New Results from Long-time Photometric Study of UX Orionis Star GM Cephei

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Abstract. New results from long-term optical photometric observations of the pre-main sequence star GM Cep from UX Orionis type are reported. During ongoing photometric monitoring of the GM Cep, four deep minimums in brightness are observed. The collected multicolour photometric data shows the typical for UXor variables colour reversal during the minimums in brightness. Recent $BVRI$ photometric observations of GM Cep have been collected from November 2014 to October 2020.
Key words: stars, stellar evolution, UX Orionis stars

1. Introduction

The pre-main sequence star (PMS) GM Cep is situated in the field of the young open cluster Trumpler 37 ($\sim$4 Myr old and at a distance of 870 pc, Contreras et al. [2002]). It is likely to be a member of the cluster (Marschall and van Altena [1987], Sicilia-Aguilar et al. [2005]).

According to the study of Sicilia-Aguilar et al. [2008] GM Cep has a solar-like mass ($M \sim 2.1 M_{\odot}$), with radius that ranges between 3 and 6 $R_{\odot}$. It is of G7V-K0V spectral type and with a strong IR excesses that can be explained by the presence of a very luminous and massive circumstellar disk. In the study, the Hα emission line in the spectrum of GM Cep was observed to have a strong P Cyg profile. It is also observed that the equivalent width of the line varies significantly from 6$\mathring{A}$ to 19$\mathring{A}$ and that the variable accretion rate is up to $\sim 10^{-6}$ $M_{\odot}$/year.

A long-term photometric study of GM Cep was made by Xiao et al. [2010] in the period of several decades. The long-term B and V light curves of the star are constructed by using the photographic plate archives from Harvard College Observatory and from Sonneberg Observatory. The results suggest that the light curves of GM Cep seem to be dominated by dips superposed on the quiescent state, and that there is a lack of fast rises in brightness typical for the EXor variables. In their study, Xiao et al. [2010] have not found evidence for periodicity of observed dips in brightness.

The results from the $BVRI$ photometric observations of GM Cep, collected in the period 2008 June - 2014 August and reported in our previous studies (Semkov and Peneva [2012] and Semkov et al. [2015]) show very strong photometric variability of the star. In this period we have registered five deep minimums in brightness in the light curve of GM Cep. On the basis of these observations, we concluded at the time that the variability of GM Cep is dominated by fading events rather than by bursting events. The collected multicolour photometric data shows the effect of a colour reversal at the deep minimum of brightness, which is evidence of variable extinction from the circumstellar environment, typical for UXor variables.

In the study of Chen et al. [2012], while carrying out an intensive BVR photometric monitoring of GM Cep during the period 2009-2011, they confirm the UXor nature of its variability and suggest an early stage of planetesimal formation in the star environment. A periodicity of about 300 days of the observed deep declines in brightness is suggested by Chen and Hu [2014].

The multicolour observations give us the opportunity to clarify the mechanism of the brightness variations.

2. Observations

The CCD observations of GM Cep cover the period from June 2008 to October 2020. They were performed in two observatories with four telescopes: Rozhen National Astronomical Observatory (Bulgaria) with its 2-metre RCC, 50/70-cm Schmidt and 60-cm Cassegrain telescopes, along with Skinakas Observatory of the University of Crete (Greece) with the 1.3-m Ritchey-Crétien telescope. Five different types of CCD cameras were used during the observations. Their technical characteristics and optical specifications are given in Table 1.

We used the published in the work of Semkov and Peneva [2012] fifteen stars in the field around GM Cep for reference. A standard set of Johnson-Cousins' filters were used for all the frames that were taken. Twilight flat fields in each filter were obtained each clear evening. All frames obtained with the ANDOR and Vers Array cameras are bias subtracted and flat fielded. CCD frames obtained with the FLI PL16803 and FLI PL09000 cameras are dark subtracted and flat fielded. Using IDL DAOPHOT routines, an aperture photometry was performed. In order to obtain comparable results with our previous obserations we used the same aperture to analyse all the data. It was chosen as 6 arcsec in radius, while the background annulus was from 10 to 15 arcsec.

