	0.16	361:	also P 188 d, A 0.13
BI Cyg	800 ± 50	0.18	—	also P 319 d, A 0.13
V485 Cyg	55 ± 5	0.09	—	
V1152 Cyg	118	0.17	—	
V2429 Cyg	503	0.27	—	
CT Del	82.2	0.12	83.5	LSP 350 ± 10 d, A 0.16
KP Del	27 ± 2	0.27	—	
AZ Dra	367	0.23	357	AAVSO data give 357 d
AV Eri	232	0.22	78.6	also P 123 d, A 0.12 overtone?
WY Gem	344	0.05	23550	
FI Gem	149	0.10	95.89142	also P 70 d? results uncertain
GN Her	91.7	0.09	—	LSP 533 d, A 0.17
V939 Her	67.6	0.13	—	LSP 417: d, A 0.14
TU Lyr	146.5	0.19	—	also P 278: d, A 0.16
PX Lyr	66	0.14	—	LSP 500 ± 100 d, 0.18
EX Ori	112:	0.19	115	LSP 910 d, A 0.15
V352 Ori	114 ± 5	0.10	118.6	
GO Peg	75 ± 5	0.09	79.3	
PV Peg	36.9	0.11	520	LSP also present?
FR Per	218.5	0.12	—	
ST Psc	822	0.28	540	also P 75–100 d?
V727 Sco	390:	0.09	—	
CP Tau	273	0.09	—	LSP 1365 d, A 0.12
V TrA	250	0.08	—	
FI Vel	40.4	0.02	—	not a PRG?
NSV 14284	85.9	0.20	87.7	

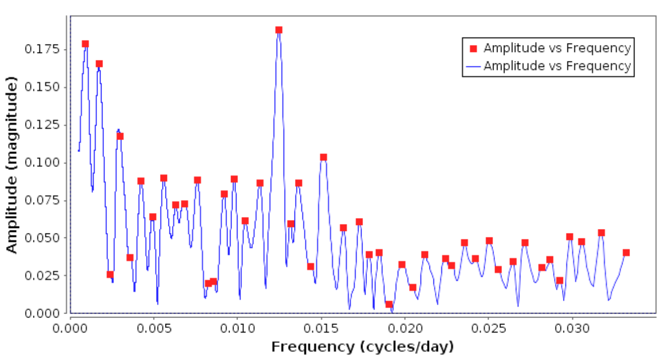

Figure 1. The Fourier spectrum of SW Cet, using ASAS-SN data. There appears to be a pulsation period of 80.5 days (frequency 0.0124 cycle / day), with an amplitude of 0.19 mag, and also a long secondary period of about a thousand days and an amplitude of 0.18 mag. The latter is not inconsistent with the period derived from AAVSO visual data, namely 1,280 days with an amplitude of 0.20. The VSX period is 53.93228 days. There is no evidence for this period, above the noise level, in the ASAS-SN Fourier spectrum.

whether these stars are truly "irregular" and/or should be removed from the AAVSO observing program—especially the visual program.

The following stars are probably non-variable: SV Aur, DR Boo, IZ Cas, UW Dra, KK Per, HU Sge, and NSV 14213. For the following stars, we were not able to obtain any results, usually because the ASAS-SN data were sparse or non-existent: NO Aur, VY UMa, NQ Cas, V391 Cas, AD Cen, AS Cep, T Cyg, RY Cyg, TV Cyg, CY Cyg, LW Cyg, QZ Cyg, V449 Cyg, V1173 Cyg, AC Dra, AT Dra, BU Gem, OP Her, TT Leo, T Lyr, X Lyr, XY Lyr, SY Peg, PR Per, X TrA, and RW Vir.

Table 1 lists stars for which we obtained some evidence of a coherent period. All these stars had ASAS-SN data, and all except RU Car, V352 Ori, V727 Sco, V TrA, and FI Vel had usable AAVSO data. Given the low amplitude of most of these stars, and their complexity—wandering periods, variable amplitudes, long secondary periods (LSPs)—the periods can usually not be specified precisely. Likewise, the amplitudes in Table 1 are "typical" values; somewhat different values might be obtained over different time periods. These amplitudes are almost all less than 0.2 mag. We also list the VSX period, PVSX, in days. The fourth column gives notes on some of the stars. Figure 1 shows the Fourier spectrum of a typical star, SW Cet. It has a pulsation period of 80.5 days which is well-defined, and much different than the VSX period of 53.93228 days. It also appears to have a long secondary period.

Detailed notes on the stars which were analyzed can be found on the following permanent, open-access website, maintained by the author's university: http://hdl.handle.net/1807/99842

4. Discussion

None of the stars in Table 1 appear to be strictly periodic, but they are candidates for reclassification as semiregular. The search for any degree of periodicity was challenging. The amplitudes were small. The ASAS-SN data were limited in length. The AAVSO visual data were limited in accuracy. Any AAVSO V data were sporadic, at best. Many of the stars that we studied did not yield any results. Many of the stars in Table 1 show evidence for long secondary periods, and the AAVSO data were useful in confirming some of these periods. It is significant that long secondary periods are reasonably common in irregular stars (or stars classified as such).

Among the stars with periods in the VSX catalogue, about half of our periods are inconsistent with the VSX periods, whereas the other half appear to be consistent. We note that a few of our stars have VSX periods which are expressed to 7 or 8 significant figures. This is not appropriate for these stars, which are semiregular at best, with "wandering" periods, and finite datasets.

Most of these stars continue to be observed visually—even the stars with amplitudes of 0.1 or less, including stars which are probably non-variable. For example: in the last decade, there have been dozens of visual measurements of NO Aur, which is probably non-variable. The AAVSO should consider how the observers' efforts can be used more productively. A few of the stars could continue to be observed photometrically but, for most of them, there is no scientific value in continuing to observe them.

5. Conclusions

The ASAS-SN data have been helpful in confirming that many of these "irregular" stars have some degree of periodicity, and should be reclassified as semiregular. For most of the stars in Table 1, the new data provide more and/or better results than obtained by Percy and Long (2010) or Percy and Terziev (2011) using AAVSO data alone. Not all of the periods of these stars are consistent with the periods in the VSX catalogue; the latter should be used with caution. Some of the stars appear to be non-variable, and almost all have small amplitudes—0.2 mag or less. Nevertheless, almost all of these stars continue to be observed visually, which is only marginally useful, at best. The AAVSO should address the question of whether and/or how these program stars should continue to be observed.

6. Acknowledgements

This paper made use of ASAS-SN photometric data. We thank the ASAS-SN project team for their remarkable contribution to stellar astronomy, and for making the data freely available on-line. This paper also made use of AAVSO data. We thank the observers and HQ staff for making and archiving the data, and the developers of VSTAR for creating this useful package, and making it publicly available. The Dunlap Institute is funded through an endowment established by the David Dunlap Family and the University of Toronto.

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