The Reclassification of NSV 1586 from a Suspected Cepheid Star to a UG Class System

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Received November 21, 2019; revised April 20, 2020; accepted April 21, 2020

Abstract On 2018 August 9, a contribution to the VSNET mailing list suggested that due to certain photometric attributes, NSV 1586 could possibly belong to the Dwarf Nova (DN) class. Hence, the initial classification of this star as a Cepheid variable star was put into question. This prompted the authors to investigate NSV 1586 in detail. The data obtained through our campaign suggest that the original classification of NSV 1586 as a Cepheid star is inconsistent with our findings. We determined the nature of NSV 1586 as a UG-type DN that exhibits peculiar photometric features in its light curve to possibly pertain to the UGZ/IW sub-type variable star classification. However, standstills that are indicative of this class remained undetected. The amplitude of this star was found to be of 2.9 magnitudes in the V-band, with a primary cycle period of 13.9 days. We found the color index during its cyclic permutations can range from an apparent CI of 0.5 to 1.0, corresponding to a temperature change of around 1300 K. Further research is suggested to determine the nature of this star.

1. Introduction

The star NSV 1586 was discovered as a variable star on photographic plates by C. Hoffmeister and its variable nature was announced in volume 289 of *Astronomische Nachrichten* (Hoffmeister 1966). NSV 1586 was initially designated as SON 8560 and was listed as a short-period variable, possibly belonging to the δ Cepheid class with a magnitude range of 15.5 to 16.5. No reference period was then quoted for this star. SON 8560 was included in the *New Catalogue of Suspected Variable Stars* (Kukarkin *et al.* 1982) and was designated as NSV 1586.

On 2018 August 9, a contribution by Taichi Kato to VSNET mailing list (2018) stated that data downloaded from the ASAS-SN Survey indicate that NSV 1586 could possibly be a Dwarf Nova (DN), as the star's color index is compliant with this class of objects and no definite period could be determined. Hence, the classification of this star as a Cepheid variable star was put into question.

This prompted the authors to investigate NSV 1586 in detail. An observational campaign was initiated by the authors through the observatories mentioned in Table 1. The data obtained through our campaign suggest that the original classification of NSV 1586 as a Cepheid star is also inconsistent with our findings. We determined the nature of NSV 1586 as a UG-type DN that exhibits peculiar photometric features in its light curve to possibly pertain to the UGZ/IW sub-type variable star classification. However, standstills that are indicative of this class remained undetected.

NSV 1586 is also designated as UCAC4 690-030039 and has been listed in a number of catalogues under other

Table 1. Equipment and observatories details.

Observatory	*Location*	*Observer*	*Telescope*	*Filter*	*CCD Sensor*	*Field-of-View (arcmin)*	*Binning (arcsec/pixel)*	*Pixel Scale*
Antares	Fgura, Malta	W. Grech	0.279-m SCT	C	SBIG STL-11000/ KAI-11000M	45.9 × 30.6	2 × 2	1.37
Flarestar	San Gwann, Malta	S. M. Brincat	0.254-m SCT	C	Moravian G2-1600/ KAF 1603ME	25.5 × 17.0	1 × 1	0.99
Tacande	La Palma, Spain	K. Hills	0.500-m Optimised Dall Kirkham	V	FLI ML3200/ KAF3200ME	35.7 × 24.1	1 × 1	0.98
Znith	Naxxar, Malta	C. Galdies	0.203-m SCT	C	Moravian G2-1600/ KAF 1603ME	30.0 × 20.0	1 × 1	1.17

Note: CCD cameras were operated at sensor temperature ranging from –20° to –15° C. All images were calibrated through dark frame and flat field subtraction.

designations. The GAIA DR2 catalogue (Gaia Collaboration *et al.* 2018) designated the star's unique source identifier as "258046621605141888." The GAIA DR2 catalogue has listed this star at the following coordinates (2000.0): R.A. $04^h\ 24^m\ 17.9677655784^s$, Dec. +47° 52' 12.620239643" with a stellar effective temperature of 5628.54 K. The GAIA DR-2 lists the distance of this star as 573.564 pc with a higher and lower bound of confidence interval of 595.069 and 553.534 pc, respectively.

