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Identification of Bimodal Period and Long Secondary Period Carbon Red Giants Misclassified as "Miscellaneous" in VSX

Introduction:

In a 2015 *JAAVSO* paper, Percy and Huang applied VStar analysis software to AAVSO visual observations of known carbon red giants in order to better determine the periodicities of these stars. In particular, they sought to separate false periodicities (due to alias and spurious periods) from truly biperiodic stars with two pulsation periods as well as long secondary period (LSP) stars. Previous work by this author and her students has determined that while pulsating red giants in general have sufficient irregularities and multiple periodicities to confound automated classification algorithms, for example those of ASAS (All-Sky Automated Survey) and ASAS-SN (All-Sky Automated Survey for Supernovae), VStar analysis can often identify improved periods and lead to the proper classification of these stars' variability type. This project, motivated by the work of Percy and Huang, is a preliminary analysis of 250 spectral class C red giants with V-band variability that are classified as MISC in VSX (Variable Star Index) on the basis of their MISC classification in the ASAS Catalogue of Variable Stars (Pojmański 2002). The goal is to better determine their periodicities, and in particular to identify biperiodic and LSP carbon red giants in order to improve the accuracy of their VSX citations.

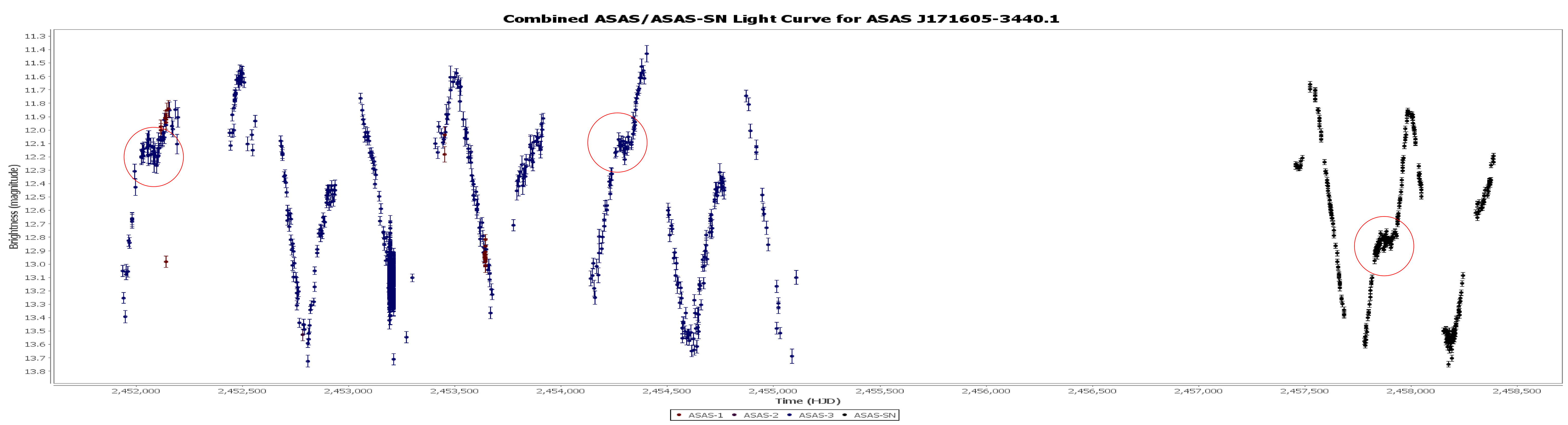
The process mirrors that of a survey of 173 MISC stars in VSX (selected by their listed periods of 1000-2500 d), explained in detail in Larsen (2020). Initial candidates were selected using a sorted search in VSX for stars with listed spectral classes of C, C: and C?. The ASAS data for each star was initially analyzed using VStar to determine potential periods. LSP and bimodal pulsation candidates (along with selected other interesting examples) were further investigated by analyzing their ASAS-SN data in VStar. Preliminary results for selected stars is reported here. As V-band amplitudes for carbon stars are generally less than their oxygen-rich counterparts, the SR/M distinction is not obvious in this data (where the largest amplitude is 2.17). The more generic term long-period variable (LPV) will therefore be used here to cover semiregular (SR) and Mira-type stars (Evans 2010).