Table 1. CCD cameras and optical specifications

Telescope	CCD Camera Type	Size	Field	Pixel size	Scale	RON	Gain
		(px)	(arcmin)	(μm)	("/px)	(e^-rms)	(e^-/ADU)
2m RCC	Vers Array 1300B	1340x1300	5.8x5.6	20.0	0.26	2.00	1.0
2m RCC	ANDOR iKon-L	2048x2048	6.0x6.0	13.5	0.17	6.90	1.1
Schmidt	FLI PL16803	4096x4096	73.8x73.8	9.0	1.08	9.00	1.0
60cm Cass	FLI PL9000	3056x3056	16.8x16.8	12.0	0.33	8.50	1.0
1.3m RC	ANDOR DZ436-BV	2048x2048	9.6x9.6	13.5	0.28	8.14	2.7

3. Results

In the current paper, the data from the multicolour photometric observations of GM Cep is presented for the period from August 2014 to October 2020. They are a continuation of the observations that were begun by us in June

2008. Previous data is published in the work of Semkov and Peneva [2012] for the period June 2008 - February 2011 and in the work of Semkov et al. [2015] for the period April 2011 - August 2014.

The new data in the period from November 2014 to October 2020 is shown in Table 2. The columns provide the Julian date (JD) of observation, $BVRI$ magnitudes, and the telescope used. In the column Telescope, the abbreviation 2-m denotes the 2-m Ritchey-Chrétien-Coudé, Schmidt - the 50/70-cm Schmidt and the 1.3-m Ritchey-Crétien telescope. The values of the instrumental errors are in the range $0.^m01$-$0.^m05$ (for B), $0.^m01$-$0.^m03$ (for V) and $0.^m01$-$0.^m02$ (for R and I) (Semkov and Peneva [2012]).

As presented by the graphics in Figure 1, the new photometric data shows continued strong brightness variability of GM Cep. The same brightness variability was also registered in the previous studies of Sicilia-Aguilar et al. [2008], Xiao et al. [2010], Semkov and Peneva [2012], Chen et al. [2012], Semkov et al. [2015], Huang et al. [2019].

On the time scale of days and months outside the deep minimums, GM Cep also shows significant brightness variations. The summarized results of over 12 years period of observations show very strong photometric variability. We have registered four new deep minimums in brightness in the light curve of GM Cep: August 2015, January 2017, November 2017, August 2020.

In Figure 2 are shown, respectively, colour-magnitude diagrams $V/B-V$, $V/V-R$ and $V/V-I$. The collected multicolour photometric data shows the typical for UXor colour reversal during the minimums in brightness. This coincides with the model of blurring of the dust-like material. The observed reversal of the colour is caused by the diffused light from small dust grains. This is a typical characteristic of PMS stars from the Uxor type. From visual inspection, for each of the colour diagrams such point of reversal is observed at different star brightness: in the $V/B-V$ diagram, the point of reversal is observed at V about 14.0 mag, in the $V/V-R$ diagram at V about 14.5 mag and in the $V/V-I$ diagram at V about 14.6 mag.

Usually, when there are clusters of dust in the line of sight, the star becomes redder. But during a maximum eclipse the blue part of the diffused light in the observed light becomes significant and the star colour becomes bluer.

4. Conclusion

In the time scale of days and months outside the deep minimums, GM Cep shows significant brightness variations.

The last data confirms again the presence of an "blueing effect" during the minimum of brightness and this is an independent evidence that the variability of GM Cep is dominated by the variable extinction. The collected multicolour photometric data shows the typical of UXor variables colour reversal during the minimums in brightness.

We can confirm our conclusions, made in our previous paper (Semkov et al. [2015]), that the photometric properties of GM Cep can be explained by a superposition of highly variable accretion from the circumstellar disk onto the stellar surfice and occultation from circumstellar clumps of dust, planetesimals or from other features of the circumstellar disk.

