

Short Term Photometric Behaviour of RS CVn Binary Sigma Geminorum

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Abstract

This study presents a combined short-term photometric study of the chromospherically active RS Canum Venaticorum (RS CVn) binary Sigma Geminorum. The analysis brings together five years (1st January 2021 to 31st December 2025) of archival observations from the American Association of Variable Star Observers (AAVSO) with a thorough investigation of the PEP and CCD subset. The short baseline includes Photoelectric Photometer (PEP) and Charge-Coupled Device (CCD) measurements in the Johnson B and V filters; the subset also contains B–V measurements and comprises 363 observations. Python-based analysis was used to organize the observations and construct short-term light curves and phase-related representations. The five years of observations display an irregular quasi-periodic variability of the light curves as coupled with the B-V color index. The variations in the color index have a standard deviation of about 0.05 magnitude. The changing morphology of the light curves (as evident from the color index) and the repeated brightening and fading are associated with rotational modulation by evolving starspots on the K1 III primary. The results extend the photometric record of Sigma Geminorum and support its continued use as a laboratory for stellar magnetic activity and starspot evolution.

Keywords: Variable Stars; Sigma Geminorum; Photometric; Photoelectric Photometer (PEP); Charge Coupled Device (CCD).

1. Introduction

Sigma Geminorum (Sigma Gem; HR 2973; HD 62044; HIP 37629; 75 Gem) is a bright, non-eclipsing, single-lined spectroscopic binary. Its optically dominant component is a K1 III giant and the secondary is a faint late-type companion. The orbital period is approximately 19.6 d (Fried et al., 1983) while historical photometry established a photometric period close to 19.423 d.

Photometric observations of variable stars provide an effective means of investigating stellar structure, rotation, evolution, and magnetic activity. Brightness variations may arise from pulsation, eclipses, mass transfer, or rotational modulation associated with starspots (Hall, 1977; Strassmeier & Hall, 1988a) Short-term monitoring is especially valuable because it reveals changes in the amplitude and morphology of light curves and can trace the temporal evolution of active regions and stellar magnetic activity. RS CVn binary stars provide an important tool for such studies because their evolved late-type components are magnetically active and rotate rapidly in close binary systems.

Earlier observations established that Sigma Gem does not preserve a fixed light-curve morphology. (Fried et al., 1983) reported changing light-curve shape and migrating minima, while later long-term photometry identified evolving spot distributions and active longitudes (Cao et al., 2022). Spectroscopic studies have also demonstrated chromospheric activity that changes with rotational phase. Doppler and interferometric imaging subsequently provided clear evidence for complex and evolving surface structure.

The purpose of the present study is twofold: (i) to examine the AAVSO photometric behavior over the span of five years (2021–2025), and (ii) to characterize the PEP and CCD observations, including the B–V colour information. Combining the two approaches provides a more continuous view of recent variability while retaining the longer temporal context.

2. Sigma Geminorum and Previous Studies

2.1 Fundamental Physical Parameters

Physical quantity	Reported Value	Reference
Variable star	Sigma Geminorum (HR 2973, HD 62044, HIP 37629, 75 Gem)	Bopp & Dempsey (1989)
Variable type	RS Canum Venaticorum (RS CVn)	Bopp & Dempsey (1989)
Binary classification	Single-lined spectroscopic binary (SB1)	Zhang & Zhang (1999)
Primary spectral type	K1 III giant	Bopp & Dempsey (1989)
Secondary	Faint late-type dwarf companion	Roettenbacher et al. (2015)
Orbital period	≈ 19.6 d; 19.6027 ± 0.0005 days in the cited orbital solution	Roettenbacher et al. (2015)
Photometric period	19.423 d	Fried et al. (1983); Zhang & Zhang (1999)
Primary mass	$1.28 \pm 0.07 M_{\odot}$	Roettenbacher et al. (2015)
Secondary mass	$0.73 \pm 0.03 M_{\odot}$	Roettenbacher et al. (2015)
Maximum cited V-band amplitude	≈ 0.17 mag	Zhang & Zhang (1999)
Reported spot/activity cycle	≈ 2.7 yr	Strassmeier et al. (1988); Zhang & Zhang (1999)

2.2 Historical photometric and spectroscopic behaviour

Photometric variability in Sigma Gem was first reported by Hall, Henry & Landis (1977). Subsequently established a photometric period of about 19.423 d and demonstrated that the light variations are associated with cool starspots. Short-term observations (Strassmeier & Hall, 1988b) and Oláh et al. (1989)

showed year-to-year changes in spot distribution and evidence for long-lived active longitudes. combined UVB photometry with H α spectroscopy and related chromospheric activity to photospheric spotted regions (Zhang & Zhang, 1999).