2. Observations

2.1. Multiband photometric data

Most of the photometric data during our campaign were acquired from the observatories listed in Table 1. Our dataset was supplemented by archival photometry gathered by the "All-Sky Automated Survey for Supernovae" (ASAS-SN; Kochanek *et al.* 2017) spanning the duration of our observations campaign. The ASAS-SN images utilized by this research were those taken through V and g-bands. An offset for g-band photometry was applied.

All photometric magnitudes were obtained through differential aperture photometry with zero-points calibrated to the APASS Catalog (Henden *et al.* 2016). Observations by ASASS-SN were usually taken in batches of two or three images in one night and they were repeated with intervals ranging from 1 to 5 days. There have been occasions where the interval period was longer due to unfavorable weather conditions.

In order to minimize scatter in our light curve, all of our images had a minimum exposure of 5 minutes to enable a good signal-to-noise ratio. In some cases when the star was observed to be at minimum, 10-minute exposures were utilized by Flarestar, Znith, and Antares Observatories. Tacande Observatory employed 5-minute exposures throughout our campaign and all of our observations were predominantly carried out under an airmass of less than two atmospheres. We utilized differential aperture photometry for all image analysis. The source of comparison stars (i.e. 000-BMT-664, 000-BMT-665, 000-BMT-666 extracted from AAVSO chart X23245AX) used were those supplied by the AAVSO Sequence Team. These comparison stars were used by all observatories involved except for the ASAS-SN data that may have made use of the same APASS source but possibly utilizing different comparison stars. Our monitoring campaign commenced on 2018 August 8 and was concluded on 2019 April 11, spanning a 246-day monitoring period as acquired from the observatories listed in Table 1.

2.2. Results

In order to investigate the behavior of NSV 1586, we commenced our research through the acquisition of the data from the ASAS-SN survey (Kochanek *et al.* 2017) that was taken prior to our campaign. Using PERANSO (v2.60) (Paunzen and Vanmunster 2016), we performed a period search on this data ranging from 2014 December 16 up to 2018 October 10. A total of 425 V-band observations derived from the ASASS-SN Survey were analyzed for any periodicity; however, no clear periodicity was obtained from this dataset using Lomb-Scargle, Fourier Analysis of light curves (FALC), Phase Dispersion Minimization (PDM), and Phase-binned Analysis of Variance algorithms. The light curve based on the ASAS-SN survey data is shown in Figure 1.

A total of 411 observations were acquired in the V-band from Tacande Observatory in addition to a small number of B-filtered observations in the Johnson system to obtain color photometry. A total of 101 V-band and 606 CV-band observations were gathered from Flarestar Observatory. Znith and Antares Observatories contributed 94 and 76 observations respectively through a C-filter reduced to a V standard. Heliocentric JD corrections have been applied to all observations. This observational campaign yielded a total of 1432 observations.

Observations acquired during our observation window (HJD 2458338 to 2458585) revealed that the star underwent several cycles during which the brightness varied from magnitude ~15.2 to ~18.1 mv. The light curve shown in Figure 2 illustrates our contributions along those gathered from the ASASSN survey to monitor the photometric activity of NSV 1586. During the initial period (i.e. HJD 2458338 to 2458385.4), we observed three cycles each with a period of 12.55 d, 13.8 d, and 11.0 d, and with a mean cycle of 12.45 d. Despite our expecting the next cycle to complete by reaching the minimum, the cycle did not materialize and the star remained brighter than 16.2 mv. The next "unsubdued" minimum occurred on HJD 2458461.41 at magnitude 17.67 mv, 30.12 d later. The next deep minimum was recorded on HJD 245488.44 at ~18.0 mv, 27.03 d after the previously-mentioned minimum. A short cycle of 10.80 d was then recorded after this minimum when the star declined in brightness down to magnitude 17.03 mv on HJD 2458499.24. Due to weather constraints, we could not maintain our previous coverage density. Notwithstanding this, we managed to record two additional short cycles that started on HJD 2458530.27 and HJD 2458543.28, with a quasi-periodic duration of 13.01 d and 12.97 d, respectively.