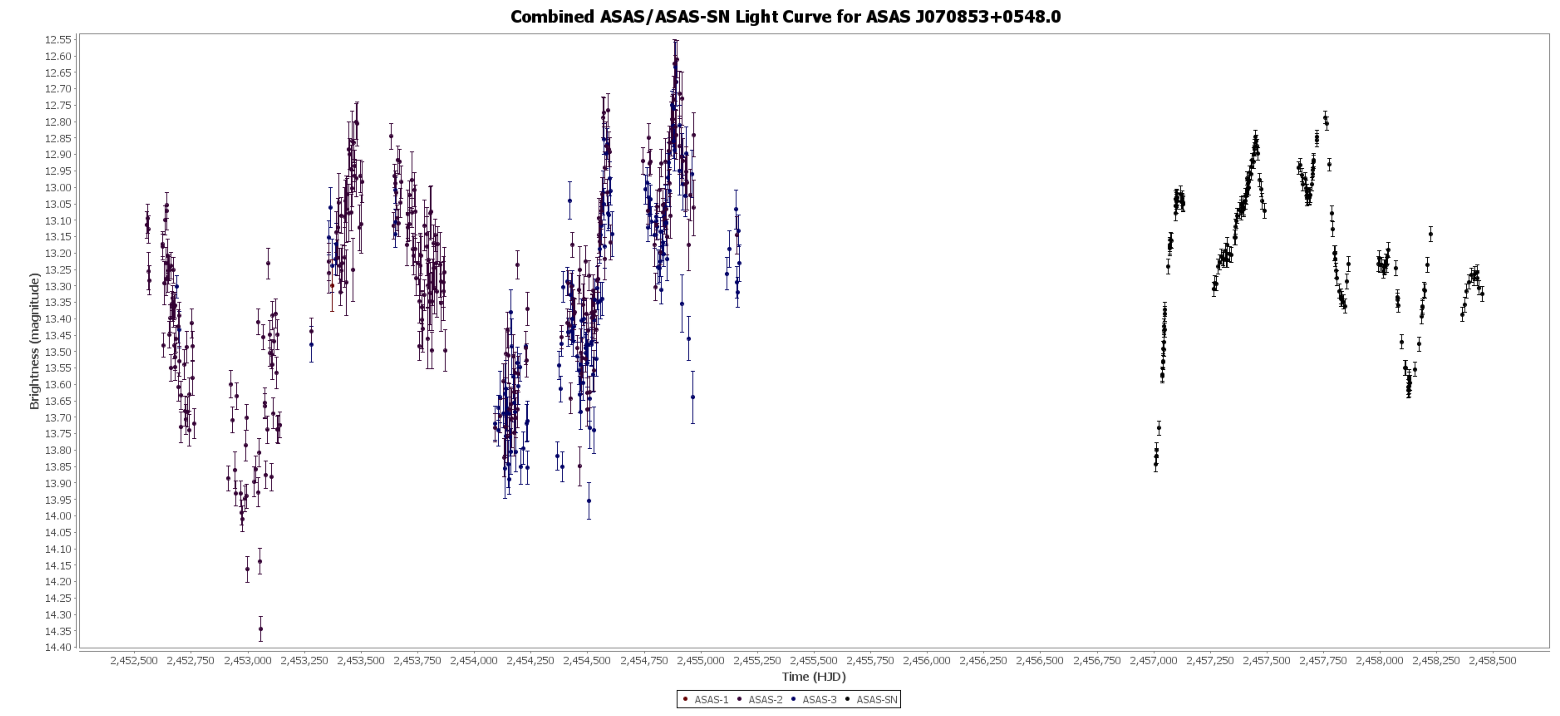
The preliminary classification of the 250 stars is shown in the table below:

Preliminary Classification (Based on ASAS data)	Number (out of 250)
LPV: Confirmed/Refined VSX Period (+/- 10% of VSX value)	46
LPV: New Period determined	59
Long Secondary Period Candidates	19
Bimodal Pulsation Candidates	53
Not Periodic	2
Inconclusive	71

