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On the Period Change of the Contact Binary GW Cephei

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BVR CCD observations of GW Cep were made on 15 nights in November through December 2008 with a 1-m reflector at the Jincheon station of the Chungbuk National University Observatory. Nineteen new times of minimum lights for GW Cep were determined and added to a collection of all other times of minima available to us. These data were then intensively analyzed, by reference to an *O-C* diagram, to deduce the general form of period variation for GW Cep. It was found that the *O-C* diagram could be interpreted as presenting two different forms of period change: an exclusively quasi-sinusoidal change with a period of 32.6 years and an eccentricity of 0.10; and a quasi-sinusoidal change with a period of 46.2 years and an eccentricity of 0.36 superposed on an upward parabola. Although a final conclusion is somewhat premature at present, the latter seems more plausible because late-type contact binaries allow an inter-exchange of both energy and mass between the component stars. The quasi-sinusoidal characteristics were interpreted in terms of a light-time effect due to an unseen tertiary component. The minimum masses of the tertiary component for both cases were calculated to be nearly the same as the 0.23-0.26 $M_\odot$-ranges which is hardly detectable in a light curve synthesis. The upward parabolic *O-C* diagram corresponding to a secular period increase of about 4.12×10^{-8} d/yr was interpreted as mass being transferred from the lesser to more massive component. The transfer rate for a conservative case was calculated to be about 2.66×10^{-8} $M_\odot$/yr which is compatible with other W UMa-type contact binaries.

Keywords: eclipsing binaries, GW Cephei, period change, light-time effect, mass transfer

1. INTRODUCTION

Since the light variability of GW Cep (CSV 5941, BV 7, Sp = G3, P = 0.3188d) was discovered by Strohmeier (Geyer et al. 1955), it has been the subject of several investigations aiming to determine its basic system parameters. The first photoelectric light curve was measured by Meinunger & Wenzel (1965), who classified GW Cep as a W UMa eclipsing binary with a G3 spectral type. After their study photoelectric or CCD observations of the system were made and/or analyzed by Hoffmann (1982), Kaluzny (1984), Landolt (1992), Pribulla et al. (2001a), and Lee et al. (2010). There have been no reports of spectroscopic observations until now, with the detailed history of the system described by Lee et al. (2010). Through the results of the investigators above, the following consensus of the general photometric properties of GW Cep has been reached: (1) GW Cep belongs to Binnendijk's (1970) W-subtype of late-type contact binaries and has a total eclipse of about 24 minutes at primary eclipse; (2) two solar-type stars (T_1= 5,800K and T_2= 6,108K) with unequal mass (q=0.379) and moderate contact (f=0.174) are revolving circularly around their common center of mass, with a high orbital inclination of 84.4 degrees; (3) GW Cep has displayed remarkable light changes both during and between eclipses, implying strong magnetic activity in

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the system (Lee et al. 2010).

Period studies for the system have been carried out by Ragazzoni & Barbieri (1994, 1996), Pribulla et al. (2001a), Qian (2003), Chochol et al. (2006), and Lee et al. (2010). A secular decrease of period was first considered by Ragazzoni & Barbieri (1996) and later by Pribulla et al. (2001a), and Qian (2003). Chochol et al. (2006) suggested the possibility that the period of GW Cep may vary with either a single light-time effect (hereafter LITE) with a period of 32.6 years due to a tertiary body or a LITE with a short period of 13.5 years superposed on a downward parabola. Lee et al. (2010) showed that a single LITE with a period of 32.6 years would suffice to explain the period change of GW Cep with the latest measured and collected times of minima. The aim of this paper is to resolve the confusion regarding the period variation of the GW Cep system with new eclipse timing observations.

2. OBSERVATIONS AND DATA REDUCTION

BVR CCD observations of GW Cep were made on 15 nights from November through December 2008 with a 1-m reflector at the Jincheon station of the Chungbuk National University Observatory in Korea. An electrically cooled FLI 2K CCD imaging system with a 21.5’ × 21.5’ field of view, and a standard *BVR* filter set were used. GSC 4502-0538 and GSC 4502-0542 were chosen as the comparison and check stars, respectively. Our comparison star was the check star used by Lee et al. (2010). The camera exposure time ranged between 40 s and 200 s according to nighttime visilbility.