More recent observations strengthened this picture (Kővári et al., 2015) and Korhonen et al. (2021) used surface-imaging techniques to investigate spot evolution and differential rotation. (Roettenbacher et al., 2015) used optical interferometry to constrain the binary and compare surface structures. Cao found rotationally modulated chromospheric activity and changes between orbital cycles, while the more recent high-energy observations cited in the source draft extend evidence of magnetic activity into the stellar corona. (Cao et al., 2022).

3. Observations and Data Reduction

3.1 AAVSO archival data

Photometric observations were conducted to investigate from the AAVSO International Database. The complete dataset is of 25 years however, there are only 363 observations prior to 2021. From 2021-2025 the observation cadence is good enough for this study. Therefore we included only the dataset that covers 1st January 2021 to 31st December 2025 and includes PEP and CCD observations in the Johnson B and V bands. The five year long temporal coverage makes it possible to compare relatively separated observing epochs and to investigate changes in mean brightness, amplitude, and light-curve morphology.

3.2 Data reduction and analysis

The downloaded observations were inspected before analysis. Duplicate or incomplete entries were removed where applicable, valid Johnson B- and V-band photometric observations were retained, and the observations were sorted chronologically using Julian Date. Separate datasets were generated for prepared for the principal observing intervals and photometric bands.

The data processing and analysis were carried out using Python scientific libraries, including Pandas, NumPy, Matplotlib, SciPy, and Astropy. Long-term light curves were constructed by plotting magnitude against the observational coordinate. For each dataset, the minimum and maximum observed magnitudes, magnitude range, light-curve morphology, repeated brightening and fading, possible periodic behaviour, and anomalous measurements were examined.

4. Results

4.1 Variability in PEP observations

The five year AAVSO observations using photoelectric photometer has 7 observations in B-band and 38 observations in V-band. Figure 1 shows the PEP B and V band light curves. The light curves of both the bands show persistent photometric variability and repeated rise and declines over relatively short intervals. The light curves varies by roughly 0.44 mag and 0.5 mag. The mean value for these light curves are 5.65 and 4.33 mag while the standard deviations is found to be 0.06 mag for both the bands.

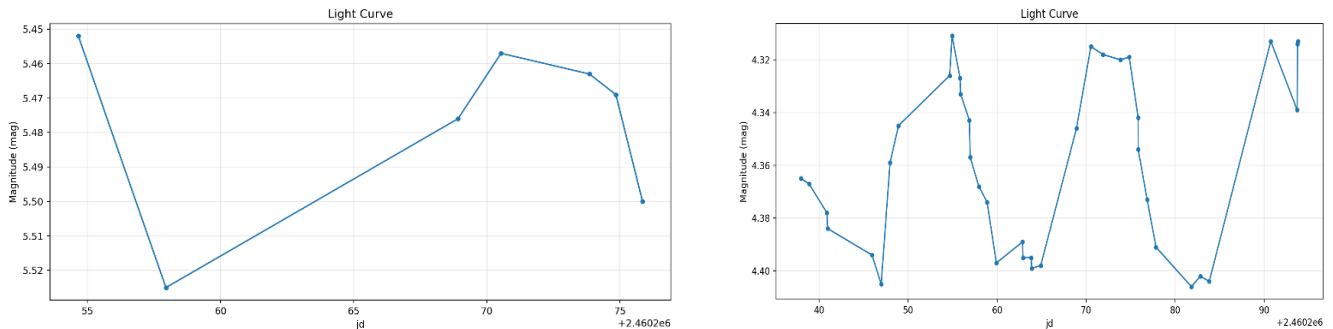


Figure 1. PEP observations in Johnson B-band (left) and Johnson V-band (right) light curves of the Sigma Gem.

