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PERIODICAL FEATURES IN THE Lc VARIABLE STAR BU GEMINORUM DURING THE YEARS 1972-1977

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ABSTRACT. PERIODICAL FEATURES IN THE Lc VARIABLE STAR BU GEMINORUM DURING THE YEARS 1972 - 1977.

The results of the observations of BU Gem, made by the GEOS observers during the years 1972 to 1977 are presented.

Starting from the total of 1034 visual magnitude estimates a mean light curve has been calculated via a computerized method. From the curves obtained, we put in evidence a weak semi-regular variability of the star, with a period of about 240 days and a more marked irregular fluctuation with a time-scale of a thousand days.

There is no evidence of any eclipses caused by suggested duplicity of the star, the red supergiant being the main responsible for the light variations.

On the basis of the photometric behaviour, a classification as an Lc is suggested for BU Gem.

RESUME. PERIODICITES PRESENTEES PAR L'ETOILE VARIABLE DE TYPE Lc BU GEMINORUM AU COURS DES ANNEES 1972 - 77.

Cette étude donne les résultats des observations de BU Gem effectuées par les observateurs du GEOS pendant les années 1972 à 1977.

A partir d'un total de 1034 estimations visuelles d'éclat, on a calculé une courbe de lumière moyenne grâce à un traitement sur ordinateur. A l'aide des courbes obtenues on a mis en évidence une variabilité semi-régulière peu marquée de l'étoile sur une période de l'ordre de 240 jours et une fluctuation irrégulière plus nette sur une échelle de temps d'un millier de jours.

Il ne semble pas y avoir eu d'éclipses causées par la binarité (suggérée) de l'étoile, la supergéante rouge étant la principale responsable des variations d'éclat.

Sur la base de son comportement photométrique on propose de cataloguer BU Gem comme Lc.

RIASSUNTO. INDIZI DI PERIODICITA' NELLA VARIABILE Lc BU GEMINORUM FRA IL 1972 E 1977.

Sono presentati i risultati delle osservazioni di BU Gem, fatti dagli osservatori GEOS fra il 1972 e il 1977.

Dalle curve di luce medie, ottenute per via computerizzata da 1034 stime di magnitudine visuali, si è messa in evidenza una debole variabilità semiregolare della stella, su tempi scala di 240 giorni e una più marcata fluttuazione su scala di un migliaio di giorni.

Non c'è evidenza di eclissi a seguito della possibile duplicità della stella, essendo la supergigante rossa la principale responsabile delle variazioni di luce.

Sulla base del comportamento fotometrico si suggerisce per BU Gem una classificazione tipo Lc.

RESUMEN. PERIODICIDADES PRESENTADAS POR LA ESTRELLA BU GEMINORUM DURANTE LOS AÑOS 1972 - 77.

En este trabajo, se discuten los resultados de las observaciones de BU Gem, efectuadas por los observadores del GEOS durante los años 1972 a 1977.

A partir de un total de 1034 estimaciones visuales de brillo, se ha calculado una curva de luz media gracias a un tratamiento por ordenador.

Con la ayuda de las curvas obtenidas, se ha puesto en evidencia una variabilidad semi-regular poco marcada de la estrella, sobre un periodo del orden de 240 días, y una fluctuación irregular más neta sobre una escala de tiempo de 1000 días.

No parece haber eclipses causados por la duplicidad (sugerida) de la estrella, siendo la supergigante roja la principal responsable de las variaciones de brillo.

Sobre la base del comportamiento fotométrico, se propone clasificar BU Gem como una Lc.

INTRODUCTION

BU Gem (6 Gem,HR 2197,HD 42543,BD+22'1220) is a 6th-magnitude star, catalogued in the 3rd edition of the GCVS (1969) as an Lc?-type variable star, ranging from 6.1 to 7.5v. The references quoted therein are Parenago (1937) and O.I.Čudovičeva (1953). Both authors had observed BU Gem photographically over several thousands of days (from J.D. 24 14691 to 19447 and from J.D. 24 28545 to 33712 respectively). Their light curves do not show a clear trend of variation. This fact is due mainly to the bad precision of observation. Even if no one of them gives an estimation of the error of measurement, we can suppose, from the direct inspection of the light curves, that their mean error (on a single measure) turns out to be of the order of ±0.3 mag., so that only details of great amplitude can be investigated.