The instrumentation and reduction method used for the raw CCD frames have been described in detail by Jeong et al. (2009). The resultant standard errors of our observations in terms of comparison minus check star were about $\pm 0.^{m}003$ in blue, $\pm 0.^{m}009$ in yellow and $\pm 0.^{m}021$ in red, respectively. A total of 1,381 individual observations were obtained in three colors (469 in blue, 465 in yellow and 447 in red). New light curves are under analysis and will be published elsewhere. From our *BVR* observations 19 new times of minimum lights were determined by the conventional Kwee & van Woerden (1956) method. Each of these timings, as listed in Table 1, was a weighted-mean of three *BVR* timings defining the same epoch.

3. PERIOD STUDY

For our study of the period variation of GW Cep, a total of 164 (46 visual, 4 sky patrol, 2 photographic, 16 photoelectric, and 95 CCD) times of minimum light were collected from a modern data-base (Kreiner et al. 2001) and from the recent literature. Table 1 lists all of the collected photoelectric and CCD minima. The minima marked by an asterisk in column 9 were determined with the consideration of two-spots model using the Wilson-Devinney binary code by Lee et al. (2010).

To see a general pattern of period change of GW Cep, the (*O-C*) residuals of all 164 timings were calculated with Lee et al.’s (2010) linear ephemeris:

$$C = \mathrm{HJD}\ 2451799.49465 + 0.^{d}318831533\,E. \qquad (1)$$

The *O-C* diagram is shown in Fig. 1 where the dashed and solid lines represent the theoretical LITEs calculated with the orbital parameters (see the second column of Table 2) of Lee et al. (2010) and ours to be discussed later, respectively. Assorted symbols distinguish the timings according to observation method and type of eclipse. As seen in Fig. 1, it is clear that the period of GW Cep has varied in a cyclic way over time-interval of about 45 years, confirming Lee et al.’s (2010) result. We can undoubtedly rule out the possibility of any secular period decreases, which some previous investigators have proposed.

The cyclic behavior of the residuals, as seen in Fig. 1, has usually been interpreted in two mechanisms: a LITE due to an unseen third body; and a cyclic magnetic effect(s) in one or both of the components, as proposed

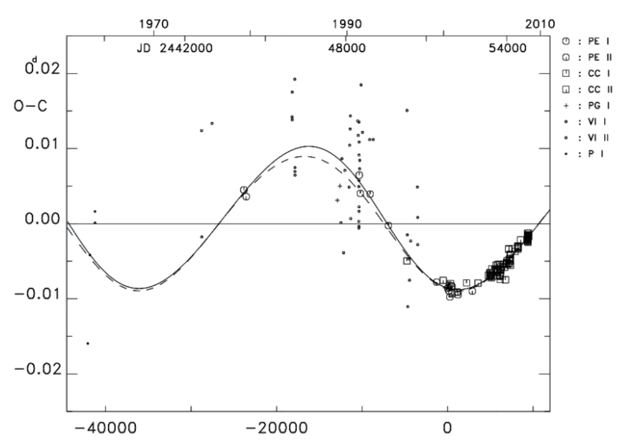

Fig. 1. History of the timings of minimum light for GW Cep against Eq. (1). The residuals are coded by observational method. The dashed curve represents the sinusoidal term from the LITE ephemeris of Lee et al. (2010). The solid line represents our LITE orbit.

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Table 1. Photoelectric and CCD times of minimum lights of GW Cep.

