THE FREQUENCY OF OUTBURSTS OF THE DWARF NOVA U GEMINORUM

LEWIS M. COOK
1730 Helix Court
Concord, CA 94518

Received 3 December 1987

Abstract

U Geminorum visual data from 1855 through 1985 are used to determine variations in the frequency of outbursts of this dwarf nova. Patterns in the O-C curve of times of outbursts resemble other types of dwarf novae in that intervals of more or less frequent outbursts occur for periods of up to ten years. The duration of outbursts is determined to be bimodal with peaks at 9 and 16 days. Wide outbursts tend to be more common when the interval between outbursts is longer. Changes in the published counts of maxima were determined to be necessary to correct discontinuities in the O-C curve. A new table of outbursts is presented.

* * * * *

1. Introduction

The light curve of the dwarf nova U Geminorum has been published in **AAVSO Monograph 2** (Mattei et al. 1987). All visual observations in the AAVSO data archives from 1855 to 1985 were represented in that publication. Szkody and Mattei (1984) included U Gem in a study of statistical relationships in the light curves of dwarf novae.

An investigation (Cook 1985) into the behavior of the frequency of outbursts of two other dwarf novae, SS Aurigae and AH Herculis, showed that prolonged intervals existed when outbursts occurred consistently more or less often than the mean. Variations in cycle length would not occur randomly from one outburst to the next, but rather the frequency would remain more or less constant and then jump to another value. Both of these dwarf novae display a bimodal distribution of outburst duration, having outbursts classified as wide or narrow. During intervals when outbursts occurred less frequently than the average outburst interval, the proportion of wide outbursts was higher than during those intervals of very frequent outbursts. When outbursts occurred very frequently, wide outbursts became rare or disappeared completely for long intervals.

Similar behavior was also noted in a study of the SU UMa type variable VW Hydri (Cook 1987).

The present investigation is an examination of the O-C curve for U Gem to determine if the frequency of outbursts shows similar trends.

2. Analysis

The dates of the outbursts of U Gem were determined from the graphical presentation of the data in **AAVSO Monograph 2.** Data before 1964 were presented as a historical light curve in a condensed format. The dates of outbursts from 1855 to 1964 were determined by measuring enlargements of the historical light curves. Because a different scale was used for the graphical presentation of the older data, outburst dates determined from the older data are subject to uncertainties of a few days, but this does not significantly affect the shape of the O-C curve. The errors in the determination of outburst dates do not accumulate. The errors are smaller than the symbols on the curve. The data are shown in Table I.

Using the mean frequency of outbursts given in Mattei et al. (1987) of 102 days, an O-C curve was computed using the equation

$$O\text{-}C = JD - (2398932 + 102\ E), \quad (1)$$

where JD is the Julian date of the outburst and E is the epoch of the outburst. The O-C curve is shown in Figure 1.

In the light curve of U Gem there are gaps in the observations which occurred when the sun was near the star. The outbursts in **AAVSO Monograph 2** have been assigned numbers, although there are often no obvious clues about how many outbursts occurred during some of the intervals.

The effect of missing an outburst or assuming that an outburst occurred when one actually did not is that a stepwise jump will appear in the O-C curve. This discontinuity is equal to the mean frequency between outbursts used to compute the O-C curve (102 days here), and is shown by a bar in Figure 1.

In examining the light curve it was apparent that there were outbursts assumed when no outbursts actually occurred. Some apparent discontinuities in the O-C curve occurred when there were extended gaps in the data. These apparent discontinuities are shown by the arrows in Figure 1. There were 24 of them in the 455 data cycles; they are listed in Table II. The other two cases where too few outbursts were assumed are shown by downward-pointing arrows in Figure 1. The outbursts which were not counted occurred before maxima 104 and 116.

The effect of removing these discontinuities is to vertically displace all of the curve to the right of the discontinuity by an amount equal to the cycle length used to develop the O-C curve. The displacement is in the direction of the arrow. The O-C curve with these revisions is shown in Figure 4.

The data from 1964 to 1985 were used to determine the distribution of the widths of the outbursts. Forty-five outbursts were observed well enough to determine the duration (called "width" here) of the outburst. The histogram of outburst width in one-day bins is shown in Figure 2. Clearly the distribution is bimodal with peaks at 9 and 16 days. There is also a clear separation between the peaks at 13 days, which may be used to classify an outburst as either wide or narrow without much ambiguity.

All observed outbursts were placed into either a wide, narrow, or undetermined category based upon an examination of the data in **AAVSO Monograph 2.** Wide outbursts are shown as circles in Figure 1. All other outbursts are shown by a dot.