In a more general way, from their curves mainly shows a long-term fluctuation, perhaps with a time-scale of 1000 days (or more) and an amplitude of about 1 mag. but with quiescent phases several years long during which the amplitude of the variation (if any) could be weak, of the order of the error of observation. During these intervals, the star seems to be at the minimum of its range of variation.

The GCVS Supplement (1974) gives 5.74-7.5 V, as a new and more accurate range of light variation, while some other elements reported are the spectrum (M1 Ia) and the color index B-V (variable from 1.63 to 2.24).

A possible duplicity of the star could be inferred from Čudovičeva. The star could be a VV Cep-type system with a period of about 32 years, but no other references or details are given in this regard. The Catalogue of Radial Velocities (1972), gives two determinations of the mean radial velocity Vr of the star: +22.0 Km/s from 4 measures in 1923 and +22.2 Km/s from 4 measures in 1970. Both values (as well as the low galactic latitude: b=+2°) seem typical of a population I star. The scatter in the single measures of Vr has been found to be of the order of ±3 Km/s.

Tab. 1 - List of the GEOS observers.

Name	Place		Instr.	tot.N	1972/73	1973/74	1974/75	1975/76	1976/77
A.Figer	Paris	(F)	B 8x40	151	73	36	27	15	--
J.F.Le Borgne	Toulouse	(F)	B 7x30	112	--	--	20	--	--
			B 8x50		--	--	--	29	63
E.Poretti	Arconate	(I)	B 12x50	97	--	--	--	97	--
Ph.Ralincourt	Nantes	(F)	B 7x50	96	--	12	60	24	--
P.Baruffetti	Massa	(I)	B 7x50	93	--	--	--	87	6
J.Vialle	La Rochelle	(F)	B 7x50	93	--	17	37	31	8
R.Boninsegna	Marcinelle	(B)	B 10x30	82	--	--	--	52	30
J.C.Misson	Paris	(F)	B 7x50	56	--	--	--	43	13
G.Troispoux	Fleury-les-Aubrais	(F)	B 10x50	44	--	--	--	44	--
J.P.Clovin	Marcinelle	(B)	B 7x30	39	--	--	--	39	--
J.Remis	Aix-en-Prov.	(F)	B 10x50	38	--	--	--	28	10
P.Guiraudou	Montgeron	(F)	B 10x50	34	--	--	--	31	3
A.Buzzoni	Ferrara	(I)	R 30x40	32	--	--	7	9	16
M.Franchini	Cerro Magg.	(I)	B 20x70	25	--	--	--	--	25
G.Pacifico	Massa	(I)	B 7x50	15	--	--	10	5	--
C.Agnesoni	Siena	(I)	B 10x30	14	--	--	--	--	14
J.Squelard	Somzée	(B)	B 10x80	13	--	--	--	--	13
				1034	73	65	161	534	201

THE GEOS OBSERVATIONS

BU Gem has been patroled by the GEOS observers during the years 1972-1977. Some other red variable stars, like OP Her (Figer and Remis,1978), AT Dra (Maurin,1979), U Del (Ralincourt,1980), EU Del (Ralincourt,1981), W Boo (Buzzoni and Lucentini,1981), WY Gem (Buzzoni,1981), V449 Cyg (Dumont 1983), ρ Per (Boistel,1983), RR Ari (Buzzoni, 1983), were included in the same campaign of observation, whose purpose was to detect some possible periodicities in the light curve of these stars, with periods of several months. A total of 1034 visual magnitude estimates of BU Gem have been collected: their partition among the observers and some other remarks (observation places and instruments) are reported in Tab.1. All the measures have been made according to the Argelander method, taking the stars listed in Tab.2 as a comparison sequence.

