Current Research in Next Generation Materials Engineering

PRIME OPEN ACCESS

Volume 1, Issue 1

Research Article

Date of Submission: 11 April, 2025
Date of Acceptance: 06 June, 2025
Date of Publication: 23 June, 2025

Unveiling U Gem Outbursts: Light Curve Analysis and Exploring Correlations of Outburst Mechanism

Md. Talha Zobair[1*] and S.M. Fuad Hasan[2]

[1]Ideal School and College, Dhaka, Bangladesh

[2]Brac University, Dhaka, Bangladesh

***Corresponding Author:**
Md. Talha Zobair, Ideal School and College, Dhaka, Bangladesh.

Citation: Zobair, Md. T., Hasan, S. M. F. (2025). Unveiling U Gem Outbursts: Light Curve Analysis and Exploring Correlations of Outburst Mechanism. *Curr Res Next Gen Mater Eng, 1*(1), 01-06.

Summary

As a nova-type cataclysmic star, U Gem exhibits outbursts in brightness; stars of this nature have left astronomers puzzled about the underlying mechanism. By analysing U Gem's light curve (a graph representing its changing magnitude over time which reveals the outburst cycle), spectrums, and the temperature variation of its white dwarf component, we gained a bit of understanding of these outbursts. Using professional data sites like The American Association of Variable Star Observers (AAVSO) and the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST), we gathered light curves to identify different phases of outbursts as well as collected the visible spectrums and UV spectrums. During the narrow and wide outbursts, it brightened about an average of 4.7 mags, and 5.6667 mags respectively in Vis. band, the radial velocity increased 314.486 ± 11.2 km/s from the quiescence phase to the decline phase, and the WD cools from a temperature of ~41,500 K, 15 days after the peak of the outburst, to ~36,250 K, 56 days after the peak of the outburst.

By studying periods of outbursts, we have linked them to material activities in U Gem. The Balmer spectral lines were also investigated to follow the variations in radial velocity during outburst phases. Correlating these phases with variations in radial velocity, derived from spectral line shifts, and white dwarf temperature changes during quiescence provides crucial insights into the system's behaviour and helps to understand the dynamics of the accretion disk and the evolution of cataclysmic variable stars. This, I hope, is going to make it easier for others who may wish to study further about cataclysmic variable stars and the intricate dynamics of peculiar stars like this one to do so.

Introduction

Cataclysmic variable stars (CVs) constitute a class of binary star systems whose brightness increases by several orders of magnitude and then drops back down to a quiescent state [1].These are semi-detached interactive binaries where the primary is a compact white dwarf (WD) accreting material from a Roche-Lobe filling companion, which normally is a late-type star very close to the main sequence [2]. Observational phenomena like outbursts dwarf novae and novae are caused by gravity, hydrodynamics, and magnetism, acting together in a CV accretion process that is not simple [3].

U Geminorum is the prototype of a subclass of dwarf novae (DN), which belongs to the Cataclysmic Variable systems (CVs) [4]. It is located about 304.5 ± 0.8 light-years (93.4 ± 0.3 pc) away in the constellation Gemini which was discovered in 1855 [4]. U Gem has an orbital period of 0.1769061911 days and a mass ratio of q = 0.35±0.05 [5]. Also, with an inclination of i = 69.7° ±0.7° the system parameters become = 1.20 ± 0.05 $M_{\odot}$, = 0.42 ± 0.04 $M_{\odot}$ and a = 1.55 ± 0.02 $R_{\odot}$ [6]. U Gem goes into outburst every ~118 days, brightening from mv= 14.9 to mv = 8.2 for an average outburst time of ≈12 days [7,8]. The outbursts of stars like this are believed to develop from instabilities in the accretion disk surrounding the white dwarf [9,10]. However, what specific events or mechanisms tend to cause these outbursts is still unclear. Understanding these outbursts' physical processes is important for unravelling the complex dynamics of CVs as well as their role in stellar evolution.