To examine intervals to determine the mean frequency between outbursts, the data were divided into segments by inspection of the curve. Each segment was at least four outbursts in length where the slope of the O-C curve was more or less constant. In choosing the segments of the O-C curve, those instances where errors in the counts of outbursts are believed to have occurred were used as end points of the segments. The 30 segments are shown by the horizontal bars in Figure 1.

The fraction of observed outbursts which were wide maxima was calculated for each interval. This fraction was plotted against the mean cycle length in each interval (Figure 3). Assumed outbursts were ignored in determining this fraction. Because some of the observed outbursts may have been wide maxima where there were not enough observations to determine if the outburst was a wide one, the percentage of wide maxima may be erroneously low in some of the points plotted in Figure 3.

3. Discussion

The plot of the O-C curve for the outbursts shows that there is considerable variation in the outburst frequency. The intervals during which the cycles are longer than the chosen average cycle length are characterized by upward-sloping segments. Intervals during which the outbursts occur more frequently are characterized by downward-sloping parts of the curve. The curve is flat when the outbursts occur at the expected frequency.

Before 1922 (about JD 2423459) the overall slope of the curve is downward, but the second half of the curve slopes upward. In the 67 years prior to the change the mean frequency was 98 days. In the succeeding 63 years the average interval between maxima was 124 days.

The average cycle length in the 30 intervals ranges from 79.1 days to 163.9 days. While we chose to use the 102-day frequency of outbursts published in **AAVSO Monograph 2**, the O-C curve in Figure 4 shows an overall upward trend. This means that the long-term value of the interval between outbursts is greater than 102 days. For the era examined here, 1855 to 1985, the mean interval between the 433 outbursts is 109.1 days, after adding 2 suspected missed and removing 24 "extra" outbursts which were assigned numbers but are believed not to have occurred. There is no observational evidence for assuming they occurred. In a few cases, there is substantially complete coverage of the light curve between outbursts, although the interval between successive outbursts may have been much longer (as much as twice as long) as the historical value.

In Table II, the outbursts which are believed not to have occurred are listed along with the reason for that conclusion. While some of these criteria are admittedly subjective, the adjustment does not alter the overall shape of the O-C curve nor does it materially affect the results found here.

In U Gem there is an overall tendency for the outbursts to alternate between wide and narrow maxima. This can best be seen from the data in Table I. This trend is not at all rigorous. Figure 3 shows there is no strong correlation between cycle length and the fraction of the outbursts which are wide. In the case of SS Aur, wide maxima (which usually appeared every 100 to 300 days) disappeared for over five years. During this time SS Aur had 33 consecutive narrow maxima without a wide maximum. The behavior of U Gem is not as extreme. There were no long strings of outbursts when the wide maxima were not present.

4. Conclusions

The frequency of outbursts of U Gem shows systematic changes. Prior to 1922 the outbursts occurred according to a 98-day average frequency. Since 1922 the average outburst interval has been 124 days. The distribution of outburst duration is bimodal, with 9 and 16 day peaks.

5. Acknowledgements

The vigilance of the observers of U Gem is appreciated. The interesting behavior of these stars is difficult to interpret when the light curves are incomplete. The dedication of observers who struggle to obtain observations when the star is near the sun in the sky is a significant help in defining the behavior of these stars, and their work is especially appreciated.

REFERENCES

Cook, L. M. 1985, **Proceedings of the Ninth North American Workshop on**

Cataclysmic Variables, P. Szkody (Ed.), Univ. of Washington, Seattle p. 35.
_____ 1987, **Publ. Var. Star Section RASNZ** (in press).
Mattei, J. A., Saladyga, M., Waagen, E. O., Jones, C. M. 1987, **AAVSO Monograph 2, U Geminorum Light Curves 1855-1985**, AAVSO, Cambridge, MA.
Szkody, P., and Mattei, J. A. 1984, **Publ. Astron. Soc. Pacific 96**, 988