Table 2. $BVRI$ photometric observations of GM Cep

JD (24...)	B	V	R	I	Tel	JD (24...)	B	V	R	I	Tel
56988.217	14.51	13.26	12.48	11.57	Sch	57969.371	14.46	13.17	12.39	11.55	Sch
57005.259	-	13.15	12.33	11.45	Sch	58011.342	14.81	13.51	12.65	11.71	Sch
57006.315	14.34	13.14	12.32	11.45	Sch	58012.352	14.93	13.58	12.72	11.74	Sch
57016.251	14.41	13.16	12.29	11.49	2-m	58013.348	14.88	13.55	12.69	11.75	Sch
57017.202	14.40	13.10	12.28	11.51	2-m	58039.325	-	-	12.51	11.61	Sch
57074.579	14.60	13.32	12.52	11.59	Sch	58043.304	14.59	13.27	12.48	11.62	Sch
57136.511	14.71	13.41	12.60	11.66	Sch	58080.294	16.27	14.81	13.83	12.66	Sch
57138.450	14.54	13.27	12.47	11.56	Sch	58081.311	16.39	14.95	13.98	12.85	Sch
57162.406	14.47	13.23	12.42	11.52	Sch	58109.346	15.61	14.18	13.29	12.20	Sch
57164.479	14.58	13.31	12.47	11.59	Sch	58113.284	15.50	14.08	13.16	12.09	Sch
57167.433	14.52	13.21	12.41	11.57	2-m	58114.287	15.63	14.18	13.27	12.18	Sch
57186.480	14.66	13.40	12.55	11.64	Sch	58217.551	15.08	13.79	12.96	11.97	Sch
57187.498	14.68	13.39	12.54	11.66	2-m	58218.535	15.09	13.79	12.95	11.95	Sch
57190.410	14.48	13.16	12.37	11.53	2-m	58220.493	15.00	13.71	12.89	11.91	Sch
57220.402	14.30	13.02	12.21	11.40	Sch	58278.436	15.19	13.84	12.94	11.91	Sch
57221.459	14.22	13.05	12.25	11.44	Sch	58312.365	15.27	13.90	13.02	12.00	Sch
57223.437	14.37	13.08	12.29	11.50	2-m	58316.323	15.09	13.74	12.85	11.85	Sch
57246.395	14.83	13.48	12.62	11.74	1.3-m	58340.393	14.62	13.33	12.51	11.61	Sch
57247.411	14.71	13.37	12.52	11.66	1.3-m	58342.379	14.58	13.28	12.46	11.58	Sch
57259.363	15.86	14.67	13.71	12.59	Sch	58343.391	14.58	13.29	12.47	11.59	Sch
57260.404	15.93	14.65	13.81	12.81	Sch	58344.388	14.55	13.26	12.45	11.57	Sch
57269.401	15.45	14.03	13.05	11.94	Sch	58346.344	14.62	13.36	12.53	11.64	2-m
57271.468	15.04	13.57	12.63	11.71	2-m	58363.360	14.94	13.60	12.74	11.82	Sch
57330.255	15.20	13.87	12.93	11.89	Sch	58364.323	14.83	13.50	12.66	11.73	Sch
57331.274	15.26	13.93	13.00	11.97	Sch	58365.533	14.90	13.56	12.69	11.80	2-m
57332.264	15.34	14.00	13.08	12.05	Sch	58409.220	14.60	13.29	12.49	11.64	Sch
57333.265	15.39	14.04	13.12	12.08	Sch	58428.174	15.34	13.90	12.97	11.95	Sch
57334.244	15.41	14.08	13.18	12.11	Sch	58435.295	15.49	14.04	13.09	12.04	Sch
57369.257	14.63	13.29	12.47	11.61	2-m	58492.225	15.16	13.75	12.84	11.84	Sch
57370.229	14.62	13.23	12.45	11.59	2-m	58496.201	15.24	13.87	12.94	11.92	Sch
57371.224	14.59	13.27	12.44	11.61	2-m	58547.625	14.68	13.36	12.54	11.65	Sch
57372.241	14.63	13.34	12.47	11.58	Sch	58603.481	15.14	13.74	12.83	11.84	Sch
57374.299	14.73	13.42	12.51	11.58	Sch	58604.532	15.07	13.68	12.77	11.79	Sch
57425.221	15.18	13.82	12.94	11.94	Sch	58665.455	14.25	12.98	12.22	11.41	Sch