Timing (HJD2400000+)	Error	Min	Me	Epoch	O-C_1	O-C_{1full}	O-C_{2full}	Reference
44200.48206	0.00004	I	PE	-23834.0	0.003676	0.00036	0.00028	Hoffmann (1982)*
44289.27556	0.00015	II	PE	-23555.5	0.002777	-0.00092	-0.00083	Hoffmann (1982)*
48504.3821	0.0010	I	PE	-10335.0	0.005694	0.00087	0.00085	Hubscher et al. (1992)
48544.87119	0.00008	I	PE	-10208.0	0.003263	-0.00137	-0.00141	Landolt (1992)*
48909.2948	0.0009	I	PE	-9065.0	0.003179	0.00040	0.00025	Hubscher et al. (1993)
49592.5452	0.0004	I	PE	-6922.0	-0.000992	0.00001	-0.00002	Agerer & Hubscher (1995)
50283.447	0.002	I	CCD	-4755.0	-0.005705	-0.00106	-0.00087	Diethelm (1996)
51391.5409	0.0002	II	PE	-1279.5	0.008522	0.00012	0.00022	Agerer & Hubscher (2001)
51634.8091	0.0001	II	CCD	-516.5	-0.008282	0.00082	0.00086	Nelson (2001)
51799.48420	0.00016	I	PE	.0	0.009330	-0.00002	-0.00001	Pribulla et al. (2001a)*
51845.39552	0.00011	I	PE	144.0	0.009656	-0.00030	-0.00030	Pribulla et al. (2001a)*
51854.32356	0.00012	I	PE	172.0	0.008881	0.00048	0.00048	Pribulla et al. (2001a)*
51858.30860	0.00010	II	PE	184.5	0.009227	0.00014	0.00014	Pribulla et al. (2001a)*
51884.61089	0.00012	I	PE	267.0	0.010484	-0.00110	-0.00110	Pribulla et al. (2001a)*
51900.3948	0.0002	II	CCD	316.5	0.008703	0.00070	0.00069	Agerer & Hubscher (2002)
51935.7847	0.0001	II	CCD	427.5	0.009030	0.00040	0.00038	Nelson (2002)
51957.7830	0.0001	II	CCD	496.5	0.010061	-0.00062	-0.00064	Nelson (2002)
51968.3054	0.0001	II	PE	529.5	0.009080	0.00037	0.00035	Pribulla et al. (2001b)
52143.5022	0.0002	I	CCD	1079.0	-0.009847	-0.00034	-0.00039	Agerer & Hubscher (2002)
52185.2687	0.0002	I	PE	1210.0	0.010192	-0.00068	-0.00073	Pribulla et al. (2002)
52185.4285	0.0001	II	PE	1210.5	0.009808	-0.00029	-0.00035	Pribulla et al. (2002)
52502.5070	0.0003	I	CCD	2205.0	-0.008616	0.00077	0.00069	Agerer & Hubscher (2003)
52723.2963	0.0002	II	PE	2897.5	0.009699	-0.00055	-0.00064	Pribulla et al. (2005)
52935.3199	0.0001	II	CCD	3562.5	-0.008633	0.00017	0.00010	Krajci (2005)
53322.2222	0.0001	I	CCD	4776.0	-0.007603	0.00034	0.00030	Kim et al. (2006)
53363.6701	0.0002	I	CCD	4906.0	-0.007717	0.00011	0.00009	Krajci (2006)
53378.0179	0.0001	I	CCD	4951.0	-0.007307	0.00049	0.00046	Kim et al. (2006)
53378.1769	0.0001	II	CCD	4951.5	-0.007722	0.00007	0.00004	Kim et al. (2006)