TABLE I

Observed Outbursts of U Geminorum

Outburst Number	Julian Date	Width	Outburst Number	Julian Date	Width	Outburst Number	Julian Date	Width
1	2398933	?	102	2408829	W	171	2415366	n
6	2399408	?	104	2409101	n	172	2415460	W
8	2399610	W	105	2409200	n	174	2415722	W
13	2399993	n	106	2409305	W	175	2415851	n
14	2400084	W	108	2409472	W	178	2416128	W
16	2400362	n	109	2409543	?	181	2416382	n
18	2400519	W	110	2409634	W	182	2416454	W
22	2400889	W	112	2409806	?	183	2416546	n
24	2401130	W	113	2409882	?	186	2416805	W
26	2401394	W	114	2409966	W	187	2416886	?
27	2401500	n	116	2410237	W	188	2416954	W
28	2401597	W	117	2410325	n	189	2417092	?
30	2401740	?	119	2410533	?	190	2417153	W
31	2401860	n	120	2410635	?	191	2417254	n
33	2402138	n	121	2410740	n	194	2417531	W
34	2402234	W	123	2410940	n	195	2417598	n
35	2402340	n	124	2411023	W	196	2417684	W
38	2402616	W	125	2411142	?	198	2417837	W
39	2402706	n	126	2411265	?	199	2417920	?
40	2402869	?	128	2411378	W	200	2417975	n
42	2403036	?	129	2411445	?	202	2418250	n
44	2403304	W	132	2411737	W	203	2418372	W
46	2403449	W	133	2411864	?	204	2418448	?
48	2403590	n	135	2412032	n	205	2418553	W
50	2403736	W	136	2412116	W	206	2418694	W
53	2403973	n	137	2412185	n	207	2418791	n
54	2404075	W	139	2412349	?	209	2418940	n
55	2404144	n	140	2412440	W	210	2419035	W
56	2404293	W	142	2412575	W	211	2419161	n
57	2404421	n	144	2412798	W	212	2419270	W
58	2404552	W	145	2412899	n	213	2419344	n
62	2404839	W	147	2413163	?	214	2419467	W
64	2405076	W	148	2413254	W	216	2419634	?
66	2405217	?	149	2413354	?	217	2419706	?
68	2405446	W	150	2413489	W	218	2419778	n
69	2405557	?	152	2413629	W	219	2419859	n
72	2405901	W	155	2413890	n	221	2420009	n
80	2406668	W	156	2413984	W	222	2420096	W
83	2406969	n	157	2414079	?	223	2420178	n
84	2407088	W	158	2414152	?	224	2420262	n
86	2407353	W	159	2414249	n	226	2420473	W
89	2407650	?	160	2414323	W	227	2420561	n
90	2407740	W	161	2414412	?	230	2420925	W
91	2407853	n	163	2414609	?	232	2421120	n
92	2407940	W	164	2414704	?	233	2421237	n
93	2408069	?	165	2414773	W	234	2421341	W
94	2408169	W	166	2414925	?	236	2421551	W
98	2408498	W	167	2415017	n	237	2421637	n
99	2408591	?	168	2415106	W	238	2421730	?
101	2408766	n	170	2415297	?	239	2421860	n

TABLE I (cont'd)

Observed Outbursts of U Geminorum

Outburst Number	Julian Date	Width	Outburst Number	Julian Date	Width	Outburst Number	Julian Date	Width
240	2421948	W	311	2429994	n	393	2438888	n
241	2422052	n	314	2430416	W	395	2439108	n
243	2422208	n	316	2430611	?	396	2439212	W
244	2422280	W	318	2430834	W	398	2439376	W
245	2422359	n	319	2430966	n	399	2439467	n
246	2422442	?	321	2431221	W	400	2439580	W
248	2422599	n	323	2431374	?	402	2439769	W
249	2422679	n	324	2431478	W	403	2439893	n
250	2422762	W	325	2431596	n	405	2440166	n
252	2422983	W	328	2431804	W	407	2440376	?
253	2423068	n	329	2431940	n	408	2440493	n
254	2423166	W	330	2432080	W	409	2440576	W
256	2423337	W	331	2432176	n	410	2440657	n
257	2423459	n	332	2432326	W	412	2440854	n
260	2423820	W	333	2432477	?	413	2440980	W
262	2424147	W	334	2432610	W	415	2441243	W
263	2424259	n	336	2432846	?	416	2441401	n
264	2424421	n	338	2433041	n	418	2441594	W
265	2424486	n	340	2433231	W	419	2441787	W
266	2424596	W	342	2433418	n	421	2442031	W
268	2424758	W	344	2433743	n	423	2442347	n
269	2424897	n	346	2433957	W	424	2442447	W
271	2425185	n	347	2434083	n	425	2442565	n
272	2425277	W	350	2434494	W	426	2442708	W
273	2425363	n	351	2434601	n	427	2442837	n
274	2425502	W	352	2434798	n	429	2443055	n
276	2425760	W	355	2435079	n	430	2443170	W
278	2425993	W	356	2435135	n	431	2443295	n
280	2426434	W	360	2435452	W	432	2443435	W
281	2426632	W	361	2435556	n	433	2443563	n
282	2426788	W	363	2435770	n	434	2443673	?
284	2427069	W	364	2435907	W	435	2443796	n
285	2427142	n	367	2436199	n	436	2443956	W
288	2427468	W	369	2436527	n	437	2444142	W
291	2427797	n	370	2436642	W	438	2444238	n
292	2427872	W	372	2436826	?	439	2444366	W
293	2427951	?	373	2436902	n	440	2444522	W
294	2428095	?	374	2437007	W	441	2444637	n
295	2428184	n	375	2437078	?	442	2444708	W
296	2428298	W	376	2437170	?	444	2444856	n
298	2428511	W	377	2437251	n	445	2444944	W
301	2428832	n	380	2437665	W	446	2445043	n
302	2428926	W	381	2437732	n	448	2445280	n
303	2429031	n	382	2437805	n	449	2445393	W
304	2429167	W	383	2437907	n	451	2445606	W
305	2429303	W	385	2438100	W	452	2445713	n
306	2429491	n	388	2438360	W	453	2445849	W
308	2429671	W	389	2438467	n	454	2445952	n
310	2429869	?	392	2438782	W	455	2446057	W