4.2 Variability in CCD observations

The photometric light curves of the RS CVn binary were analyzed to investigate its long-term variability of the CCD observations in B and V-bands. The detailed 2021–2025 period contains 363 CCD measurements in B and V. The CCD observations are substantially denser than the PEP observations, providing better sampling of brightness changes over a longer duration. The resulting light curves further reveal repeated brightening and fading, consistent with rotational modulation by active regions.

The light curves varies by roughly 0.08 mag and 0.05 mag, respectively. The mean value for these light curves are 5.48 and 4.33 mag for B-band and V-band, respectively while the standard deviations is found to be 0.02 mag for both the bands. However, the very sharp variability around JD $\approx$ 2,460,310–2,460,320 Careful examination is required because these variations may be attributed to outliers, observational uncertainties, or changes in observing conditions rather than intrinsic stellar variability. We also It should be noted that the variability observed here is very lees as compared to the PEP observations, however, we should attention should be drawn to the fact that the observational techniques may have caused this apparent less variations here.

On the longer timescale, the mean brightness does not show any obvious strong monotonic trend throughout the observations. Instead, the star appears to undergo irregular/quasi-periodic brightness modulation (as seen in the CCD B & CCD V-band light curve in fig. 2) superimposed on a relatively stable long-term level.

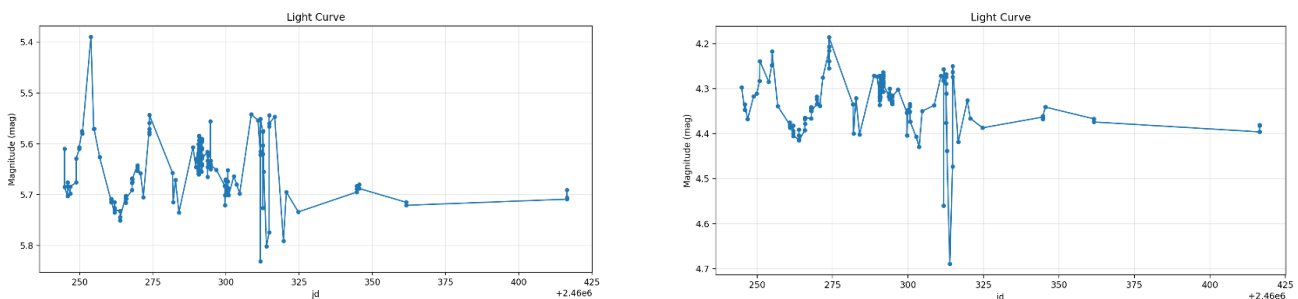


Figure 2. CCD observations in Johnson B-band (left) and Johnson V-band (right) light curves of the Sigma gem.

4.3 B–V color index

The B–V color index provides an additional diagnostic of changes in the observed colour of the system. Both the PEP and CCD observations show a measurable scatter in B–V color index rather than a single constant colour value. For the PEP B–V color index, the mean value and the standard deviation are 1.32 mag and 0.05 mag, respectively and that for the CCD observations are 1.13 mag and 0.4 mag, respectively. From figure shows 3 the PEP B–V color index plot we can clearly see a linear increase in the color value suggesting the cooler and redder stellar surface as shown in figure shows 4. In the starspot interpretation, cooler spotted regions can make the integrated stellar light redder when they occupy a larger fraction of the visible hemisphere. The colour information therefore complements the B- and V-band light curve variations, although a quantitative temperature or spot-filling-factor determination would require a dedicated calibrated analysis.

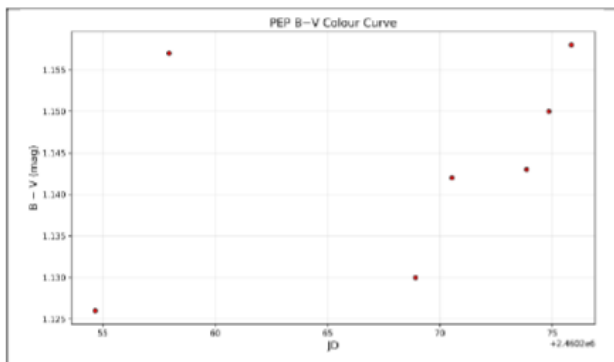


Figure 3. PEP B–V color index variation during 2021–2025. The recent data show distinct brightness changes and irregular sampling.

