Recent Multispectral Observations of Nova V1280 Sco

Abstract

Classical nova V1280 Sco (Nova Scorpii 2007, Number 1) appeared in February 2007. Between 2007 and 2011 there were numerous multiband optical and spectrographic observations. V1280 Sco reached visual magnitude of approximately 3.8, then faded to about 13.2, brightened to about 12.7, and underwent a dust dip in 2007 to less than 15.6V. It recovered to about 10.3 a year later and has remained around that magnitude until mid-2017. These observations have indicated that V1280 Sco is an extremely slowly evolving nova in the historical record. In early 2018, the AAVSO issued an alert notice (AAVSO Alert Notice 634) for continuing filtered observations, preferably in V and/or B band with ideally a nightly cadence. Additionally, it was suspected that there might be periodicity that should be investigated. This paper will present the results of U, B, V, R, I, and visual observations since the alert notice was issued. Data has been obtained by both AAVSO observers and ASAS-SN automated assets.

1. Introduction

Classical novae result from thermonuclear runaway in a close binary system containing a white dwarf (WD) and a normal star when material accreted onto the white dwarf explodes as it reaches its critical limit. Novae are categorized by their rate of decline as well as their spectroscopic parameters. In particular, the rate of decline is the time it takes to decrease three orders of magnitude from maximum brightness. When nova brightness declines by three orders of magnitude in less than approximately 100 days, it is classified as a fast nova whereas if the decline is greater than about 150 days it is classified as a slow nova.

Spectral characterizations of novae are Fe II with slow spectral evolution, and He/N types showing very rapid spectral evolution. Slow novae tend to be the Fe II type whereas He/N novae are found only among the fast class. It is generally accepted that the nova speed class is mainly determined by the mass of the white dwarf component of the binary system. To understand the entire physical process involved in a nova explosion, it is critical to observe over its entire evolutionary life cycle from the very early phase including the pre-maximum to the late decline phase over a long period of time. In this respect, slow novae provide an opportunity to follow the entire evolution very closely. V1280 Sco is a classical nova that is extremely slowly evolving, thereby making it an excellent candidate for long-term observations. The AAVSO Alert Notice 634 requests these observations in V-band, B-band, and visual. The author made observations in U, B, V, R, and I optical bands over two observing seasons i.e., 2018 and 2019.

2. Methods

2.1 Analysis Method

In response to the alert notice, multiple CCD observations were made by the author in V, B, U, R, and I bands. Other AAVSO observers took V and B images to contribute to the total light curve. All observations contributed by the author were made using the iTelescope system; in particular T17 and T30 at the Sidings Spring Observatory (SSO). These systems were selected since they have the complete UBVRI filter arrangement. Exposure time was typically 60 seconds in all bands. For both telescopes, an ensemble of comparison stars was used so that differential magnitudes of the object relative to comparison stars could be obtained using aperture photometry with the AAVSO VPhot software package. CCD observations were undertaken throughout two observing seasons for V1280 Sco from May 12, 2018 to October 9, 2018 and from January 23, 2109 through October 12, 2019.

Additionally, observations from ASAS-SN were incorporated. ASAS-SN data included ASAS-SN V data from March 3, 2016 through September 23, 2018 (HJD 2457456.83901-HJD 2458385.49876) and ASAS-SN g data from February 25, 2018 through June 11, 2019 (HJD 2458174.88916-HJD 2458645.82444). All analyses were performed using the AAVSO VStar visualization and analysis tool. The ASAS-SN observations were converted by VStar into Johnson V and Sloan g data which made this information compatible with the AAVSO data.

2.2 Analysis Results

The composite light curve, containing all of the observations from February 7, 2007 through October 12, 2019 is shown in Figure 1. This is the composite light curve for the entire observational data set, including visual, Johnson V-band, B-band, U-band, Cousins I-band, Cousins R-band, and ASAS-SN V and g bands (converted to Johnson V and Sloan g).