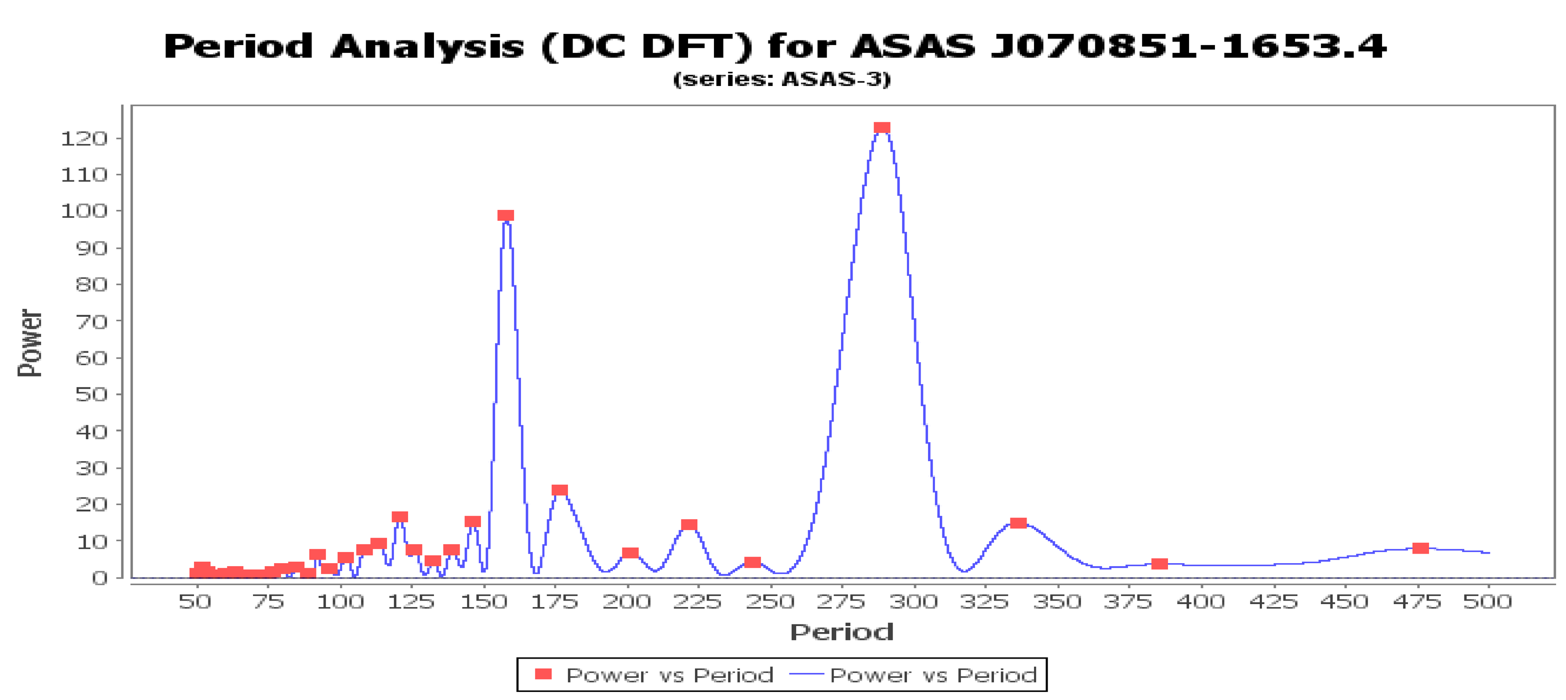
"Shoulder Pads":

Two carbon stars included in the previous study (Larsen 2020) demonstrated the existence of "shoulders pads" on their light curves, intermittent ascending branch "humps" (Marsakova & Andronov 2007). Seven stars in the current study showed evidence of this behavior. A representative light curve (combined ASAS/ASAS-SN data) is shown below.