53378.3368	0.0001	I	CCD	4952.0	-0.007238	0.00055	0.00053	Kim et al. (2006)
53380.2497	0.0002	I	CCD	4958.0	-0.007323	0.00046	0.00044	Kim et al. (2006)
53385.9887	0.0005	I	CCD	4976.0	-0.007279	0.00049	0.00047	Kim et al. (2006)
53407.9878	0.0007	I	CCD	5045.0	-0.007510	0.00020	0.00018	Kim et al. (2006)
53433.6533	0.0001	II	CCD	5125.5	-0.007895	-0.00026	-0.00028	Chochol et al. (2006)
53449.4366	0.0002	I	CCD	5175.0	-0.006724	0.00087	0.00085	Chochol et al. (2006)
53449.5952	0.0001	II	CCD	5175.5	-0.007539	0.00005	0.00004	Chochol et al. (2006)
53491.5213	0.0001	I	CCD	5307.0	-0.007700	-0.00023	-0.00024	Pribulla et al. (2005)
53607.5766	0.0001	I	CCD	5671.0	-0.006839	0.00028	0.00028	Brat et al. (2007)
53614.5915	0.0002	I	CCD	5693.0	-0.006218	0.00088	0.00088	Brat et al. (2007)
53619.0544	0.0001	I	CCD	5707.0	-0.006951	0.00013	0.00014	Kim et al. (2006)
53663.05284	0.00009	I	CCD	5845.0	-0.007172	-0.00023	-0.00022	Lee et al. (2010)*
53664.00946	0.00019	I	CCD	5848.0	-0.007045	-0.00010	-0.00009	Lee et al. (2010)*
53664.16890	0.00015	II	CCD	5848.5	-0.007020	-0.00008	-0.00007	Lee et al. (2010)*
53665.92260	0.00010	I	CCD	5854.0	-0.006890	0.00005	0.00006	Lee et al. (2010)*
53666.08188	0.00006	II	CCD	5854.5	-0.007025	-0.00009	-0.00008	Lee et al. (2010)*
53666.24138	0.00006	I	CCD	5855.0	-0.006941	-0.00001	0.00000	Lee et al. (2010)*
53672.6182	0.0021	I	CCD	5875.0	-0.006738	0.00018	0.00019	Brat et al. (2007)
53674.6912	0.0002	II	CCD	5881.5	-0.006139	0.00077	0.00078	Brat et al. (2007)
53730.4866	0.0033	II	CCD	6056.5	-0.006143	0.00058	0.00060	Brat et al. (2007)
53747.2237	0.0003	I	CCD	6109.0	-0.007664	-0.00099	-0.00098	Parimucha et al. (2007)
53763.4836	0.0001	I	CCD	6160.0	-0.008138	-0.00152	-0.00150	Parimucha et al. (2007)
53763.6436	0.0002	II	CCD	6160.5	-0.007554	-0.00094	-0.00092	Parimucha et al. (2007)
53764.2813	0.0002	II	CCD	6162.5	-0.007516	-0.00090	-0.00088	Parimucha et al. (2007)
53764.4405	0.0002	I	CCD	6163.0	-0.007731	-0.00112	-0.00110	Parimucha et al. (2007)
53765.3975	0.0003	I	CCD	6166.0	-0.007224	-0.00061	-0.00059	Parimucha et al. (2007)
53765.5577	0.0008	II	CCD	6166.5	-0.006439	0.00017	0.00019	Parimucha et al. (2007)
53777.99175	0.00010	II	CCD	6205.5	-0.006793	-0.00023	-0.00020	Lee et al. (2010)*