Through an extensive study of U Gem's light curves, visible spectrums, and white dwarf (WD) temperature, it provides a simple analysis of the outburst phenomenon occurring in U Gem. We seek to understand the underlying astrophysical processes by examining how brightness changes over time as well as the visual spectral signatures that are associated with different phases of an outburst. Our research aims to characterize the light curve, identify various phases of the outburst cycle, and correlate them with radial velocity at different outburst phases and temperature changes at quiescence respectively, which were obtained through analysing the spectral lines and pre-existing data. Ultimately this study aims at understanding the astrophysical mechanisms driving outbursts in U Gem and related CVs.

It is shown by our findings that the light curve of U Gem consists of various stages such as a pre-outburst stage, a rapid rise to its peak brightness, a decline phase, and areturn to quiescent state. We used the apparent wavelength of the Hα line of its visible spectrums during different outburst stages and the rest wavelength of this line to get the radial velocity using the Doppler shift equation, $v_r=c(\lambda-\lambda_0)\ \lambda_0$ where v_r is radial velocity, c is the speed of light, λ is the observed wavelength of shifted hydrogen α line and λ_0 is the rest wavelength of hydrogen α line [11]. Then, we collected the pre-existing data of WD temperatures at different points in the quiescence phase which was analysed from the UV spectrums of U Gem. Finding these results suggests the systematic changes in radial velocity and WD temperature during the outburst cycle which will help us to glance at the outburst mechanism.

In this paper, an attempt has been made to understand the nature of outbursts in U Geminorum by comparing the light curve variation of U Gem with its observed visible spectra along with the evolution of WD temperature. Coping with the examined spectra in different phases of outburst and comparing them with the form of the light curve, one can suggest what mechanisms regulate such a brightening. Moreover, the effects during the quiescent phase, the white dwarf temperature and the overall light curve synthesis help in the study of the long-term activities and symptoms of the possible outburst. For this reason, studies such as these are the foundation for future discussions on cataclysmic variables and accretion disk physics.

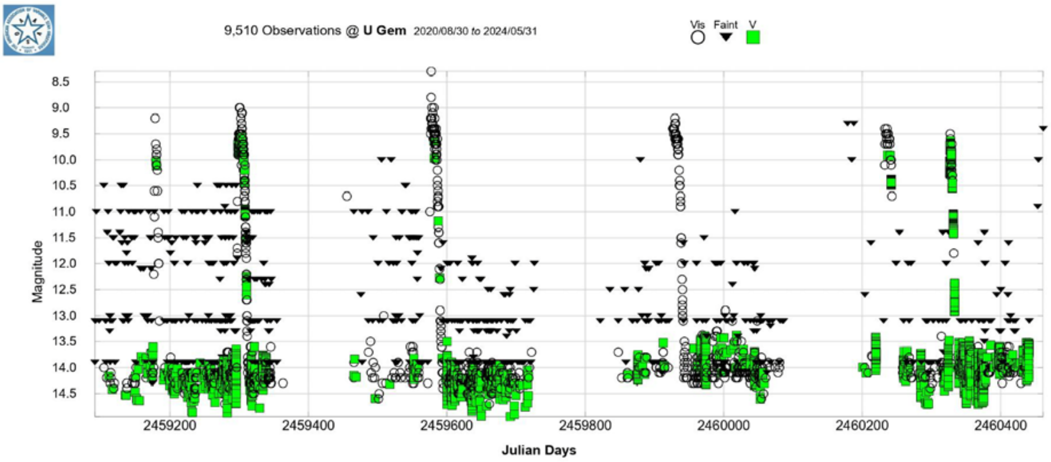

Figure 1: Light Curve of U Geminorum Spanning Jd 2459001 To Jd 2460521.970

Results

Light Curve Analysis

We analysed the light curves of U Geminorum to characterize its outburst behaviour. The primary goal of this analysis was to understand its brightness variations relating to time and identify its different phases within the outburst cycle. This study was crucial for the proper correlation with other parameters such as WD temperature and radial velocity.

The light curves were acquired from the American Association of Variable Star Observers (AAVSO) for analysis. We took the light curve of U Gem in V and Visual bands for the last 4 years. The light curve helped us to get a visual representation of its outbursts and by analysing this we identified the variation of its apparent magnitude in the V band and Visual band during the outburst phases.