The processing of the measures has been made with the CDC CYBER 70/76 computer, at CINECA (Bologna, Italy), using the ALCEP programme. This method of processing has been widely and succesfully used in many other studies by GEOS; it allows the user to obtain the mean light curve, calculated from the series of measures of each observer, by an iterative algorithm. It is also possible to estimate, in the same way, the error bar of the normal points and of the mean measure of each observer. For further information on the method, the reader is referred to Figer and Remis (1978) or Buzzoni (1981).

Because the algorithm requires at least two observers and a set of measures well distributed over the whole period of observation, isolated sets of measures as well as observations made by only one observer (this is the case for the curve in 1972-73, from Figer's observations only) have been considered separately. No statistical determination of their random error is possible (see for example Buzzoni,1981), but we can give the value of ± 0.05 mag. as a rough (but sufficient) estimation of the error bar for these normal points.

This upper limit can be easily calculated, for example from Fig.1 and Tab.1 and 7 (see next Section). Setting N=4 for the isolated normal points and $\langle \sigma \rangle_{m.o.} \lesssim 0.1$ mag., we derive $\langle \sigma \rangle_{n.p.} \lesssim 0.1/\sqrt{4} = 0.05$ mag.

Tab. 2 - Visual sequence of comparison.

Star	BD	HD	Spectrum	Mv
C	+22°1198	42049	K2	6.0
D	+23°1232	42216	B9	6.7
E	+22°1180	41710	G5	7.3
BU	+22°1220	42543	M1-M2 Ia-Iab	var.

RESULTS

The light curves, obtained after the third iteration, are reported, for each season of observation, in the series of Fig.1 to 5. The ALCEP normal points are marked there by squares, while open dots represent isolated measures. All the magnitudes relative to the points up to years 1973-74 are also listed in Tab.3 to 6. In Tab 7. we have calculated the mean error bar in magnitude of the ALCEP points for each curve and the random error of the single estimation of the mean observer. It can be seen, from the values of the mean error bar (reported also top right in each figure), that light curve variations must be considered as real. The error in the sense of time, shown in the figures, refers to the step of integration of the automatic routine. These steps are constant in each curve and their values are 11 days in 1973-74 and 7 days for all the other curves. Of course, it is assumed that no important variations are present inside the integration range; it is easy to see that this requirement is always satisfied.

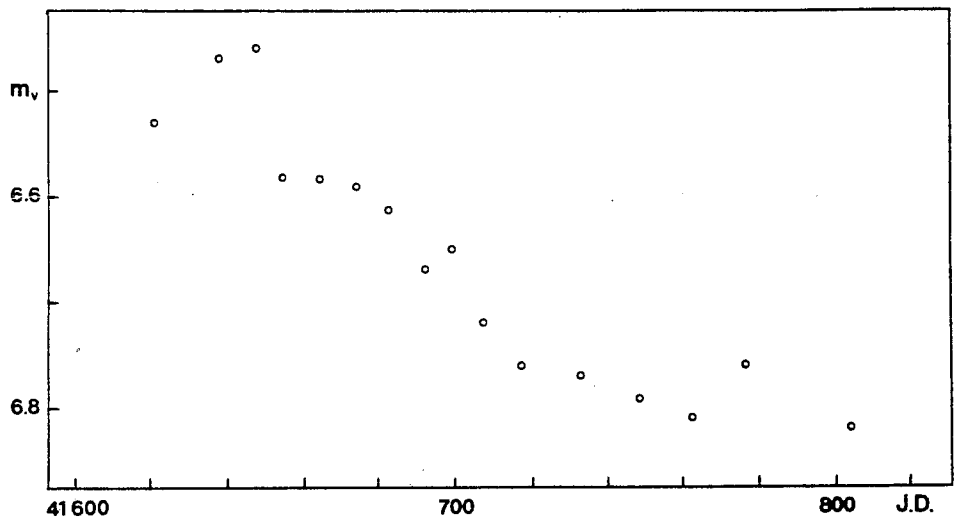

Fig.1 - Light curve of BU Gem in 1972-73 (Figer's measures only).