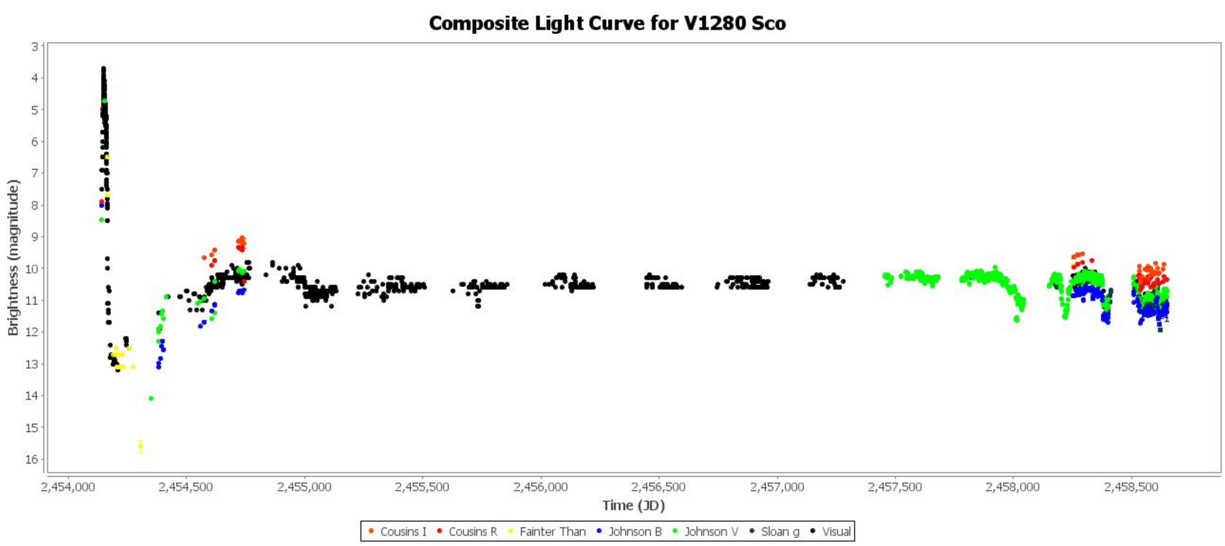

Figure 1: Composite Light Curve for V1280 Sco

Figure 2 shows the observations, in the same bands as above, from March 9, 2016 through the end of the observing season in 2019, obtained by all observers responding to the AAVSO Alert Notice 634 as well as the ASAS-SN data. The gap between the observation periods is due to V1280 Sco being near or below the horizon from the Siding Springs and ASAS-SN telescopes.

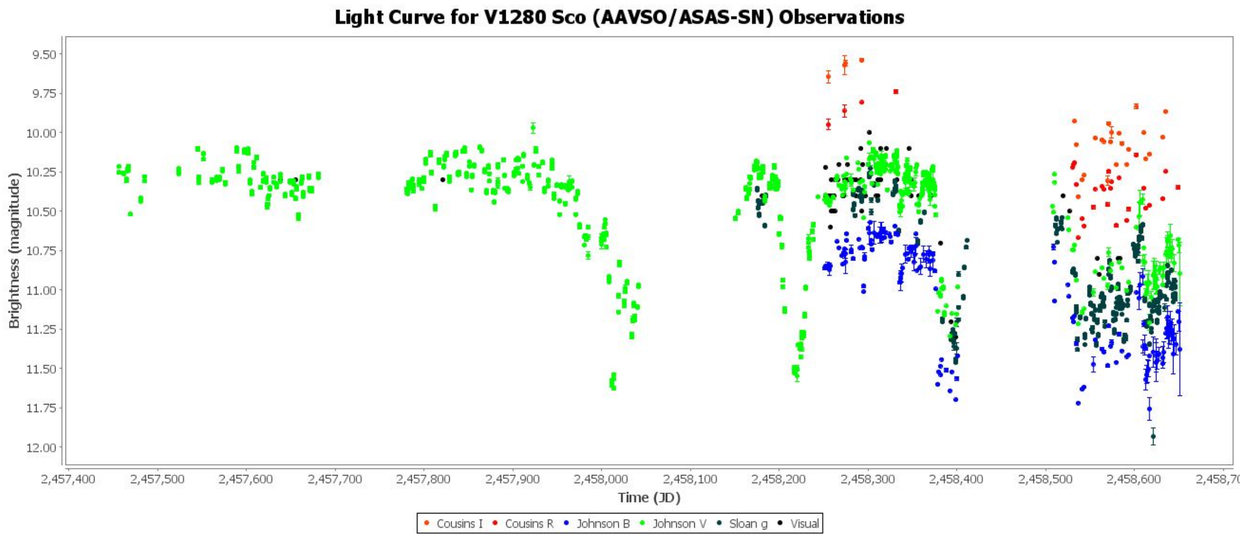

Figure 2: Alert Notice 634 Light Curve for V1280 Sco (all AAVSO and ASAS-SN bands)