U Geminorum displayed two types of outbursts: narrow and wide (Figure 1). In Vis. and V Bands the narrow outbursts had a mean peak magnitude of 9.6 and 9.774 ± 0.01 respectively and brightened in 2 days, the decline phase was more gradual and it returned to quiescence throughout an average of 8 days (Figure 2a). Extended outbursts displayed similar patterns but with a longer duration of about 5.667 ± 0.01 days and in Vis. and V bands the peak magnitude is approximately 0.767 and 0.044 ± 0.01 mag respectively brighter than narrow outbursts (Figure 2b).

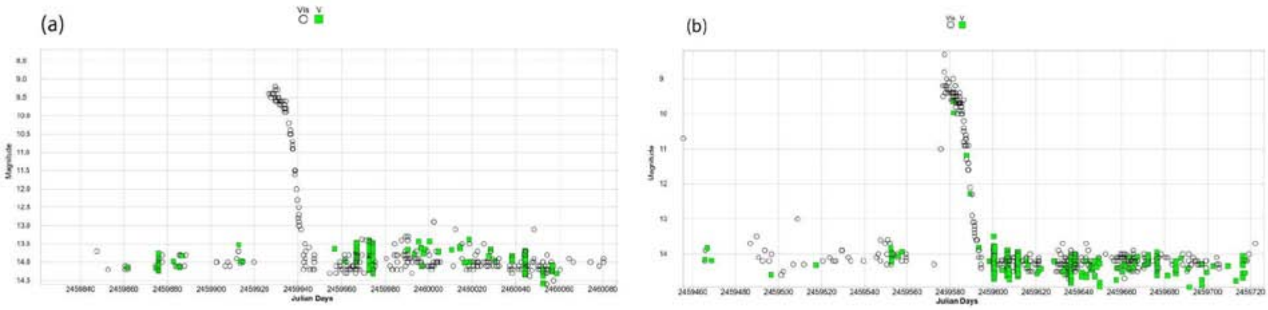

Figure 2: Light Curves of U Geminorum Showing (a) Narrow and (b) Wide Outbursts

Visible Spectrums Analysis and Correlation with Light Curve

The visible spectrums of U Gem were analysed for physical condition evaluation in different outburst phases, and it was important for extracting the information about radial velocity, which we had utilized to understand outburst mechanisms. For this, we collected the visible spectrums of U Gem from the AAVSO during the time of different outburst phases. By analysing specific spectral lines such as, we estimated radial velocity variation during different outburst phases by utilizing the Doppler shift of the hydrogen α lines.

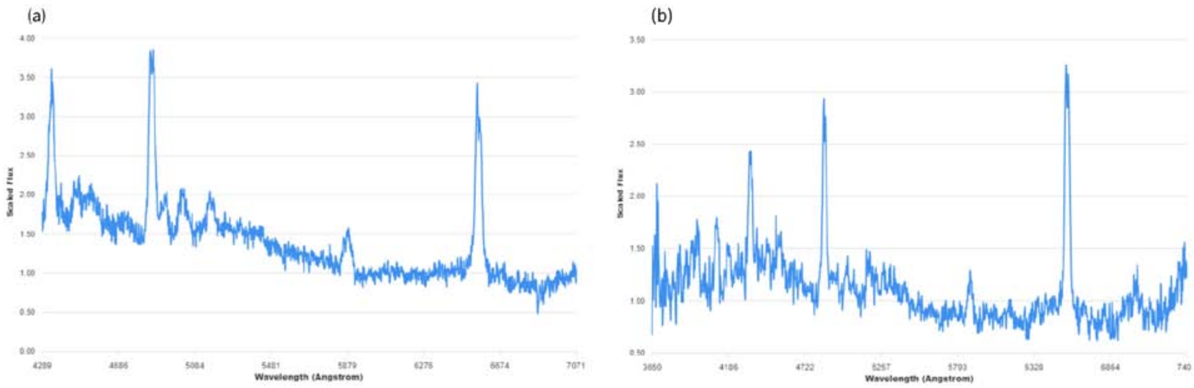

Figure 3: Visible Spectra of U Geminorum During the (a) Quiescence and (b) Pre-Outburst Phases

The radial velocity was blue-shifted to -142.455 ± 5.0 km/s at the quiescence phase and at pre-outburst, the radial velocity was increased and approached us at -95.478 ± 4.5 km/s which was obtained by using the shift of Hα from its spectrum at these phases (Figure 3a,3b). At the peak of the wide outburst, radial velocity increased and blue-shifted to -34.344 ± 3.8km/s (Figure 4a). At the decline phase, it redshifted and the radial velocity was 172.031 ± 6.2 km/s. (Figure 4b).