W - Wide outburst (over 13 days duration)
n - Narrow outburst (less than 13 days)
? - Outburst width undetermined

TABLE II

Serial Numbers of Non-Existing Outbursts of U Geminorum

Outburst Number	Notes	Outburst Number	Notes	Outburst Number	Notes
12	o,b	259	g,o	320	n
21	o,b	275	n	337	n
29	o,g	277	n	341	n
49	n	287	g,o	343	n
61	o,b	290	g,o	354	g,o
79	o,b	300	g	359	g
97	o,b	307	n	366	g
127	o,g	317	n	406	n

In Column 2:

g - gap in the data inconsistent with assumed count
n - no gap in data where outburst could have occurred
o - O-C curve discontinuity reduced
b - large gap in data

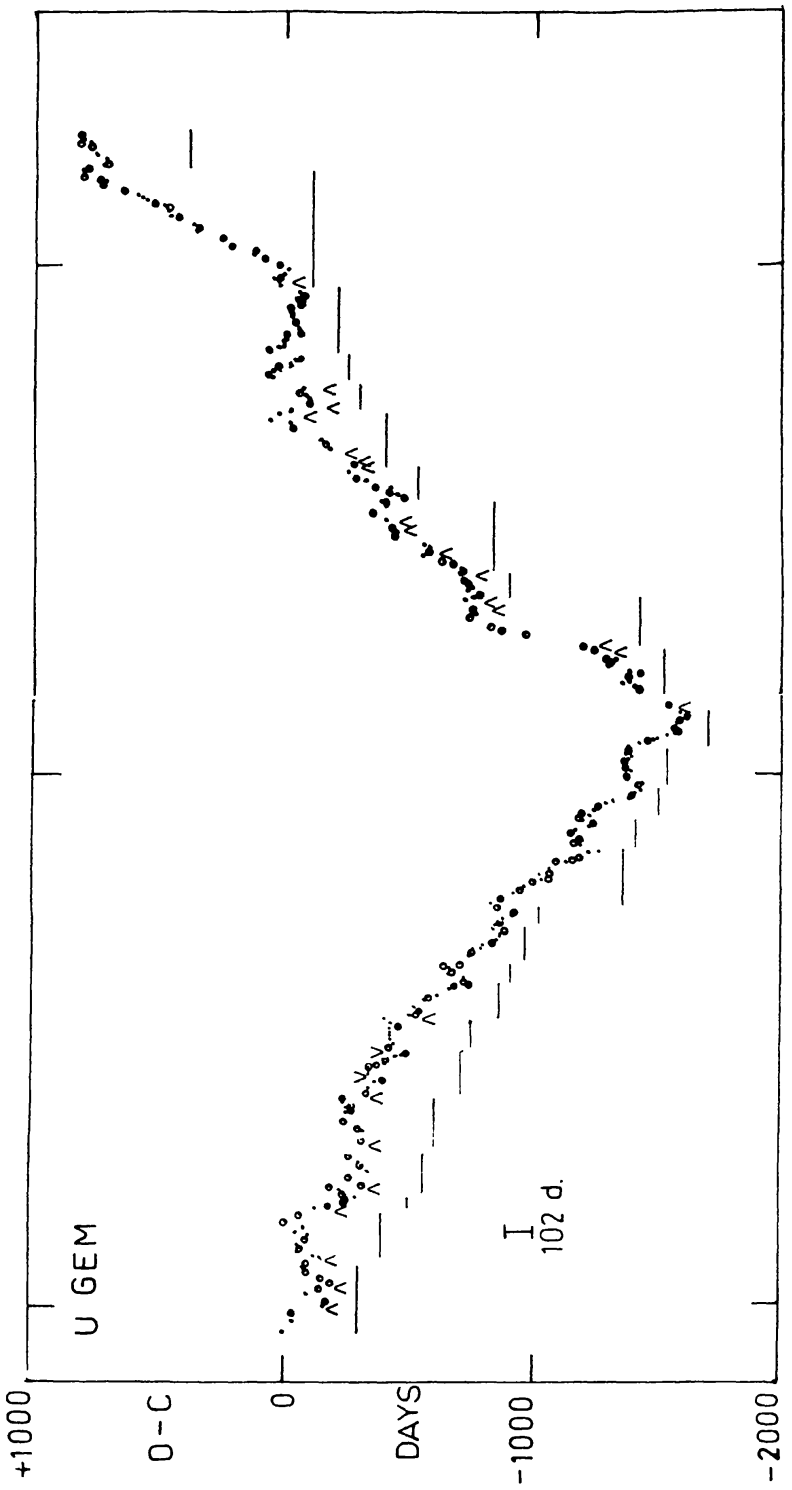