Figure 3 shows the AAVSO observations made in U, B, V, R, I and visual bands, while Figure 4 shows the ASAS-SN V and g bands (converted by VStar to Johnson V and Sloan g).

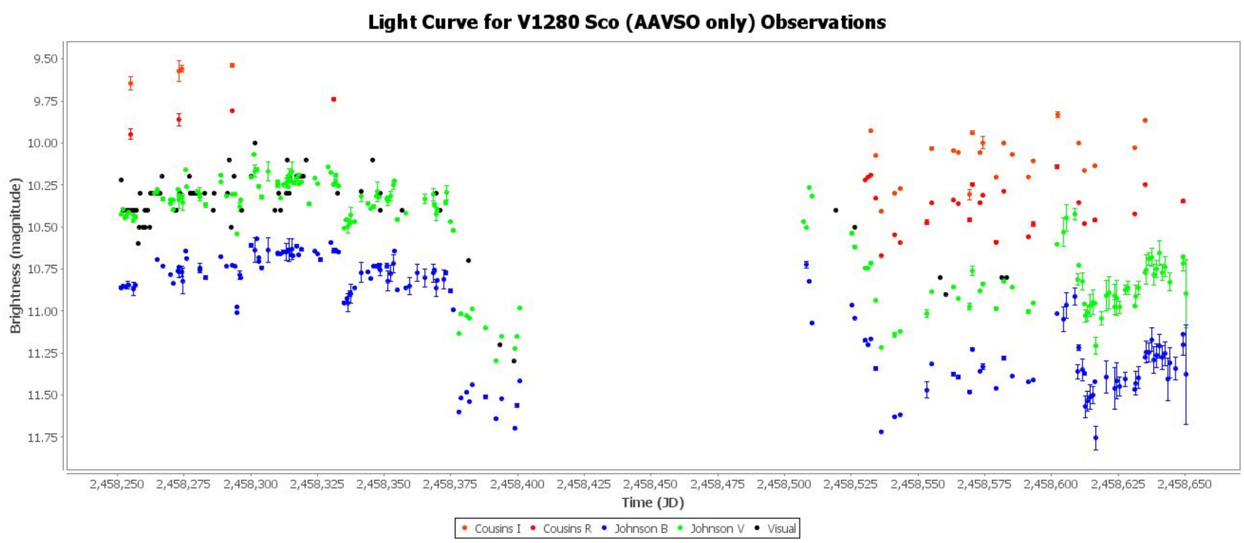

Figure 3: Alert Notice 634 Light Curve for V1280 Sco (all AAVSO bands)