57426.226	15.22	13.88	12.97	11.99	Sch	58666.459	14.38	13.10	12.31	11.47	Sch
57483.462	14.47	13.19	12.39	11.52	2-m	58667.494	14.40	13.12	12.33	11.49	Sch
57484.480	14.44	13.20	12.38	11.52	2-m	58690.370	14.38	13.08	12.31	11.50	2-m
57522.460	14.69	13.39	12.58	11.63	Sch	58691.450	14.39	13.06	12.31	11.51	2-m
57523.448	14.70	13.39	12.57	11.63	Sch	58692.389	14.44	13.06	12.31	11.54	2-m
57540.447	14.89	13.43	12.55	11.65	2-m	58704.371	14.72	13.40	12.56	11.66	Sch
57565.485	14.92	13.56	12.69	11.67	Sch	58705.404	14.60	13.29	12.46	11.60	Sch
57581.424	14.75	13.41	12.58	11.64	Sch	58706.402	14.53	13.23	12.41	11.55	Sch
57582.459	14.67	13.38	12.56	11.62	Sch	58707.476	14.53	13.21	12.40	11.54	Sch
57583.434	14.74	13.41	12.57	11.63	Sch	58726.384	14.44	13.14	12.44	11.55	2-m
57603.384	14.88	13.47	12.63	11.74	2-m	58727.428	14.38	13.07	12.28	11.51	2-m
57605.412	14.88	13.54	12.72	11.74	Sch	58728.465	14.33	13.00	12.26	11.46	2-m
57607.392	14.72	13.40	12.60	11.65	Sch	58729.395	14.32	13.02	12.27	11.47	2-m
57664.304	14.57	13.28	12.52	11.63	Sch	58730.464	14.38	13.09	12.30	11.46	Sch
57698.280	14.31	13.07	12.32	11.47	Sch	58758.414	14.25	12.97	12.20	11.38	Sch
57714.306	14.48	13.16	12.38	11.57	2-m	58759.461	14.29	13.01	12.23	11.41	Sch
57715.272	14.39	13.12	12.35	11.53	2-m	58864.243	14.22	12.97	12.20	11.39	Sch
57716.286	14.38	13.10	12.32	11.50	2-m	58865.243	14.20	12.96	12.18	11.39	Sch
57755.231	15.68	14.29	13.39	12.29	Sch	58869.221	14.33	13.05	12.26	11.48	2-m
57756.243	15.64	14.26	13.34	12.24	Sch	58870.238	14.34	13.07	12.28	11.46	Sch
57781.221	15.16	13.81	12.93	11.87	Sch	58993.457	14.49	13.18	12.35	11.49	Sch
57782.230	15.19	13.82	12.85	11.90	2-m	59040.398	15.34	14.00	13.07	12.07	Sch
57784.227	-	13.75	12.81	11.86	2-m	59041.413	15.36	14.02	13.09	12.09	Sch
57785.251	15.17	13.75	12.83	11.89	2-m	59042.403	15.33	14.02	13.09	12.10	Sch
57786.222	15.20	13.77	12.86	11.91	2-m	59059.412	15.37	14.10	13.21	12.22	Sch
57800.205	15.00	13.67	12.81	11.80	Sch	59060.436	15.39	14.11	13.21	12.21	Sch
57801.208	14.98	13.64	12.78	11.79	Sch	59075.371	15.61	14.25	13.31	12.28	2-m
57817.531	14.54	13.28	12.51	11.57	Sch	59085.314	15.39	14.03	13.10	12.10	Sch
57845.516	14.35	13.15	12.39	11.51	Sch	59101.456	15.27	13.91	12.98	11.98	Sch
57846.547	14.57	13.34	12.57	11.68	Sch	59102.383	15.27	13.87	12.94	11.95	2-m
57892.498	14.76	13.50	12.71	11.79	Sch	59103.464	15.32	13.91	12.99	12.00	2-m
57893.573	14.83	13.53	12.72	11.87	2-m	59105.338	15.23	13.89	12.96	11.97	Sch
57904.451	14.56	13.30	12.50	11.65	Sch	59108.400	14.78	13.55	12.68	11.76	Sch
57967.438	-	-	12.50	11.60	Sch	59109.350	14.84	13.52	12.64	11.73	Sch
57968.369	14.54	13.27	12.49	11.61	Sch	59136.280	14.76	13.44	12.58	11.67	Sch