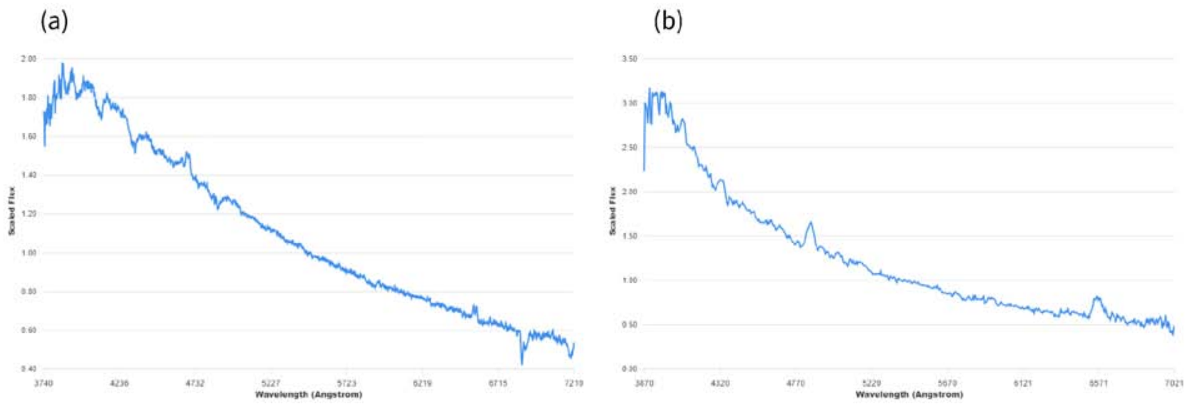

Figure 4: Visible Spectra of U Geminorum During the (a) Peak and (b) Decline Phases of a Wide Outburst

A strong positive correlation ($r = 0.85$, $p < 0.01$) was found between radial velocity variations and the light curve of U Gem (Figure 5). This suggests that the variation of the measured brightness of the binary system is highly dependent on the orbital motion. That presented radial velocity curve also showed a clear sinusoidal variation, where the maximum positive velocities correspond to the minima of the light curve, which could indicate that the system is experiencing radial velocity changes because of the orbital motion of the accreting ingredient. Also, significant increases in radial velocity suggested the enhanced accretion disk activity and associated energy release. This suggests that U Geminorum outbursts are caused by complex interactions between thermal processes and accretion disk dynamics.

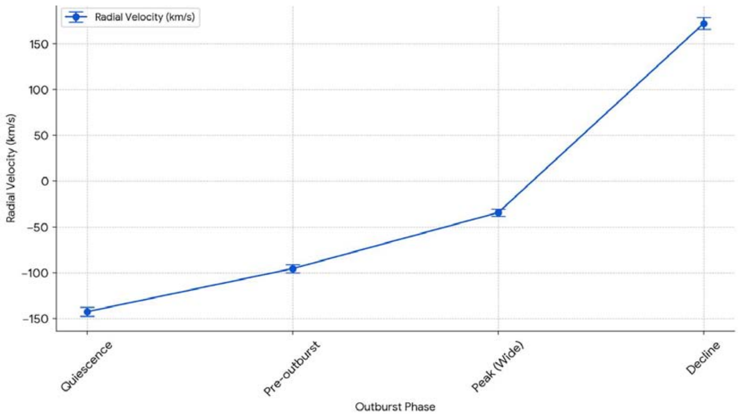

Figure 5: Radial Velocity Variations in U Geminorum during Different Outburst Phases

WD Temperature and Correlation with Light Curve in Quiescence

We obtained the white dwarf component's temperature from the pre-existed data, which was estimated by using the UV spectroscopic data from the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST). The spectrums were taken at four epochs, 15 days, 21 days, 33 days, and 56 days after the peak of the wide outburst which is marked in Figure 2b. For the first epoch spectrum, we find a WD temperature of 41,500 K ± 500 K, 15 days after the peak of the outburst, and six days later at the second epoch, the temperature cools to 39,850 ± 500 K (Figure 6a,6b)[12]. After 17 days the temperature dropped by an additional 2200 k and became 37,650 ± 500 K at the third epoch and in the fourth epoch, the temperature dropped to 36,250 ± 500 K cooling of 1400 K in 23 days (Figure 6c,6d)[12]. Then, we plotted the declination of WD temperature in a graph in terms of days passed from the wide outburst's peak phase (Figure 7).