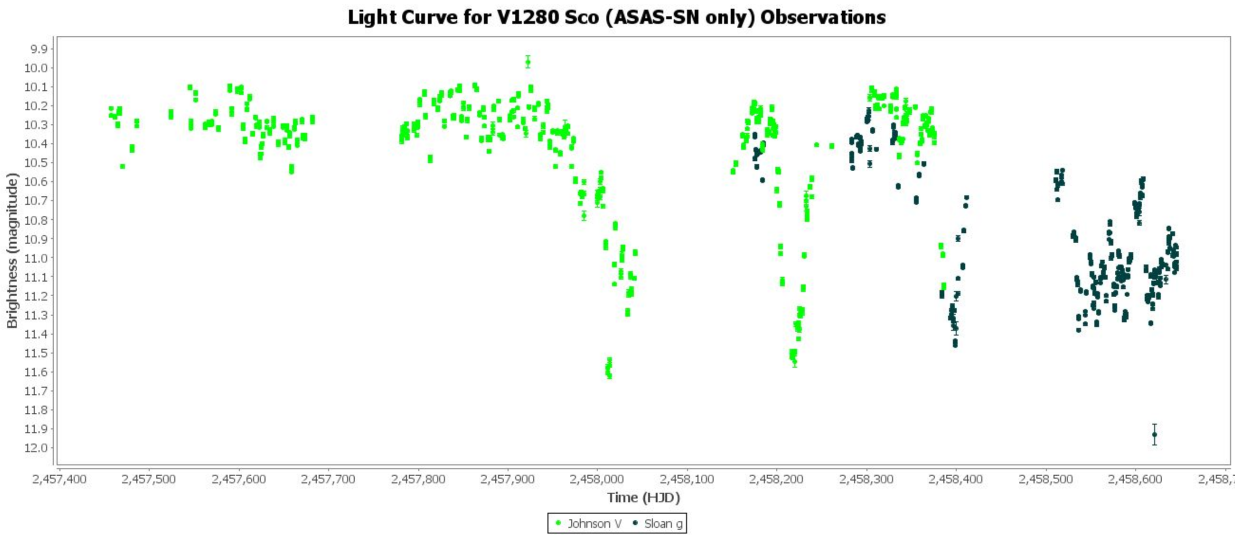

Figure 4: Alert Notice 634 Light Curve for V1280 Sco (ASAS-SN bands)

The alert notice suggested a nightly observance cadence to determine if some underlying periodicity might be occurring. While nightly cadence was not possible due to weather, telescope maintenance, etc. a reasonably close cadence (approximately every 3-4 days) was realized. The periodicity was investigated by looking at AAVSO V, B, and visual bands, as well as ASAS-SN V and g bands. There were not enough observations in U, R and I bands to determine a definitive period. All period analysis was performed by the AAVSO VStar DC DFT algorithm. Figure 5 shows the combined AAVSO/ASAS-SN Johnson V light curve data and Figure 6 shows the DC DFT period analysis for the combined Johnson V observations.