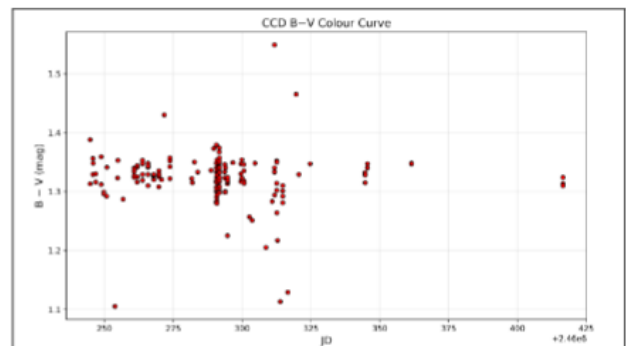


Figure 4. CCD B–V color index variations during 2021–2025, showing repeated brightness changes and the effects of uneven sampling.

4.4 Phase related behavior

Although high number of CCD observations are available in both bands but the dataset contains uneven sampling, and therefore we did not tried to find the period of rotation, independently. However, we constructed the phase-folded light curve with in B and V-band CCD observations by adopting the historically. The resulting light curves, phase-folded using the adopted rotational period, reveal shown in the figure 5. The figure shows two clear periodic, nearly sinusoidal, variation with some scatter around the sine-wave plotted using the reported period. The modulation is consistent with rotational variability due to starspot activity. The phase behavior is consistent with rotational modulation associated with persistent spotted regions. However, a formal Lomb–Scargle periodogram, uncertainty analysis, and epoch-by-epoch phase comparison would be required to determine whether the recent data support a period different from the historical value.

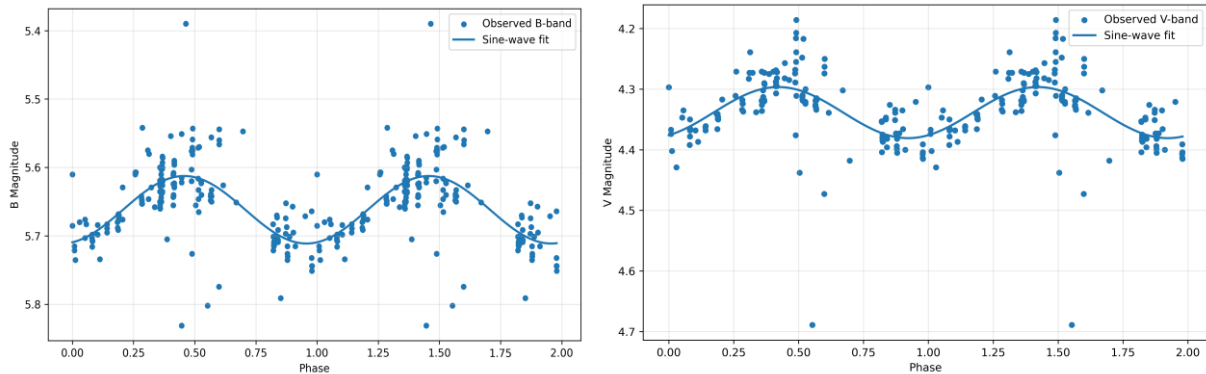


Figure 5. The phase folded light curves for B-band (left) and V-band (right) using the CCD observations.