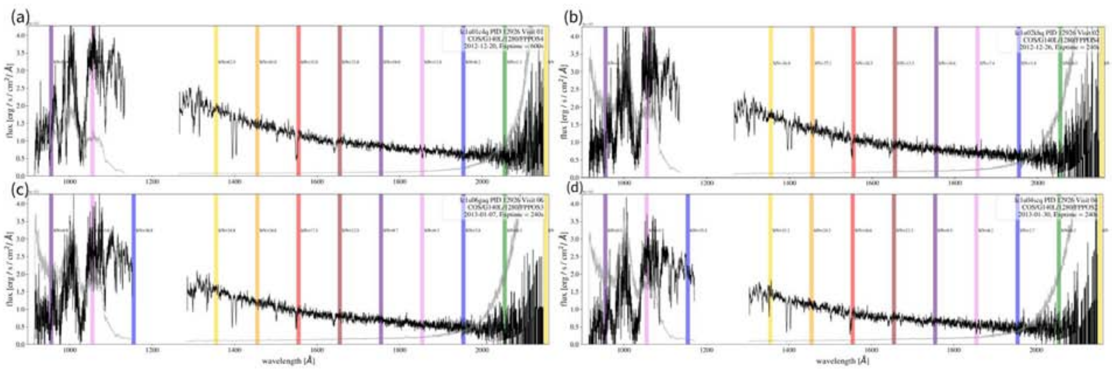

Figure 6: Figure 6. UV spectra of U Geminorum During Four Different Points in the Quiescence Phase: (a) 15 Days, (b) 21 Days, (c) 33 Days, and (d) 56 Days After the Peak of the Wide Outburst.

Integral to the two different approaches is the WD temperature which shows a clear correlation with the light curve at quiescence. As the WD cools from approximately 41,500 K to 36,250 K over the 41 days the brightness of the system decreases. It is thus tentative to identify a relationship between the thermal evolution of the white dwarf and the total luminosity of the system during quiescence. Another important step will be to establish this connection using data from multiple outburst cycles to firmly determine such dependence and to study the implications of such a relationship for understanding the underlying physical processes.

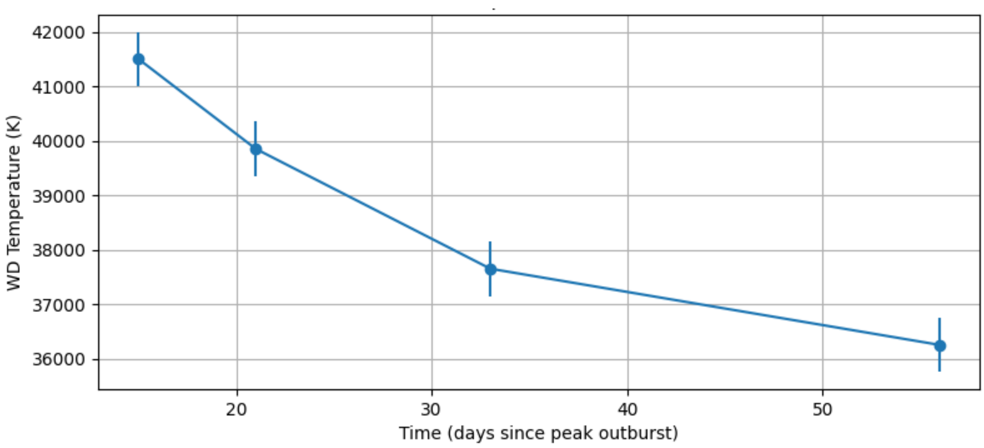

Figure 7: Variation of White Dwarf (Wd) Temperature Over Time in U Geminorum

Discussion

The analysis of light curves identified two types of outbursts where one is narrow outbursts and another is wide outbursts which differed by 0.767 mag in Vis. band and 0.044 ± 0.01 mag in V band (Figure 1). In U Gem, normal outbursts showed a rapid rise and decline in brightness (Figure 2a). Besides, extended outbursts had a longer period of 5.667 ± 0.01 days and displayed higher peak magnitudes than the normal outbursts (Figure 2b). Also, its brightness is affected when its secondary component eclipses it (13).