DISCUSSION

BU Gem being a red supergiant star, the most likely variation to be expected are those of long term periods due to radial pulsations and/or irregular 'eclipses' by ejected clouds of matter. Micro-fluctuations of the light curve cannot be excluded, of course, but no valuable conclusions can be drawn from the series of visual estimates, so that we want to focus here our attention on the slow fluctuation only.

Tab. 3 - 1973-74

J.D. 2441000.+	±d	N	Mv
955.3	0.0	1	6.78
964.3	3.0	6	6.61
987.3	4.0	2	6.52
1004.3	3.0	7	6.57
1016.3	4.0	2	6.53
1039.3	11.0	3	6.57
1058.3	5.5	5	6.55
1069.3	5.5	4	6.48
1080.3	5.5	2	6.57
1091.3	5.5	7	6.54
1102.3	5.5	4	6.57
1113.3	5.5	3	6.58
1124.3	5.5	1	6.80
1135.3	5.5	5	6.64
1146.3	5.5	13	6.95
1157.3	5.5	1	6.95

Tab. 4 - 1974-75

J.D. 2442000.+	±d	N	Mv
312.3	0.0	2	6.80
378.3	1.0	2	6.56
394.3	3.5	5	6.57
401.3	3.5	11	6.60
408.3	3.5	10	6.56
415.3	3.5	9	6.57
422.3	3.5	6	6.56
429.3	3.5	8	6.64
436.3	3.5	2	6.62
443.3	3.5	5	6.60
450.3	3.5	20	6.64
457.3	3.5	6	6.64
464.3	3.5	7	6.66
471.3	3.5	17	6.61
478.3	3.5	7	6.66
485.3	3.5	3	6.73
492.3	3.5	6	6.65
499.3	3.5	2	6.70
506.3	3.5	1	6.72
513.3	3.5	5	6.67
520.3	3.5	5	6.65
527.3	3.5	7	6.63
534.3	3.5	15	6.64

Tab. 3 to 6 - List of the normal v points of BU Gem from 1973 to 1977.

Tab. 5 - 1975-76

J.D. 2442000.+	±d	N	Mv
712.3	0.0	1	6.49
740.3	3.5	5	6.54
747.3	3.5	7	6.54
754.3	3.5	8	6.55
761.3	3.5	12	6.56
768.3	3.5	7	6.55
775.3	3.5	10	6.50
782.3	3.5	20	6.51
789.3	3.5	12	6.48
796.3	3.5	12	6.49
803.3	3.5	34	6.50
810.3	3.5	33	6.48
817.3	3.5	11	6.53
824.3	3.5	16	6.45
831.3	3.5	28	6.49
838.3	3.5	76	6.47
845.3	3.5	38	6.44
852.3	3.5	14	6.46
859.3	3.5	19	6.44
866.3	3.5	52	6.47
873.3	3.5	36	6.46
880.3	3.5	19	6.46
887.3	3.5	23	6.49
894.3	3.5	20	6.49
901.3	3.5	21	6.51

Tab. 6 - 1976-77

J.D. 2443000.+	±d	N	Mv
103.8	7.0	18	6.43
117.8	7.0	9	6.40
128.3	3.5	30	6.47
135.3	3.5	20	6.51
142.3	3.5	24	6.48
149.3	3.5	4	6.49
156.3	3.5	8	6.49
163.3	3.5	19	6.56
170.3	3.5	5	6.53
177.3	3.5	10	6.52
184.3	3.5	10	6.57
191.3	3.5	15	6.57
198.3	3.5	16	6.56
205.3	3.5	7	6.51
212.3	3.5	2	6.55
216.3	0.0	2	6.57
245.3	0.0	2	6.65