The light curve morphology of V513 Cassiopeiae (Figure 3) produced by Stubbings and Simonsen (2016) shows similarities to those observed following our observational campaign. Hence, it seems plausible that NSV 1586 belongs to the UGZ/IW class. However, the peaks of super outbursts are not readily apparent in our light curve and therefore we could not be certain that this star belongs to the UGZ/IW class.

A period analysis using the ANOVA, Lomb-Scargle (Lomb 1976; Scargle 1982), and PDM methods (PERANSO) of the lightcurve in Figure 2 yielded two combined cycle periods; PI of 13.94 ± 0.19 d and PII of 11.50 ± 0.15 d. The resultant Lomb-Scargle period spectrum (periodogram) is shown in Figure 4. The main cycle period identified for NSV 1586 is 13.9 d (± 0.2) with a secondary period of 11.5 d (± 0.2).

In order to evaluate the nature of NSV 1586, histogram analysis based on 1-day binned data was carried out and showed a distribution of the magnitude regime consistent with the UGZ/IW class.

An investigation for the presence of periodic humps was also carried-out over four nights through high cadence data (5 or 6 minutes) when the star was near maximum light. Using PERANSO software, a search was made from 0.1 to 25 cycles per day during which no significant peak was detected when using the Lomb-Scargle algorithm. The Phase Dispersion

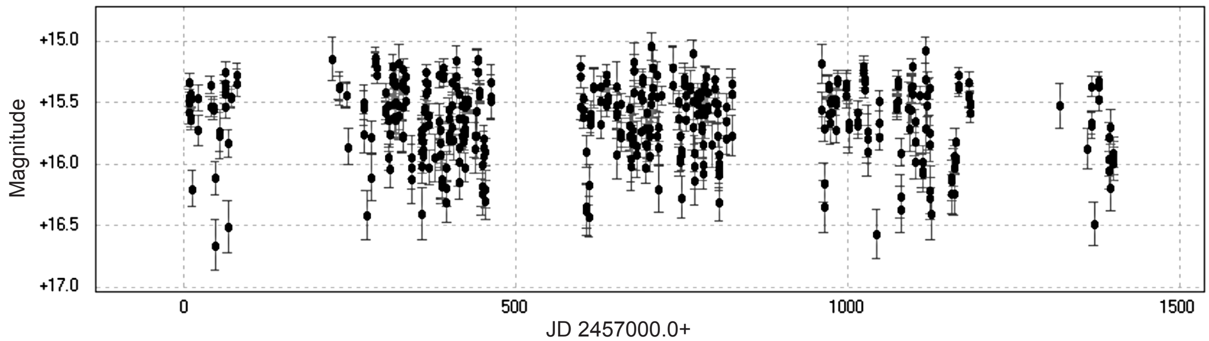

Figure 1. V-band data derived from the ASAS-SN Survey for the period 2014 December 16 to 2018 October 14.