Table 1. (Continued)

Timing (HJD2400000+)	Error	Min	Me	Epoch	O-C_1	O-C_{1full}	O-C_{2full}	Reference
3989.05873	0.00010	II	CCD	6867.5	0.005855	-0.00003	0.00001	Lee et al. (2010)*
53992.08753	0.00007	I	CCD	6877.0	-0.005948	-0.00014	-0.00010	Lee et al. (2010)*
53992.24680	0.00011	II	CCD	6877.5	-0.006093	-0.00028	-0.00024	Lee et al. (2010)*
54026.99984	0.00023	II	CCD	6986.5	-0.005619	0.00006	0.00010	Lee et al. (2010)*
54067.6504	0.0002	I	CCD	7114.0	-0.005996	-0.00047	-0.00042	Brat et al. (2007)
54080.2461	0.0004	II	CCD	7153.5	-0.004116	0.00137	0.00141	Hubscher & Walter (2007)
54080.4036	0.0003	I	CCD	7154.0	-0.006031	-0.00055	-0.00051	Hubscher & Walter (2007)
54080.5650	0.0014	II	CCD	7154.5	-0.004047	0.00143	0.00148	Hubscher & Walter (2007)
54097.3022	0.0007	I	CCD	7207.0	-0.005468	-0.00005	-0.00001	Diethelm (2007)
54129.98218	0.00008	II	CCD	7309.5	-0.005653	-0.00036	-0.00031	Lee et al. (2010)*
54130.14190	0.00007	I	CCD	7310.0	-0.005348	-0.00006	-0.00001	Lee et al. (2010)*
54134.12692	0.00013	II	CCD	7322.5	-0.005714	-0.00044	-0.00039	Lee et al. (2010)*
54137.6350	0.0002	II	CCD	7333.5	-0.004774	0.00049	0.00053	Krajci (2007)
54137.95237	0.00010	II	CCD	7334.5	-0.006235	-0.00097	-0.00093	Lee et al. (2010)*
54138.5914	0.0002	II	CCD	7336.5	-0.004866	0.00039	0.00044	Krajci (2007)
54211.2857	0.0002	II	CCD	7564.5	-0.004007	0.00097	0.00102	Dogru et al. (2007)
54314.4271	0.0001	I	CCD	7888.0	-0.004396	0.00017	0.00021	Brat et al. (2007)
54421.07667	0.00014	II	CCD	8222.5	-0.003754	0.00037	0.00041	Lee et al. (2010)*
54421.23618	0.00013	I	CCD	8223.0	-0.003660	0.00047	0.00050	Lee et al. (2010)*
54422.35188	0.00013	II	CCD	8226.5	-0.003868	0.00025	0.00029	Lee et al. (2010)*
54422.98953	0.00009	II	CCD	8228.5	-0.003880	0.00024	0.00028	Lee et al. (2010)*
54423.14906	0.00012	I	CCD	8229.0	-0.003765	0.00035	0.00039	Lee et al. (2010)*
54423.30818	0.00016	II	CCD	8229.5	-0.004061	0.00006	0.00009	Lee et al. (2010)*
54521.5093	0.0001	II	CCD	8537.5	-0.002851	0.00086	0.00088	Brat et al. (2008)
54774.98043	0.00023	II	CCD	9332.5	-0.002269	0.00035	0.00031	This paper
54775.13928	0.00011	I	CCD	9333.0	-0.002834	-0.00022	-0.00025	This paper
54776.09555	0.00015	I	CCD	9336.0	-0.003057	-0.00045	-0.00048	This paper
54776.09595	0.00009	I	CCD	9336.0	-0.002657	-0.00005	-0.00008	Lee et al. (2010)*
54780.24102	0.00010	I	CCD	9349.0	-0.002388	0.00020	0.00017	Lee et al. (2010)*
54781.03754	0.00016	II	CCD	9351.5	-0.002946	-0.00036	-0.00039	This paper
54781.19716	0.00022	I	CCD	9352.0	-0.002741	-0.00015	-0.00019	This paper
54781.19767	0.00004	I	CCD	9352.0	-0.002231	0.00036	0.00032	Lee et al. (2010)*
54781.35673	0.00007	II	CCD	9352.5	-0.002586	0.00000	-0.00004	Lee et al. (2010)*
54782.15358	0.00015	I	CCD	9355.0	-0.002814	-0.00023	-0.00027	This paper
54782.95149	0.00019	II	CCD	9357.5	-0.001981	0.00060	0.00056	This paper
54783.11000	0.00016	I	CCD	9358.0	-0.002886	-0.00031	-0.00034	This paper
54787.09572	0.00015	II	CCD	9370.5	-0.002552	0.00001	-0.00003	This paper
54788.21156	0.00009	I	CCD	9374.0	-0.002620	-0.00006	-0.00010	This paper
54789.16824	0.00006	I	CCD	9377.0	-0.002433	0.00012	0.00008	Lee et al. (2010)*
54789.32746	0.00013	II	CCD	9377.5	-0.002628	-0.00008	-0.00012	Lee et al. (2010)*
54789.96515	0.00005	II	CCD	9379.5	-0.002600	-0.00005	-0.00009	Lee et al. (2010)*
54790.12469	0.00007	I	CCD	9380.0	-0.002476	0.00007	0.00003	Lee et al. (2010)*
54790.12428	0.00019	I	CCD	9380.0	-0.002886	-0.00034	-0.00038	This paper
54795.06680	0.00016	II	CCD	9395.5	-0.002244	0.00028	0.00024	This paper
54796.02238	0.00023	II	CCD	9398.5	-0.003157	-0.00063	-0.00068	This paper
54800.00813	0.00008	I	CCD	9411.0	-0.002793	-0.00029	-0.00033	This paper
54800.16818	0.00012	II	CCD	9411.5	-0.002158	0.00035	0.00030	This paper
54800.96500	0.00013	I	CCD	9414.0	-0.002415	0.00009	0.00004	This paper
54811.96459	0.00032	II	CCD	9448.5	-0.002491	-0.00004	-0.00009	This paper
54818.97941	0.00044	II	CCD	9470.5	-0.001950	0.00047	0.00042	This paper
54826.94980	0.00015	II	CCD	9495.5	-0.002332	0.00005	0.00000	This paper

*The minima were determined with the consideration of two-spots model using the Wilson-Devinney binary code by Lee et al. (2010).