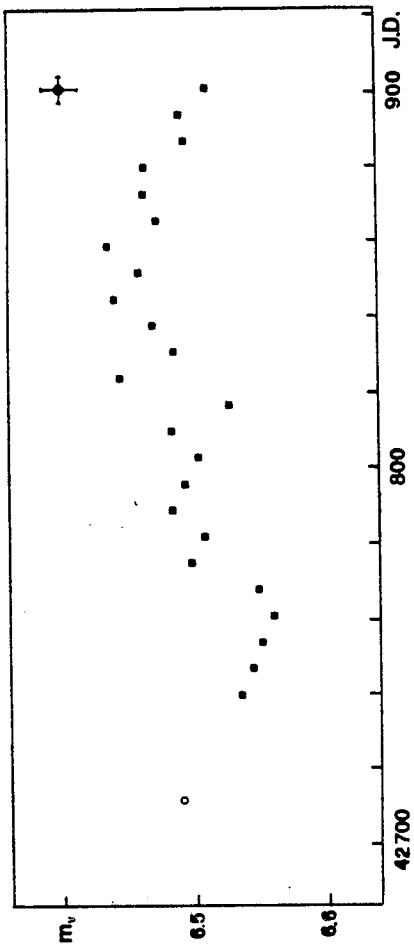

Fig.4

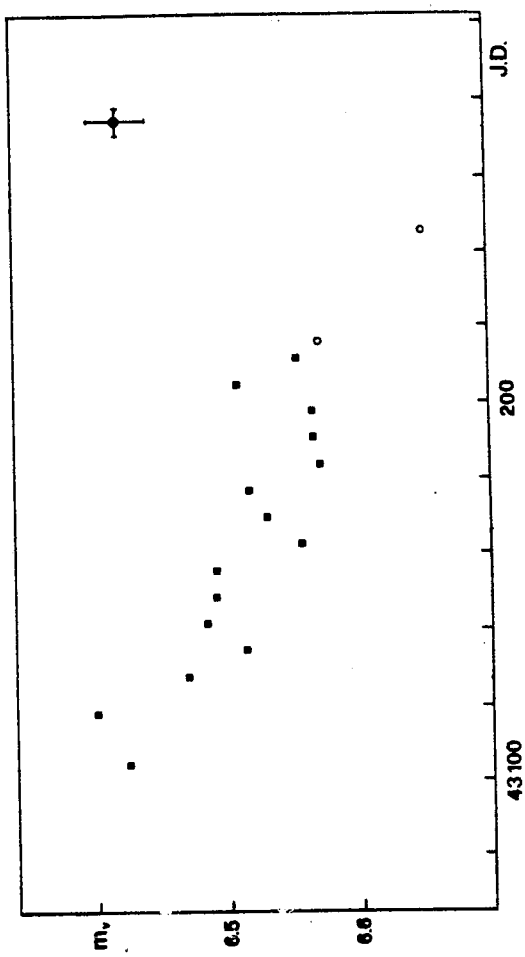

Fig.5

Fig.2 to 5 - Mean light curves of BU Gem from 1973 to 1977 (top right in each figure the mean error bar of the normal points).