Figure 1. The O-C curve for U Geminorum outbursts. Wide maxima are indicated by a circle; undetermined and narrow maxima are indicated by a dot. Intervals selected for analysis are shown by horizontal bars below the curve. Arrows indicate changes in the outburst count (see text).

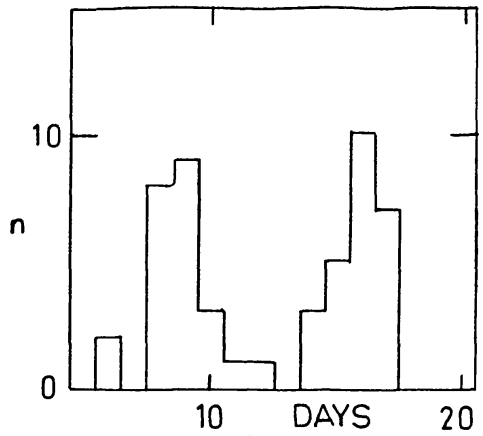

Figure 2. The distribution of outburst duration is seen to be double-peaked at 9 and 16 days.

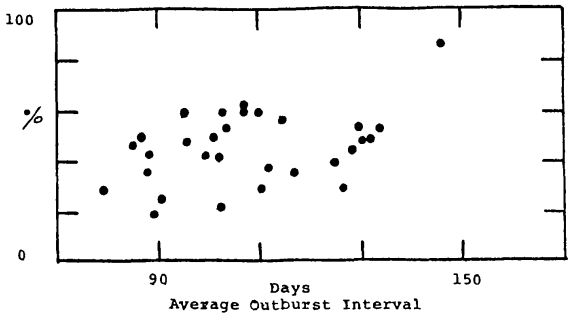

Figure 3. Percent of maxima in selected intervals which are wide outbursts versus the mean cycle length for the interval.

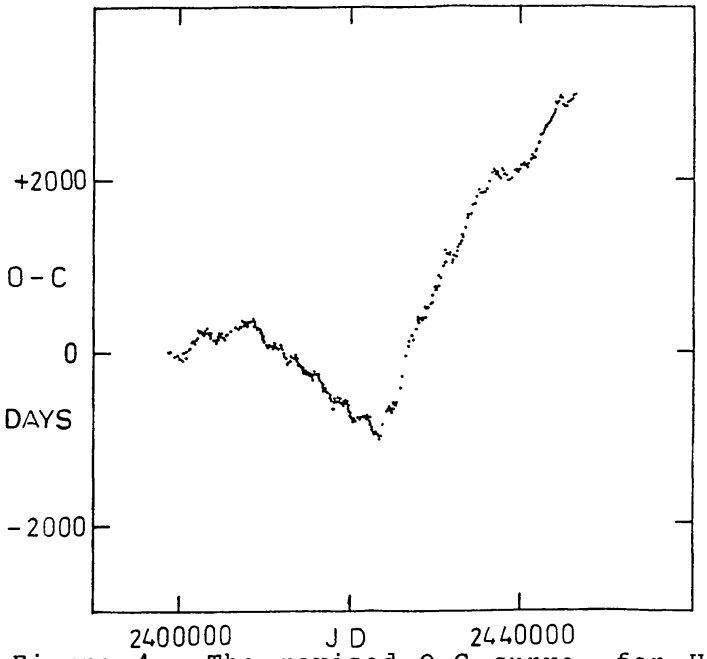

Figure 4. The revised O-C curve for U Geminorum with suspect unobserved maxima deleted.