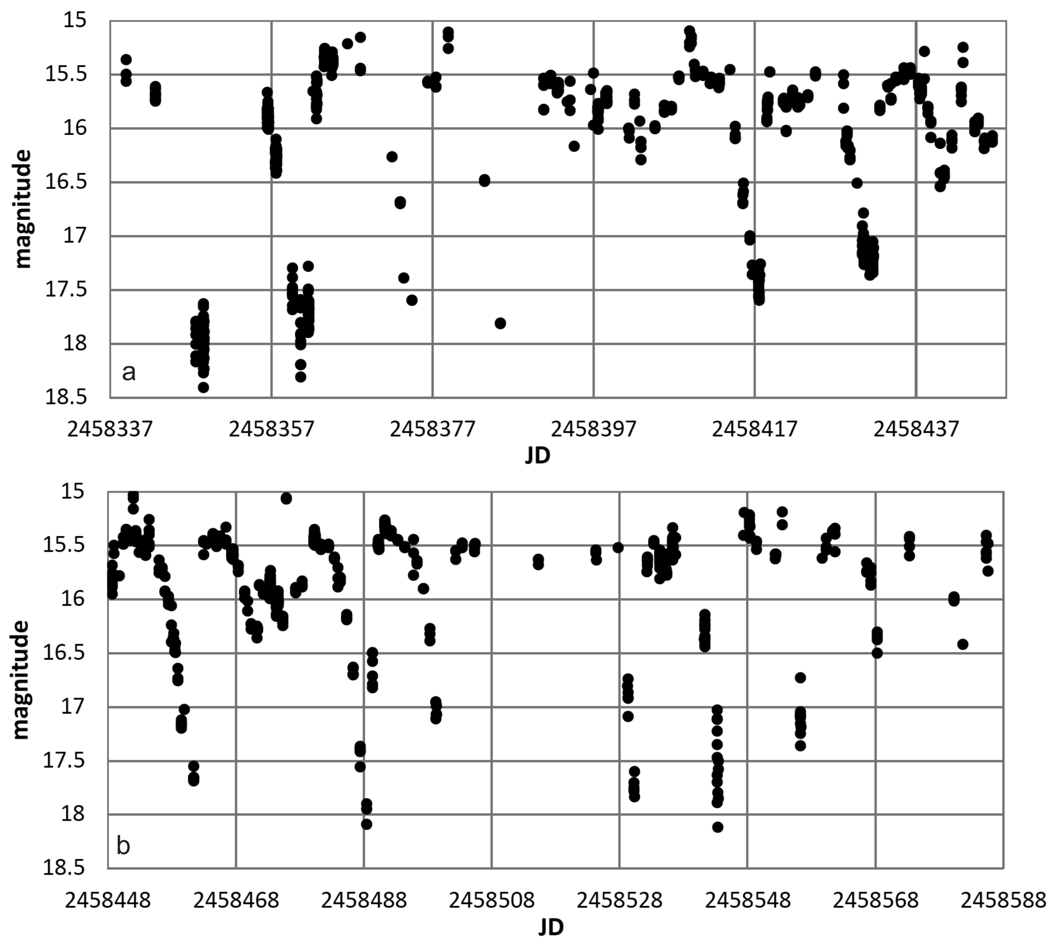

Figure 2. NSV 1586 light curve in two panels showing the light changes in V-band during the observational campaign ranging from HJD 2458338 to HJD 2458585, spanning a period of 247 days.

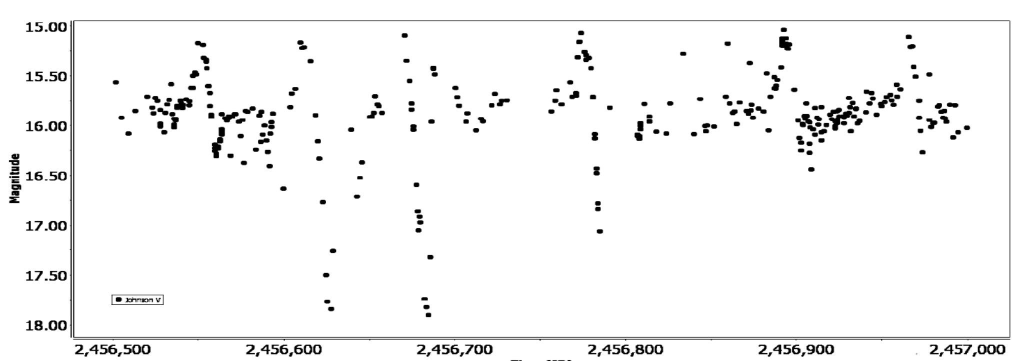

Figure 3. The AAVSO light curve of V513 Cas spanning from JD 2456500–2457000 (July 2013–December 2014) (from Stubbings and Simonsen (2016)).