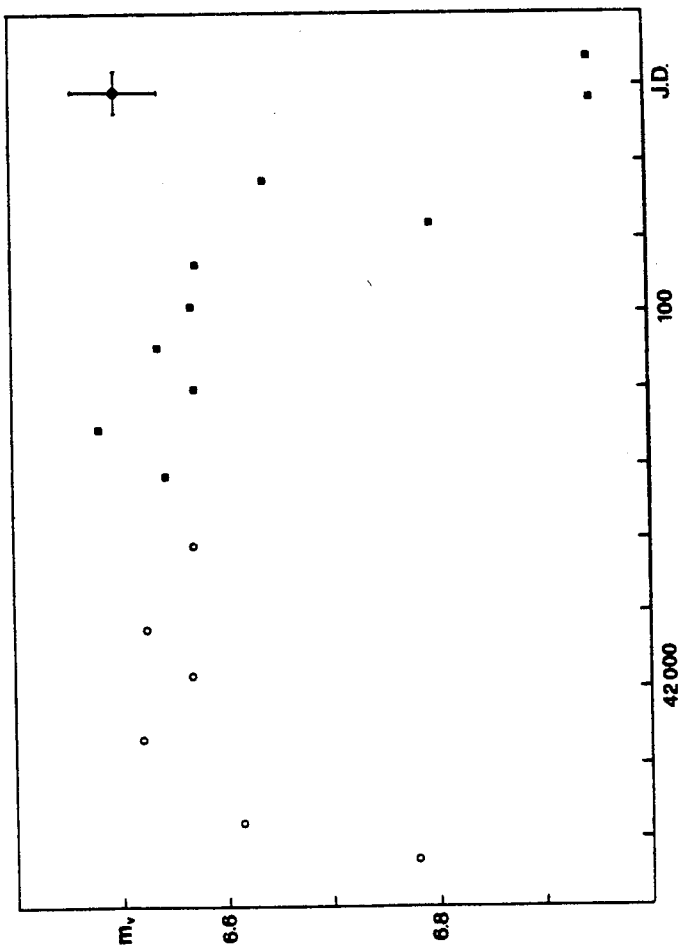

Fig.2

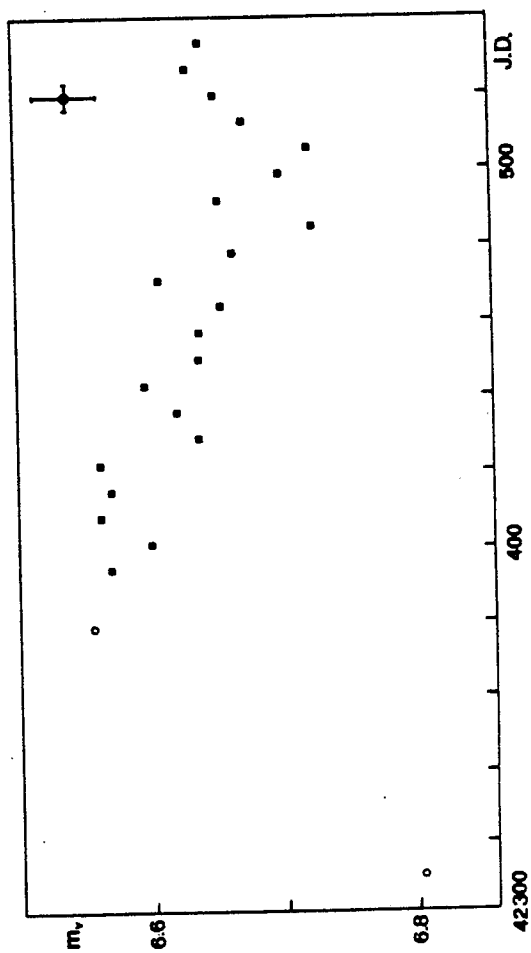

Fig.3

The distribution of the observations over the whole period leads us to carry out our analysis in two different ways: i) a search of semi-periodical variations, with period or pseudoperiods of less than one year; ii) a search of very slow fluctuations, with a time-scale of several years.

As regards point i), a glance at the light curves shows that an activity of the star over a period of few months does exist. Although the amplitude of the light variation is weak, about 0.2 magnitudes, nevertheless it seems that an almost sinusoidal fluctuation is often present in the curves, the only exception being the one in 1973-74 (Fig.2), where there is a deep negative burst at the end of the period of observation, at about J.D. 24 42150. It is worth noting that all these variations seem to be periodical and in reasonable agreement between each other, with a period of about 240 days. It is even possible to calculate an ephemeris by least squares, including in the calculation, for more accuracy, all the well observed extrema listed in Tab.8 and assuming a phase of 0.6 for the minimum.
We obtain:

$$\text{Maximum light} \quad \text{J.D. } 24\ 41641 \underset{\pm 11}{} + 241.E \underset{\pm 5}{} \qquad (1)$$

(the error bars refer to a confidence level $1-\alpha = 0.95$).

This ephemeris has to be taken as a mere estimation of the time-scale of the light variation, the non-formal error bars being probably much greater than those calculated in (1).

Tab. 7 - Mean error bars.