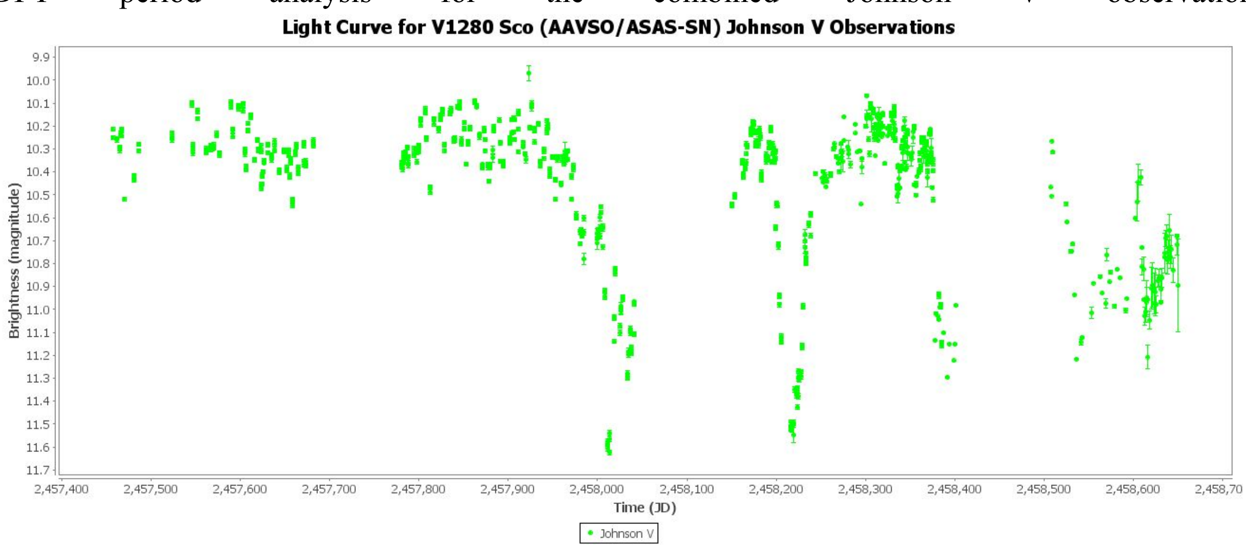

Figure 5: Light Curve for V1280 Sco (AAVSO/ASAS-SN) Johnson V Observations

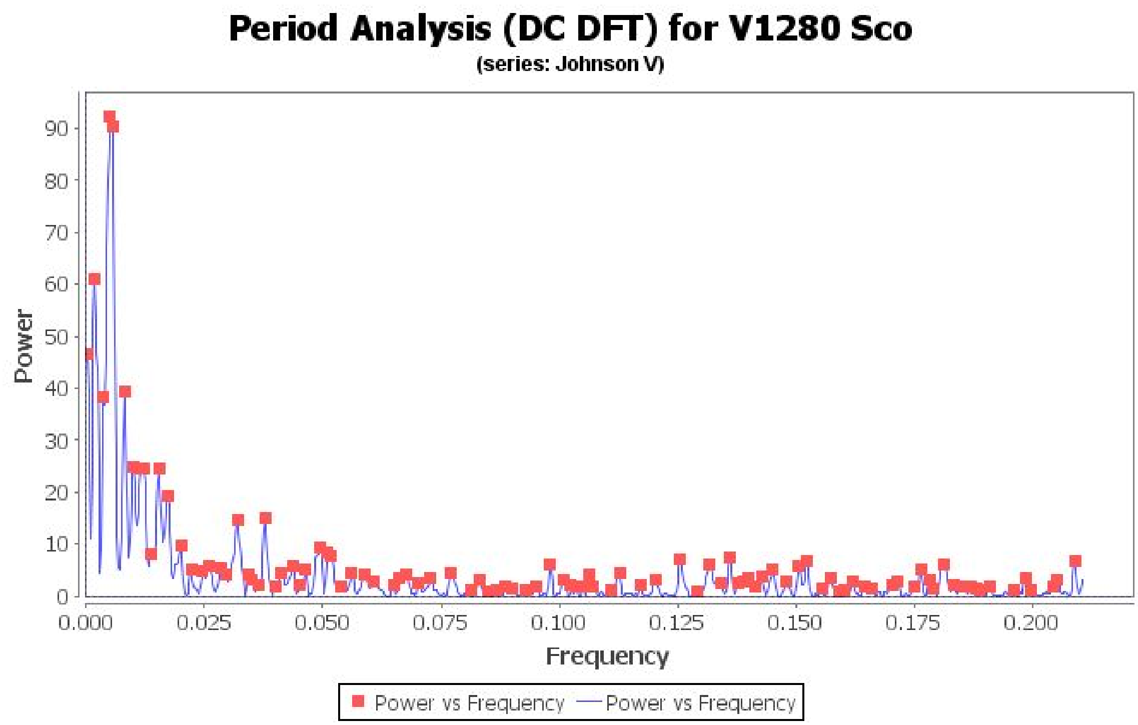

Figure 6: DC DFT Period Analysis for Johnson V Band

A model generated by VStar indicated a "top hit", i.e., maximum spectral power at a frequency as shown in Figure 7.