by Applegate (1992) and later modified by Lanza et al. (1998). Lee et al. (2010) preferred the former because they failed to find any connection between the light variation and period change of GW Cep, which would be expected by the Applegate mechanism. No matter which of the two mechanisms is responsible for the seemingly cyclic oscillation in the observed *O-C* residuals of GW Cep, Lee et al. (2010) thought that its Keplerian period has been constant for about 45 yr. Their survey, from the Atlas of *O-C* Diagrams of Eclipsing Binary Stars (Kreiner et al., 2001) showed that only 6 systems (AT Aqr, GW Cep, V906 Cyg, V743 Sgr, RZ UMi and BP Vel) among a total sample of 65 contact binaries were found to have constant periods. Finally, they suggested that the six systems signify brief episodes of constant period behavior during thermal relaxation oscillation processes. Here we note that the time-interval of about 45 yr covered by the observations corresponds to only about 1.4 times the 32.6-yr oscillation cycle. In such a case, any secular changes of period by evolutionary effects, such as mass-transfer or mass-loss, could be suppressed by the dominant cyclic change of the period. Similar cases were found in their period study histories for contact binaries such as YY Eri (Kim 1992, Maceroni & van't Veer 1994, Kim et al. 1997) and SS Ari (Kurpinska-Winiarska & Zakrzewski 1990, Demircan & Selam 1993, Kim et al. 2003). We thus investigated whether GW Cep fits this case.

Before our subsequent analysis of the times of minimum light, most of the timings were weighted according to the inversely-squared values of their published internal errors. As seen in Table 1, all photoelectric and CCD minima have errors. Among the previous 52 non-photoelectric and non-CCD timings not listed in Table 1, there were 29 minima without errors. These minima were assigned an inversely-squared weight of their standard deviation of ±0.0068 d, reasonably given by Lee et al. (2010).

With the weight system above, all times of minima were separately fitted to a LITE ephemeris with and without a quadratic term, respectively, as follows:

$$C_1 = T_o + PE + \tau \quad (2)$$

and

$$C_2 = T_o + PE + AE^2 + \tau, \quad (3)$$

where τ is the light-time term with a parametric form taken from Irwin (1952, 1959). The Levenberg-Marquardt method (Press et al. 1992) was used to solve the parameters of Equations (2) and (3). The solution converged quickly, and the results are listed in Table 2 together with those of Lee et al. (2010), wherein the parenthesized values give the standard errors of the tabulated quantities. The σ values in the ninth row of Table 2 denote the weighted standard deviations of residuals from all terms in Equations (2) and (3). These values fit Equation (3) slightly better than Equation (2). The solid line in Figure 1 was drawn using our single LITE orbital elements in the third column of Table 2. The parameters of Lee et al. (2010) were slightly modified with the inclusion of our latest timings. The (O-C_1) and (O-C_{1full}) residuals calculated with the linear term and the full terms of Equation (3) are listed in the sixth and seventh columns of Table 1, respectively. The LITE elements derived with Equation (3) in the fourth column of Table 2, however, are quite different from both Lee et al.'s (2010) and our single LITE, especially the larger eccentricity of 0.36 and the longer period of 46.2 yr. The residuals from the linear term of Equation (3) were drawn in Figure 2 using the parabolic and cyclical components fitting to (O-C_2) residuals. The

Table 2. The derived LITE and secular ephemerides for GW Cep.

Parameter	Lee et al. (2010)	This paper		Unit
	Third-body only	Third-body only	Third-body plus quadratic	
T_o	2451799.49280(26)	2451799.49352(24)	2451799.49465(23)	HJD
P	0.318830882(32)	0.318830878(28)	0.318831533(22)	d
K	0.00896(42)	0.00951(32)	0.00951(32)	d
e	0.076(40)	0.104(44)	0.361(35)	-
ω	221.8(2.1)	181.5(2.8)	164.1(3.1)	deg
T	2450716(72)	2449458(52)	2449298(50)	HJD
P_3	32.63(65)	32.58(58)	46.24(55)	yr
A	-	-	$1.80(45) \times 10^{-11}$	d/P
σ	-	0.00169	0.00166	d
$f(M_3/M_\odot)$	0.00353(18)	0.00427(16)	0.00524(14)	$M_\odot$
$M_3(i_3=90^o)$	0.21	0.23	0.26	$M_\odot$
$M_3(i_3=60^o)$	0.25	0.27	0.30	$M_\odot$
$M_3(i_3=30^o)$	0.47	0.51	0.58	$M_\odot$
dM/dt	-	-	2.66×10^{-8}	$M_\odot$/yr