Years	$\langle\sigma\rangle_{n.p.}$	$\langle\sigma\rangle_{m.o.}$
1973-74	±0.041	±0.087
1974-75	±0.024	±0.066
1975-76	±0.013	±0.062
1976-77	±0.021	±0.074

$\langle\sigma\rangle_{n.p.}$ = mean error bar of the normal points.
$\langle\sigma\rangle_{m.o.}$ = error bar of one estimate by the mean observer

Tab. 8 - O-C values from (1) for the well observed extrema of BU Gem.

J.D. 2400000.+	Type	E	O-C^d(1)
41640.	Max	0.	-1
41790.	Min	0.6	+4
42500.	Min	3.6	-10
42750.	Min	4.6	-1
42855.	Max	5.	+7

Nevertheless, from an inspection of Fig.1 to 5 and Tab.8, one can see that the ephemeris is quite well respected inside the period of observation by all the curves, excluding the one in 1973-74. We can also draw some other interesting observations about the slow variation of BU Gem by merging all the curves into a unique figure (Fig.6), which shows the general trend of the light curve over the whole period of observation (about 1700 days).

As can be seen from the figure, the long-term irregular fluctuation is present and it seems to be the same as the one that appears in Čudovičeva's light curve. The amplitude of the GEOS curve turns to be about 0.5 magnitudes, from 6.5 to 7.0 in visual magnitude, with a time-scale of variation of thousands of days. It is very probable, in our opinion, that the mean magnitude of the 'unperturbed' star is about 6.5, so that the apparent maximum at J.D. 24 42000-42100

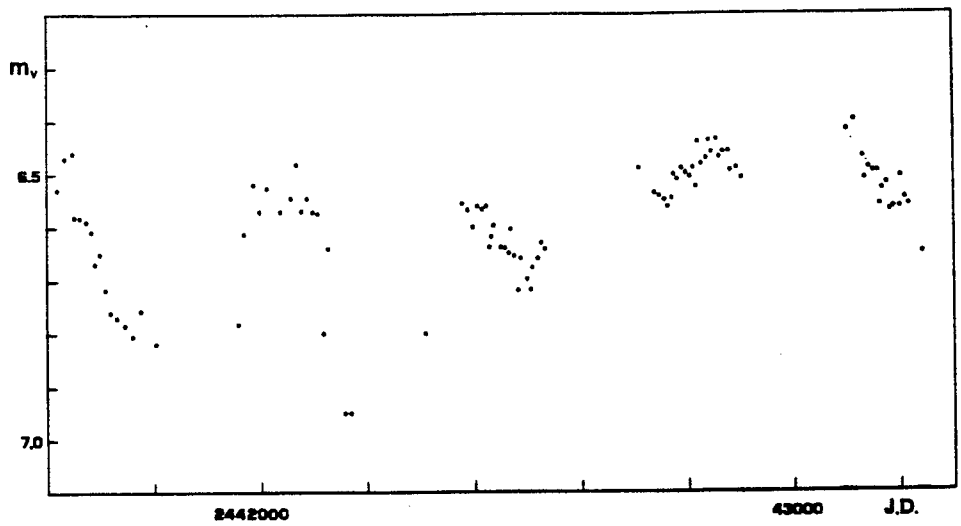

Fig.6 - Synthetic light curve of BU Gem from 1972 to 1977.

should not be considered as a positive burst but as a return to normal between two consecutive minima at J.D. 24 41800 and 42200 (contrary to Čudovičeva's curve, where the star was at minimum in the quiescent phase).
From Fig.6 again, there is no evidence of any eclipses related to the (possible) duplicity of the star.

CONCLUSIONS

To sum it up we can draw the following conclusions:
i) BU Gem shows a complex activity, with a weak variability on a time-scale of 240 days and a more evident irregular fluctuation of the order of thousands of days.
ii) This evidence leads us to consider BU Gem as an Lc variable.
iii) From the observed curves, we cannot infer anything about the duplicity of the star, but it seems clear that the star has not undergone eclipses, at least during the five years of observation.
iv) Even in the case of a binary VV Cep-system, it is almost certain that the star, which is the main (and perhaps unique) responsible for the light variations, is the red one (Bartolini et al.,1982).

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