ASAS #	ASAS period	MACC class & period	ASAS-SN Class & period	VStar/ASAS Period [P0/P1]	VStar/ASAS-SN Period [P0/P1]
J065948-1445.8	408 d	SR; 427.46 d	SR; 410.32 d	196.98 d; 432.75 d [2.20]	187.42 d; 429.75 d [2.29]
J070851-1653.4	322 d	SR; 287.46 d	SR; 277.37 d	157.83 d; 288.67 d (see plot below) [1.83]	156.35 d; 283.6 d
J102506-6656.5	577 d	Mira; 308.99 d	SR; 280.06 d	169.37 d; 310.09 d [1.83]	165.82 d; 292.49 d
J113535-5626.6	656 d	SR; 246.99 d	SR; 108.07 d	123.69 d; 140.24/148.36 d; 244.59 d [1.70 or 1.98]	106.47 d; 140.84 d; 251.01 d [1.78 or 2.36]
J075212-4403.0	272 d	SR; 260.09 d	L; -	145.16 d; 261.76 d [1.80]	139 d; 235 d [1.69]
J075533-1914.8	121.1 d	SR; 926.40 d	SR; 253.33 d	241.22 d; 462.87 d [1.92]	250.1; 443.9 d [1.77]
J094624-5658.1	217 d	LSP; 422.69 d	L; -	196.3 d; 418.72 d [2.13]	198.79; 406.41 d [2.04]



Long Secondary Periods:

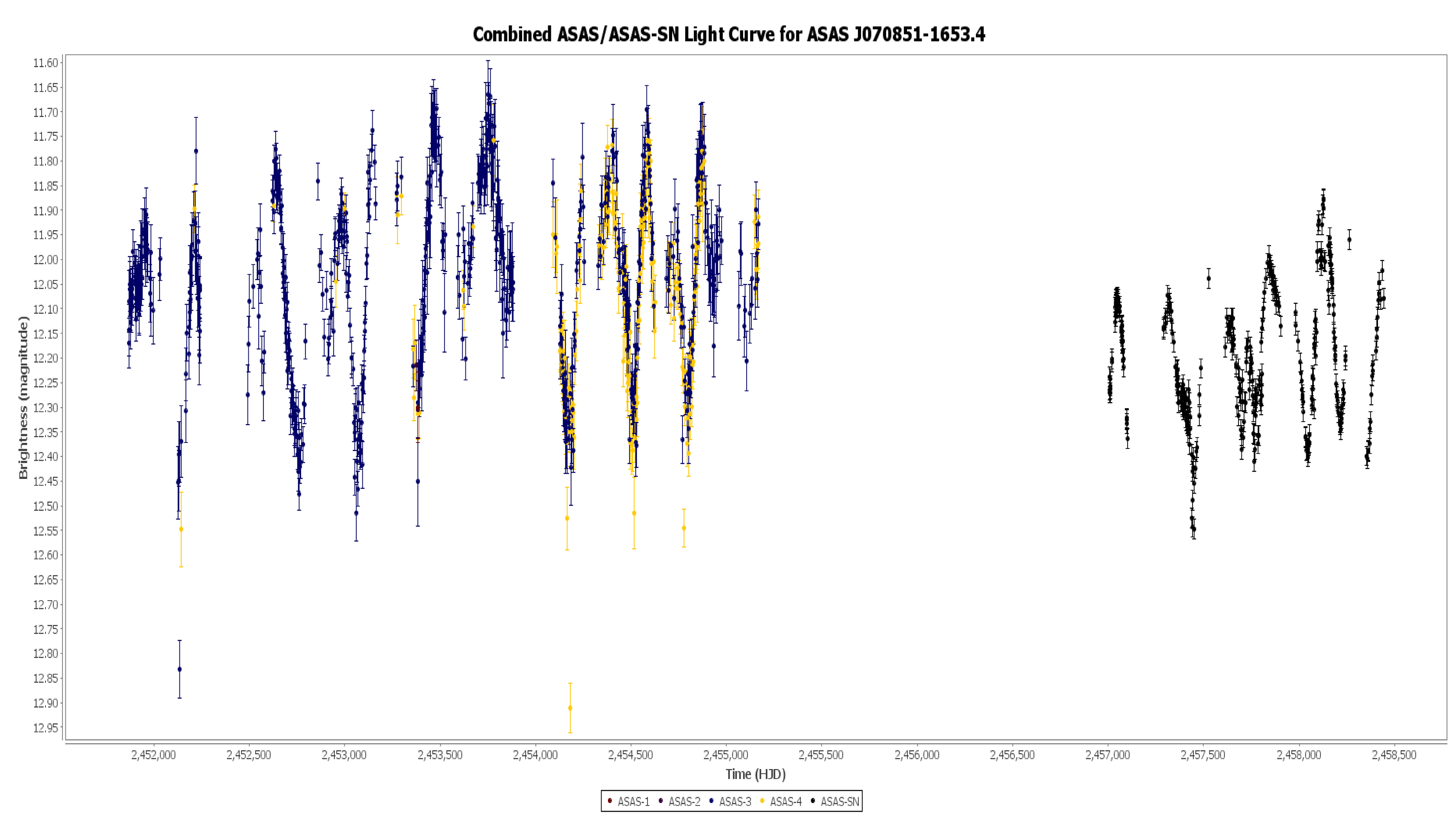
While 19 of the 250 stars demonstrated preliminary evidence of large amplitude LSP behavior in the preliminary analysis of the ASAS data, only two of these demonstrated clear, consistent LSP behavior when ASAS-SN data was also taken into account. The ASAS data for these stars was sometimes sparse or did not cover a sufficiently long time period to clearly demonstrate this behavior. One of these two solid examples is shown to the left.