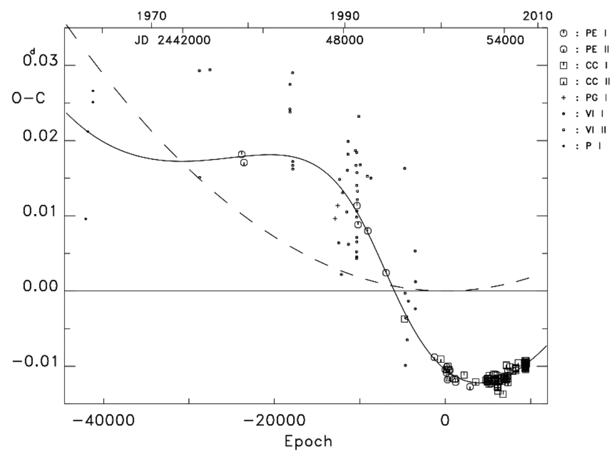

Fig. 2. The (O-C_2) residuals of timings for GW Cep against the linear term of Eq. (3). The solid and dashed curves show non-linear terms and only the quadratic term of Eq. (3), respectively.

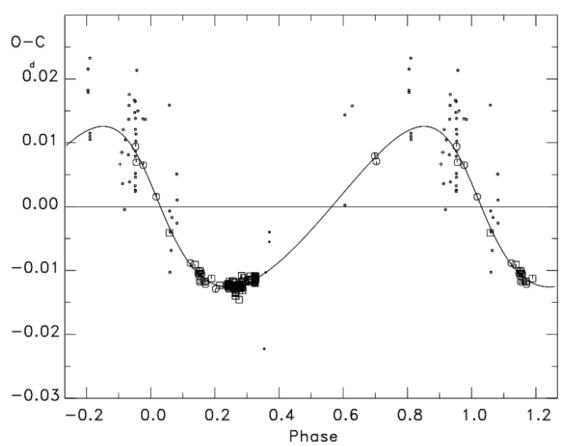

Fig. 3. The (O- C_2) residuals phased with P = 46.2 yr and e = 0.36 from the solution in Table 2. The solid curve represents the projected LITE orbit of the barycenter of GW Cep caused by a third star.

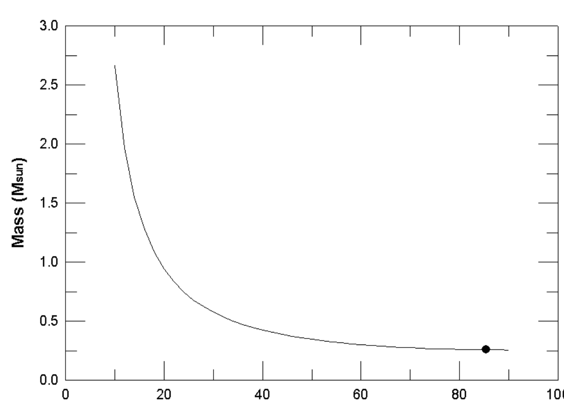

Fig. 4. A diagram of mass versus inclination of the tertiary star from the mass function in Table 2. The large dot denotes the coplanar case between the eclipsing pair and the tertiary star.

(O-C_{2full}) residuals from all terms are listed in the eighth column of Table 1. Figure 3 shows the O-C residuals from the linear and parabolic terms and the theoretical LITE curve phased with the third-body ephemeris of Table 2.

The 46.2 yr cyclic component of the period variability that appears to be present in the data set could be explained by either a LITE or an Applegate model, as discussed above. The latter interpretation is a possible mechanism explaining the apparent cyclic period change, because the two late-type stars in GW Cep could have strong magnetic activity and an activity cycle (Guinan & Gimenez 1993) and strong light variations as intensively analyzed by Lee et al. (2010). However, because of insufficient light-curve data, it may not be possible to check whether the overall brightness of GW Cep has varied in the same way as the period change, which is what the Applegate model requires. In this case, the length of the activity cycle would be about 46 yr. The LITE interpretation for the cyclic component with an eccentric orbit (e = 0.36) gave a mass function $f\,(\mathrm{m}/M_\odot)$ of 0.00524 for the LITE orbit. To estimate the mass of the third body, the mass function was solved as a function of the orbital inclination of the third body. A diagram of mass *versus* inclination in Fig. 4 shows a minimum mass of 0.26 $M_\odot$ for the hypothetical tertiary body. At the moment, however, there are no other observations that support the third-body hypothesis. If the minimum mass of 0.26 $M_\odot$ is adopted and the tertiary is assumed to be a main-sequence star, it would be a dM star with a low luminosity of 0.007 $L_\odot$ (see also Lee et al. 2010).