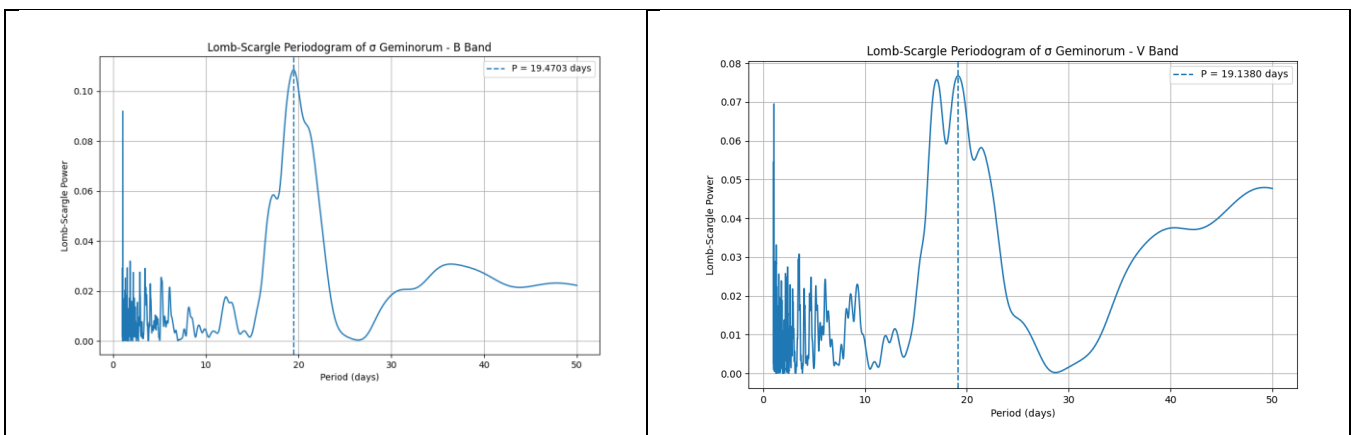


Figure 6. Lomb-Scargle periodograms for the B-band (left) and V-band (right) using the CCD observations.

5. Discussion

The 2021–2025 observations demonstrates that Sigma Geminorum has remained photometrically active, while the strength and morphology of the observed variability have changed with time. The variations in the PEP observations is compatible with the stronger and more irregular behavior seen in the CCD observations. This change is corresponding to the established picture of an evolving surface spot distribution rather than a permanently stable sinusoidal light curve.

The 0.08 mag variations observed in the CCD V-band data are of the same order expected from a low-amplitude rotational modulation by active regions. Repeated brightening and fading further supports a rotational interpretation. During the same period, the largest apparent ranges with in the dataset cannot be assigned directly to intrinsic stellar variability without accounting for sampling and measurement effects. The strong contrast between densely sampled CCD series and sparsely sampled subsets illustrates why amplitude estimates should be based on well-controlled, homogeneous datasets.

The previously reported photometric period of approximately 19.423 d is marginally shorter than the orbital period of approximately 19.6 days. This difference is of relevance to interpret the spot migration, active longitudes, and rotation. Previous long-term studies also found changing minima, amplitudes, and

active regions. Consequently, the recent light curves are best understood as another epoch in a long sequence of evolving magnetic activity rather than as evidence, by themselves, for a new stable period. Our observations reveal in the figure 6. The Lomb–Scargle periodogram of the B-band observations of σ Geminorum exhibits a dominant peak corresponding to a photometric period of 19.4703 days. Phase folding the observations using this period produces a coherent, although non-sinusoidal and asymmetric, light-curve morphology. The observed modulation, together with the established chromospherically active nature of σ Geminorum, is consistent with rotational variability associated with non-uniform surface features, particularly starspots. The scatter and departures from a simple sinusoidal shape may indicate changes in the distribution or evolution of active regions on the stellar surface.

6. Conclusions

Sigma Geminorum exhibits persistent photometric variability across the 2021–2025 AAVSO observations. The B- and V-band light curves reveal clear photometric variability with broadly correlated brightness changes in both passbands. The observed short-term fluctuations and quasi-periodic modulation are consistent with rotationally modulated variability, potentially associated with starspot activity. No pronounced monotonic long-term trend is evident. Several sharp excursions, particularly around JD $\approx$ 2,460,310–2,460,320, require careful examination for possible outliers or observational effects.

The B-V color index shows the variations consistent with the individual light curves without any monotonic long-term trend consistent with the individual light curves. It provides the supporting evidence for colour changes associated with temperature-dependent surface inhomogeneities. The phase folded light curve reveals a clear periodic variation and is represented with the 19.423 days cycle. The Lomb-Scargle algorithm gives the period of 19.47 d in the V-band confirming the reported period. The B-band periodogram, however, estimates the period of 19.13 d with two distinct nearby peaks. The secondary B-band peak may arise from the evolving starspot distribution, differential rotation, harmonic structure, or sampling-related aliasing. Further analysis of the false-alarm probability, spectral window, and time-resolved periodograms is required to establish its physical significance. The combined long-term and recent record supports the interpretation that Sigma Geminorum remains an active RS CVn system with continuously evolving starspot distributions and magnetic activity.

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