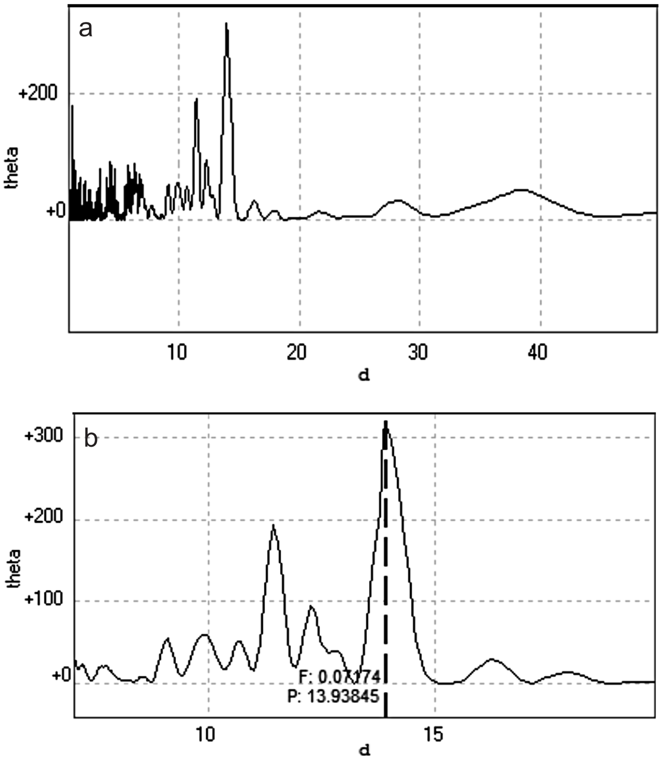

Figure 4. Lomb-Scargle periodogram of NSV 1586 showing the primary cycle of 13.94 d and a secondary cycle of 141.46 d. Figure (a) shows the periodogram ranging from 0 to 50 days. Figure (b) shows a zoomed part of Figure (a) centered on the primary cycle (F = cycles/day, 0.07).

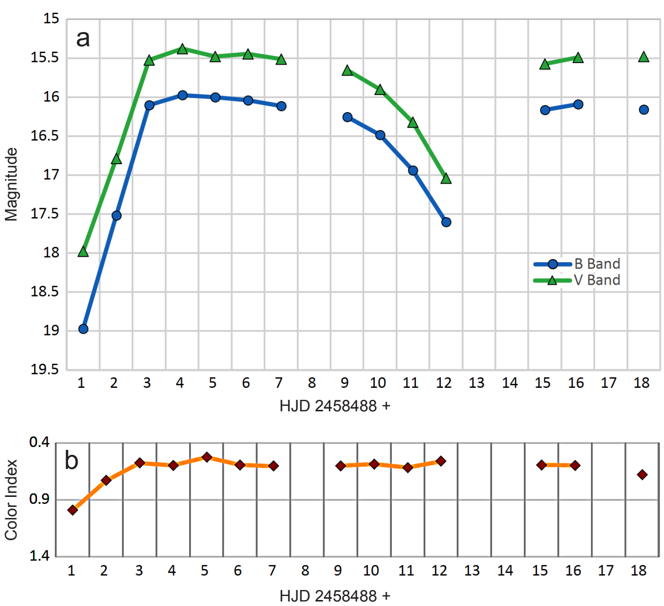

Figure 5. B, V light curves (a) and color evolutions (b). Blue (circles) and green (triangles) symbols represent B and V, respectively. Red (diamonds) symbols represent the color index B–V.

Minimization (PDM) and ANOVA algorithms yielded identical results.