Such results indicate a complicated interaction of factors affecting the outburst behaviour. The correlation between the decreasing of WD temperature in the quiescence phase supports the hypothesis of thermal instabilities that the cooling rate of the white dwarf (WD) is influenced by ongoing accretion processes. Figures 6 and 7 show the changes in temperature in the white dwarf during different points of the quiescence phase began after a wide outburst such as the gradual decrease in temperature from 41,500 K ± 500 k to 36,250 ± 500 K by 41 days after the peak phase; as well a considerable there was an increase in radial velocity from the quiescence phase to the decline phase approximately 314.486 ± 11.2 km/s which suggest higher activity in the accretion disk and energy losses (Figure 4,5). Such observations are in line with existing concepts on cataclysmic variable (CV) outbursts which emphasize thermal activities and accretion disk instability.

Whilst this research study offers great analyses about U Gem, there are however limitations that must be acknowledged. First of all, archival data are used which may lead to uncertainties in times and accuracy levels of photometric or spectroscopic measurements. There was no way for simultaneous, multi-wavelength observations; therefore, an extensive analysis of temperature and radial velocity during outbursts was impossible. Additionally, the unavailability of visible spectroscopic data for the peak phase of narrow outbursts prevented a direct comparison of spectral characteristics and radial velocity between different outburst types. Moreover, the limitation of UV spectroscopic data of U Gem restricted the analysis of its temperature changes during the outburst cycles. So, better spectral line profile analysis undertaken through time-resolved spectroscopy and more observed in lower wavelengths could offer a further understanding of the physical conditions prevailing in an accretion disk.

For future studies, it should be important to capture lower wavelength spectroscopy and high-resolution measurements of all outbursts and different phases at once spectroscopically, to learn about the dynamics of their spectral line profiles. Similarly, we should also examine how magnetic fields trigger and alter outbursts. Also, we possibly can delineate similarities and divergences in the behaviour of U Gem by comparing it to other cataclysmic variable stars (CVs) showing such similar outbursts.

It is clearly shown that analysing light curves and spectrums has an essential role in understanding the intricacies involved in U Geminorum outbursts. It also has been shown in this study that these findings help to explain the behaviour of accretion disks and their associated processes. Thus, we are limited in our ability to provide a full description of outburst events because we have relied on archival data without making simultaneous multi-wavelength measurements. Future studies should focus on high-resolution spectroscopy, long-time monitoring, and advanced modelling techniques for predicting the time when the next outburst will occur and explore to enhance our understanding of how component stars and magnetic fields affect outbursts. Therefore, these will help to improve what we know about cataclysmic variable stars and how they behave during an outburst.

Materials and Methods

Using the tools found in the AAVSO database, it is easy for anyone to collect large amounts of variable stars' information to analyse such as light curves and visible spectrums. Also, anyone can access the printable photometry or spectrum and the data underlying it as a CSV file that can be downloaded. To obtain light curves, the 'Light curve generator' tool was used, and we searched the name of the variable star, U Gem. Subsequently, it was decided to employ the V and Visual bands for the magnitude bands and specify the time span for the light curve (from JD 2459001 to JD 2460521.970). The visible spectra of U Gem were also sourced from the AAVSO database in both spectroscopic and CSV data formats by searching the name in the archival database. We used the Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) to obtain a series of far-ultraviolet (FUV; 915–2148 Å) spectroscopic observations of U Gem at four epochs, 15 days, 21 days, 33 days, and 56 days after the peak of the outburst.