The parabolic component of the period change of GW Cep corresponds to a secular period increase of +4.12 × 10^{-8} d/yr and implies a mass transfer of 2.66 × 10^{-8} $M_\odot$/yr from the less massive to the more massive star, that is, if the mass and angular momentum of the system are conserved and the masses for the eclipsing stars of M_h = 0.39 $M_\odot$ and M_c = 1.06 $M_\odot$ given by Maceroni & van't Veer (1996) are used. The mass transfer rate in the GW Cep system is moderate and is similar to the rates provided by YY Eri (Kim et al. 1997) and V432 Per (Lee et al. 2008).

4. DISCUSSION AND CONCLUSIONS

Nineteen new times of minima of GW Cep were determined from the *BVR* CCD observations, which were carried out over fifteen nights in the winter season of 2008. A total of 164 timings available to us, including our own, were intensively analyzed to resolve the diverse and discordant interpretations proposed for the system's period change. At the early stage of period study, a secular decrease was proposed with timings then available (Pribulla et al. 2001, Qian 2003, Ragazzoni et al. 1996). Several years later, a 32-yr cyclic change of period was suggested with more accumulated minima (Chochol et al. 2006, Lee et al. 2010). Finally, this paper proposed a 46-yr periodicity superposed on an upward parabolic change of period. Our proposition was motivated by following factors: 1) the 32.6-yr periodicity completed only 1.4 cycles during the time-interval of about 45 yr, 2) in such a case, any secular changes of period by evolutionary effects, such as mass-transfer or mass-loss, could be suppressed by the dominant cyclic change of period, and 3) the late-type contact binaries are not free from mass transfer and energy exchange between components because they are not in thermal equilibrium (Lucy 1976, Stepien 2006). From our discussion above, we see that diverse historical interpretations of GW Cep result from the unpredictable behavior of its period variation, which may be ascribed to a natural process when finding the dynamical properties of the system. However, when the period behavior determined with timings within a short time-interval are really a part of oscillatory change with a longer period, any derived interpretations may have a high probability of being erroneous. Furthermore, the astrophysically important parameters obtained (e.g., mass-transfer rates and LITEs) could be wrongly used in understanding the evolutionary and/or dynamical states of contact binaries. For this reason, the suggestion of Rovithis-Livaniou et al. (2005) that "it is desirable to wait and see if it will be repeated for the case of any periodicity corresponding to the time-interval covered by observations" would be properly applicable to the historical period studies of the GW Cep system.

In conclusion, the apparent secondary variation of GW Cep's period varies in a sinusoidal way, superposed on the long-term upward parabolic variation. The secularly increasing rate of the period is deduced to be 0.36 s per century ($+4.12\times10^{-8}$ d/yr), implying a mass transfer of 2.66×10^{-8} $M_{\odot}$/yr from the less massive to the more massive star for the conservative case. The mass transfer may be a possible cause of the hot spot near the neck of the facing hemisphere of the cooler, more massive star, which was consistently found in the light curve synthesis by Lee et al. (2010). The period of the quasi-sinusoidal variation is about 46.2 yr. This period could arise from a LITE due to the gravitational effect of a third body or from a cyclic period modulation due to the magnetically active component stars. The tertiary body was deduced to be a low-mass (m_3=0.26 $M_{\odot}$ sin i) and a low luminosity (L_3=0.007$L_{\odot}$) dM companion moving in an eccentric (e=0.36) orbit. However, there were no other observations supporting the tertiary body model. Although the historical light-curve variations indicate star-spots and possible high levels of magnetic dynamo activity, the possibility that the 46.2-yr periodicity arises from the varying magnetic activity of the stars seems unlikely, according to Lee et al.'s (2010) intensive investigation on that matter. At the same time, the dynamical picture of GW Cep is far from reality. The obvious way to try to further understand GW Cep is to obtain more data of all kinds to determine the following: magnetodynamic activity (e.g., cyclic effects in emission lines, maculation effects in the photometry, or radio or other EUVE and X-ray data); and other third-body effects (e.g., cyclic variations of gamma velocity, third-body spectrum in high resolution spectroscopy, detection of any third light in high precision photometry, or cyclic position-changes in astrometry).

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