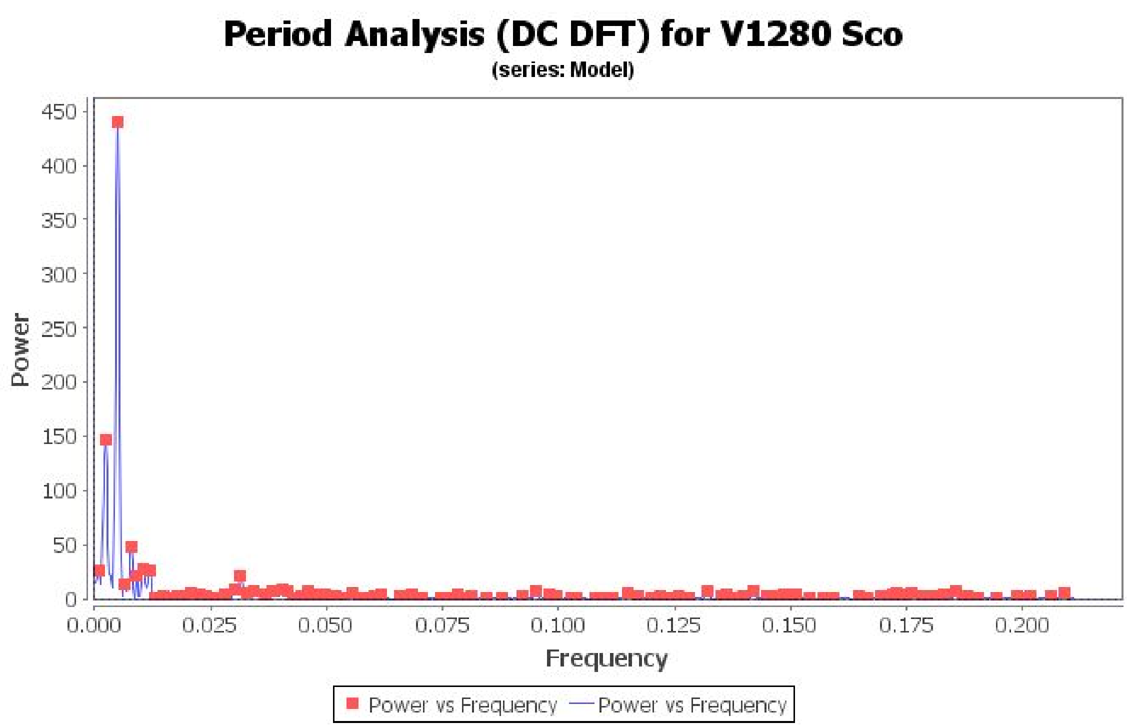

Figure 7: Periodogram of the Top Hit Maximum Spectral Power (V-Band)

Using this maximum spectral power, the Johnson V period determined by this analysis is 199.509661 days as shown in Figure 7. Performing a similar analysis for Johnson B, visual, and Sloan g (from ASAS-SN) observations gives the following period results: Johnson B-193.141621 days; visual-187.327332 days; Sloan g-175.179439 days. Cousins R and I were not used to determine a period since there were not enough observations to make accurate predictions.

3. Discussion

Returning to the light curve from Figure 1 as well as spectroscopic data previously taken, the spectral evolution of V1280 Sco can be analyzed. Generally speaking the spectral evolution can be categorized in five phases: initial rising phase, pre-maximum and maximum phase, dust phase, plateau phase, and nebular phase.

Initial Rising Phase: The initial spectrum was taken on February 5, 2007, one day after discovery. It contained $H\alpha$, $H\beta$, Fe II, Si II, O I, N I, and Na I. This spectroscopic signature indicates the presence of a wind from the photosphere during the earliest phase of evolution.

Pre-Maximum and Maximum Phase: After discovery, the nova gradually increased its brightness to 6.3V then reached maximum brightness of 3.78V on February 16, 2007. The flux in the optical region between February 12 and 18 was mainly contributed by the continuum radiation coming from the photosphere (a period called the fireball phase). Peak fluctuations occurred between February 15 and 18. The photospheric component significantly weakened and the continuum was flat by February 21. This means that the free-free radiation contributed to the continuum flux dominantly as the photosphere shrunk and the region of optically thin gas extended at the same time.

Dust Phase: About two weeks after the maximum, the nova entered a rapid decline phase in V-band until late May 2007. It was concluded that this rapid fading between early March and late May had been triggered by a dust formation in the ejecta as well as by shrinkage of the photosphere.

Plateau Phase: In late May 2007, the first significant re-brightening in V-band occurred. Additionally, there was a second re-brightening phase from August to October 2007. From 2008 to mid-2017, the magnitude in V-band remained virtually unchanged at around 10.5, suggesting that fluxes in the optical band were contributed mainly from photosphere and/or the free-free radiation field. This is an exceptionally long plateau spanning well over 1000 days. It has been generally accepted that the continuous burning of hydrogen was the primary source of energy emitted in the optical continuum, probably because there was a significant amount of hydrogen gas accreted onto the white dwarf to be burned for a long time as suggested for slow novae.

Nebular Phase: V1280 Sco entered the nebular phase between March and April 2011, more than 1500 days after maximum light (February 16, 2007). This means that it took a very long time for the photosphere to shrink and become hotter, thereby emitting enough UV radiation to excite ionized oxygen atoms to a higher energy level. Based upon the extended timeline of its spectral evolution, it was concluded that V1280 Sco is going through the slowest spectral evolution among known classical novae. The mass of the white dwarf in V1280 Sco has been estimated to be at most 0.6 solar masses, consistent with being a very slow nova.