An additional verification analysis was carried out during February and March 2020, to ascertain any stochastic behavior during different phases of NSV 1586 (N = 403). However, orbital brightness variations remained undetected. Instead stochastic brightness variations (flickering) were noted that are characteristic of many cataclysmic variable stars (Bruch 2000). These variations were observed down to a cadence of 90 seconds with amplitudes ranging from 0.02 to 0.2 magnitude. Results acquired through the 0.5-m telescope at La Palma from Tacande Observatory during quiescence showed stochastic variations up to 0.7 magnitude.

2.3. Color photometry

During the period from 2019 January 4 to January 23, we have obtained color photometry from Tacande Observatory (Table 1). This period coincided with an interval when NSV 1586 was at quiescence and rose to maximum light. We have obtained photometric measurements through B and V bands. In most cases, we acquired multiple readings per night that were averaged to improve precision and reduce any scatter in our data.

Figure 5a–b shows the light curve of a cycle from minimum light that started from HJD 2458488.442 (at magnitudes 18.96 and 17.97 for B and V bands, respectively) to maximum light that occurred on HJD 2458491.391 at B magnitude 15.97 and V magnitude 15.38.

Our Color Index (CI) results obtained through B–V bands indicate that at quiescence the light from the star system emits most of its light with an apparent CI of 1.0. Four days after an outburst was recorded, the CI decreased to 0.5 d, suggesting an increase in temperature. From the 9th day post-quiescence, the star started to decline in brightness but despite this, CI readings showed that the system's B–V radiative output remained somewhat constant. It is important to note that these CI readings did not include compensation for galactic dust extinction as we have observed some inconsistences with estimates of dust concentrations in this region.

Using the methods applied by Flower (1996) and Torres (2010), we obtained an observed CI temperature difference between the quiescent and outburst phases of 4867 K and 6182 K, respectively. Hence, our observations suggest a temperature change of the combined light output by the system of around 1300 K.

Upon examination of the morphology of our light curve, we deduce that NSV 1586 exhibits a puzzling light curve and it is difficult to classify the variable with any degree of certainty. From the evidence gathered above, we believe that the star belongs to the UG type of cataclysmic variables. Although we observed similarities to the UGZ/IW systems, further observations are needed to determine its sub-class, especially in the light that no clear standstill periods have been found throughout the period of this study including the period monitored by the ASSAS-SN survey, where observations go back to 2014 December 16 (HJD 2457007).

The absence of brighter and longer superoutbursts indicates that this is not an SU UMa type star. The damping oscillations observed at maximum light are possibly similar to those observed by Kato (2018) for other CV systems that may be due to giant flares occurring near the secondary star surface. However, in this case, more data are needed to confirm such hypothesis. The dampening phenomenon has further complicated matters as any "intrinsic" signal by this system may have been hidden by such oscillations.

In consideration of the above, it is suggested that more research is needed to unravel this intriguing star. Further spectroscopic analysis may reveal the underlying mechanisms that drive the photometric variation exhibited by NSV 1586.

3. Conclusions

We report that the original classification of NSV 1586 in the General Catalogue of Variable Stars (GCVS; Kukarkin *et al.* 1982) is inconsistent with our findings and suggest that this star is likely to be a UG class system. Over the course of its observational campaign, NSV 1586 did not yield any photometric behavior that is consistent with the former classification. The amplitude of this star was found to be of 2.9 magnitudes in the V-band, with a primary cycle period of 13.9 days and a secondary period of 11.5 d. We found that the color index during its cyclic permutations can range from an apparent CI of 0.5 to 1.0, corresponding to a temperature change of around 1300 K. No orbital variations were detected by this study. Further research is suggested, including spectroscopic analysis.

4. Acknowledgements

We acknowledge with special thanks the guidance provided by Sebastián Otero of the AAVSO in the analysis of our data and for providing a way forward in the publication of this manuscript. We are also grateful to Paul Layland for helping us in this analysis.

This research has made use of the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund and NSF AST-1412587.

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