Light Curve Analysis

Outburst events were identified regarding significant variations from the mean quiescent magnitude. We identified the phases of an outburst based on the differences in brightness. The pre-outburst phase was characterized by a slight increase in brightness compared to quiescence, the rapid ascent phase was a rapid rise to its peak brightness, and the decline phase was a return to the quiescent state.(Figure 1). By selecting the points of the light curves, we collected the brightness information with uncertainty and the time interval. We identified two types of outbursts by analysing the duration and magnitudes, where the extended outburst was an average of 0.933 mag brighter in Vis. band than the normal outbursts. Also, it was nearly 1 day longer (Figures 2a, 2b).

Visible Spectral Analysis and Correlation with Light Curve

To find the shift of the Hα line of a spectrum, we collected the nearest wavelength of the rest wavelength of the Hα line

[11]. Then, we used the Doppler shift equation, $v_r = c(\frac{\lambda - \lambda_0}{\lambda_0})$ to get the variation in radial velocities from the spectra, and the uncertainties in radial velocity were estimated using standard error propagation methods. (Figures 3 and 4). Though we collected the spectra of different outburst phases, the spectrum peak of extended outbursts was not gathered because data unavailability impacted the correlation between light curves and spectral analysis. After that, using Python we compared the variations in radial velocities during different outburst phases with the light curve plotting in the graphs to identify correlations (Figure 5).

Correlation between WD Temperature and Light Curve in Quiescence

As U Gem radiates the maximum of its energy at UV wavelength, its temperature data was taken from the UV spectrum. We collected the pre-existed data for WD temperature from 'HST/COS Far-ultraviolet Spectroscopic Analysis of U Geminorum Following a Wide Outburst', where the author analysed the same spectrums and estimated the temperature variations of WD at different points in the quiescence phase (Figure 6). Using Python, we plot the change in WD temperature at four different points of the quiescence phase in terms of a function of days after the peak of outburst, which represents the correlation between WD temperature and the light curve (Figure 7)

References

1. Warner, Bradley. Cataclysmic Variable Stars. University of Cape Town, 1995.
2. Echevarría, J., Ramírez, S. H., Fuentes, M., Sánchez, L. J., Patiño, V., & Chavushyan, V. (2023). New spectroscopy of U Gem. *Revista mexicana de astronomía y astrofísica, 59*(2), 191-200.
3. Sion, Edward M. "The Accreting White Dwarfs in Cataclysmic Variables." In The Astrophysics of Cataclysmic Variables, Chapter 7, 7-1 to 7-71. Bristol, UK: IOP Publishing, 2023.
4. "Spectroscopic Observations of Dwarf Nova U Geminorum Unveils Outburst Mechanism." Physics Org. Accessed [Insert Date].
5. Echevarría, Juan, et al. *"The Astronomical Journal." Astronomical Journal 134*, no. 2 (2007).
6. Zhang, E. H., & Robinson, E. L. (1987). The eclipses of cataclysmic variables. II-U Geminorum. Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 321, Oct. 15, 1987, p. 813-821., 321, 813-821.
7. Szkody, P. A. U. L. A., & Mattei, J. A. (1984). Analysis of the AAVSO light curves of 21 dwarf novae. *Publications of the Astronomical Society of the Pacific, 96*(586), 988.
8. Ritter, H., and U. Kolb. "Catalogue of Cataclysmic Binaries, Low-Mass X-Ray Binaries, and Related Objects." Astronomy & Astrophysics 404 (June 2003): 301–303.
9. Smak, J. "Eruptive Binaries. II. U Geminorum." Acta Astronomica 21, no. 1 (1971): 15–8.
10. Osaki, Y. "An Accretion Model for the Outbursts of U Geminorum Stars." Publications of the Astronomical Society of Japan 26, no. 4 (1974): 429.
11. Latham, David W. "Radial Velocity." In Encyclopedia of Astrobiology, edited by Muriel Gargaud et al. Berlin: Springer, 2011.
12. Godon, P., Shara, M. M., Sion, E. M., & Zurek, D. (2017). HST/COS Far-ultraviolet Spectroscopic Analysis of U Geminorum Following a Wide Outburst. *The Astrophysical Journal, 850*(2), 146.
13. Krzeminski, W. "The Eclipsing Binary U Geminorum." *Astrophysical Journal 142* (1965): 1051.