New observations of V1280 Sco triggered by the AAVSO Alert Notice 634 seem to have found the suspected periodicity. The Johnson V-Band analysis indicated a period of 199.5 days, the Johnson B-Band analysis indicated a period of 193 days, the Visual band analysis indicated a period of 187 days, and the ASAS-SN Sloan g data indicated a period of 175 days.

Strope et al. (2010) defines seven classes of light curves among classical novae based upon their shapes: S (smooth), P (plateau), D (dust dips), C (cusps), O (oscillations), F (flat-topped), and J (jitters) classes. V1280 Sco has a combination of P- and D-class features although neither of these characteristics is particularly close as compared to the original classifications.

P light curves have relatively flat intervals superimposed on otherwise smooth declines. The plateaus need not be perfectly flat and generally there is some fading during the plateau. D light curves have the characteristic sudden cutoff, minimum, and recovery in brightness. This seems to account for the observed periodicity after about March 3, 2016 (HJD 2457456.83901). These dips are well known to be caused by the formation of dust particles in the expanding shell when the material reaches such a distance from the nova that the gas cools down to approximately 1400°K and that refractory dust can form. The dust will effectively block out the light from the photosphere interior to it, causing the sudden drop of light. The recovery to the previous decline is caused by the geometric dilution of the dust as the shell expands, allowing the photosphere to be seen again with little extinction.

D-class light curves show deep dips around 100 days after maximum light, whereas V1280 Sco showed this dip 15-20 days after maximum light. P-class light curves have a smooth, gradual decline in its optical light curve, then a long-lasting plateau phase followed by a steep decline to the end of the evolution. None of the other five classifications adequately describes the light curve of V1280 Sco. Therefore, V1280 Sco should be considered to have a very rare, even unique light curve. If true, this could provide important information regarding slow nova parameters such as white dwarf mass, magnetic field strength, composition of the white dwarf envelope, and the accretion rate in the system.

4. **Conclusions**

Observations have revealed that V1280 Sco is an extremely slowly evolving nova in the historical record of all known novae. This is based upon the following evidence:

a. V1280 Sco is declining in brightness gradually at a very slow rate from the discovery in 2007;

b. It has a very long plateau spanning over 2500 days in the light curve;

c. It took a very long time (approximately 50 months after the burst) to enter the nebular phase;

d. The wind is ongoing for at least 1500 days until 2011.

V1280 Sco has spent about three times longer to enter the nebular phase than the previously longest system (V723 Cas) and has exceeded the wind-off time of GQ Mus. It has been suggested that the time scale of nova evolution has a strong correlation with the white dwarf mass, so that the observations of V1280 Sco suggest that it had burst onto a very low mass white dwarf (0.6 solar masses at most). Observations have also indicated the suspected periodicity as mentioned in the AAVSO Alert Notice 634, with a period of between 175 days and 199.5 days, depending on the band analyzed.

It is recommended that further observation be undertaken for at least the next observing season (beginning late January 2020).

3. Acknowledgements

The author would like to thank all of the contributors to the V1280 Sco light curve who responded to the AAVSO Alert Notice 634. Additional thanks goes to the AAVSO for their powerful VStar analysis software and their extensive VSX database.

References

Naito, H.; et al., 2012, Five-Year Optical and Near Infrared Observations of the Extremely Slow Nova V1280 Scorpii (https://www.aanda.org/articles/aa/abs/2012/07/aa18315-11/aa18315-11.html)

Watson, C., Henden, A.A., and Price, C.A. 2014, AAVSO International Variable Star Index VSX (Watson +, 2006-2014; https://www.aavso.org/vsx).

Strope, R.J., Schaefer, B.E., & Henden, A.A., 2010, AJ, 140, 34.

Benn, D. 2012, “Algorithms + Observations = VStar”, JAAVSO, v40, n2, pp. 852-866.

AAVSO Alert Notice 634 (https://www.aavso.org/aavso-alert-notice-634)

AAVSO Alert Notice 346 (https://www.aavso.org/aavso-alert-notice-346)

ASAS-SN Sky Patrol (https://asas-sn.osu.edu/): Shappee et al. (2014) and Kochanek et al. (2017)

iTelescope.net (www.itelescope.net)