The Machine-learned ASAS Classification Catalog (MACC) algorithm was able to identify the LSP of these two stars, but misidentified the longer of two periods in a bimodal star as an LSP of only 422 days. MACC also identified an LSP in a fourth preliminary candidate LSP star, but of a period that did not agree with suggested LSP candidate periods found by VStar in either the ASAS or ASAS-SN data. This star was deemed inconclusive.

Bimodal Pulsators:

Of the 53 bimodal pulsation candidates, only seven were deemed convincing examples when considering both the ASAS and ASAS-SN data sets. Note that the best-fit periods do not exactly agree between the two data sets; this is due to the well-known drift in the periods of pulsating red giants from one cycle to the next. This drift can be random, periodic, or directional (increasing or decreasing over long time scales). In addition, carbon stars can also undergo dimming events and other changes in amplitude, further complicating an analysis of their periodicity (Templeton et al. 2014). It is therefore not unexpected that pulsating carbon stars can confuse automated period-seeking algorithms, especially when there are multiple periods. For example, VStar DC DFT analysis of J113535-5626.6's ASAS data produced a close pair of peaks ~ 144 d, as well as peaks at 123.69 d and 244.59 d. VStar WWZ analysis suggested a sudden period shift from ~144 to 123 days over the data run; ASAS-SN data showed a shortest period of 106.47 d.

Bergeat et al. (2002) noted that for their dozen best-documented bimodal carbon stars the ratio of the pulsation periods P_0/P_1 was 2.24 +/- 0.7 (1.54-2.94). Percy & Huang (2015) found an average of 1.996 for the five bimodal carbon giants in their survey. The values found here range from 1.69 -2.29, with most of them closer to Percy & Huang's value than Bergeat et al.'s .



References:

Bergeat, J. et al. (2002) "The pulsation modes and masses of carbon-rich long period variables." A&A 390: 987-99.
Evans, T.L. (2010) "Carbon Stars." JAA 31: 177-211.
Larsen, K. (2020) "Identification and Analysis of Pulsating Red Giants Misclassified by ASAS and ASAS-SN." SAS-AAVSO 2020 Conference Proceedings, 193-8.
Marsakova, V.I. & I.L. Andronov (2007) "Variability of Long-Period Pulsating Stars. III." Astrophysics 50(1): 76-82.
Percy, J.R. & D.J. Huang (2015) "Pulsation Properties of Carbon and Oxygen Red Giants." JAAVSO 43: 118-24.
Pojmański, , G. (2020) "The All-Sky Automated Survey, Catalog of Variable Stars. I. 0h – 6 h Quarter of the Southern Hemisphere." Acta. Astr. 52: 397-427.
Templeton, M.R. et al. (2014) "CT Lacertae: Another Long-period Carbon Star with Long-Timescale Variations?" JAAVSO 42: 260-5.