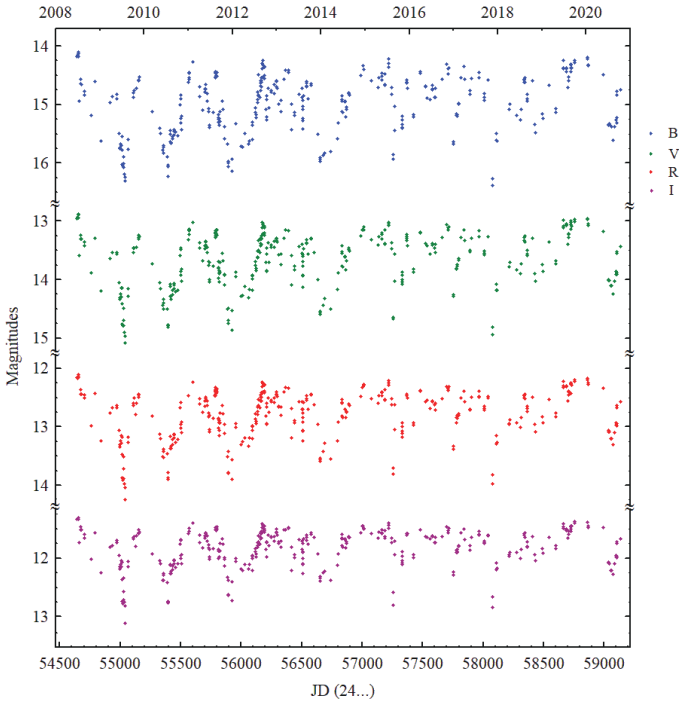

Fig. 1. BVRI light curves of GM Cep for the whole period of our photometric monitoring (2008 - 2020).

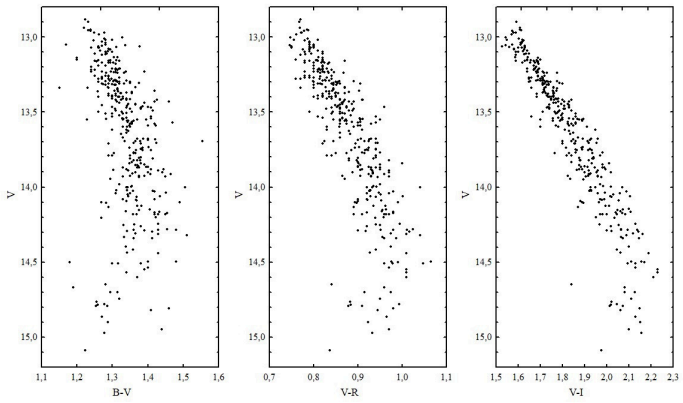

Fig. 2. The colour-magnitude diagrams $V/B-V$, $V/V-R$ and $V/V-I$ of GM Cep in the period of observations June 2008 - October 2020.

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