A&A 401, 631–637 (2003)
DOI: 10.1051/0004-6361:20030061

Astronomy & Astrophysics

An abnormal radiant luminosity of the contact binary GZ Andromedae and its possible explanation

Y. Yang and Q. Liu

National Astronomical Observatories/Yunnan Observatory, Chinese Academy of Sciences, Kunming, Yunnan, China
United Laboratory of Optical Astronomy, Chinese Academy of Sciences, China

Received 24 June 2002 / Accepted 24 September 2002

Abstract. Complete BV light curves of the W UMa type binary GZ And is presented in this paper. From the present times of minimum light and those collected from the references, the changes in the orbital period of the system are analyzed. The result reveals that the orbital period of GZ And continuously increased at a period change rate of $\frac{dp}{p} = 2.00 \times 10^{-10}$. The observed orbital period increase of GZ And may be explained by a mass transfer rate from the smaller to the larger component of $\Delta m = 1.05 \times 10^{-7}\ M_{\odot}\mathrm{yr}^{-1}$. The present light curves are analyzed by means of the latest version of the Wilson-Devinney code. The results suggest that GZ And is a W-subtype W UMa contact binary with a mass ratio of 0.511. The present photometric mass ratio is in agreement with that obtained spectroscopically by Lu & Rucinski (1999). Combining the present photometric solution with the spectroscopic orbital elements by Lu & Rucinski (1999), we give absolute dimensions of GZ And. The determined masses and radii of the components show that GZ And is an unevolved main-sequence binary, but the luminosity of the primary is abnormally low for the same mass main-sequence star. The low luminosity of the primary may be explained by transformation between gravitational energy and thermal energy of the system.

Key words. stars: binaries: close – stars: binaries: general

1. Introduction

The variable GZ And (ADS 1693 A) is the brightest component of a multiple star system. In 1908 Espin mentioned that either the ADS 1693 A or B component was a variable. In 1971 and 1972 Josties and Christy obtained multi-exposure astrometric plates of the system at the U. S. Naval Observatory in Washington, D.C. Visual estimates from these plates by Strand showed the A component to be variable with a brightness change of 0.6 mag in thirty minutes (Walker 1973). The system was discovered as a W UMa-type binary by Walker (1973). Properties of GZ And were studied by Walker (1991, 1996), who claimed that, in addition, the W UMa binary belongs to a close triple system with a period of about 5.3 years for the wide pair. Liu et al. (1987) made *UBV* photoelectric observations of GZ And and gave times of light minima. Both Walker (1991, 1996) and Liu et al. (1987) signaled that they obtained photometric solutions, but their results were not available yet. The spectroscopic observations and the radial velocity analysis of the system were published by Lu & Ruciski (1999), who were unable to detect the third component in their spectroscopic observations of GZ And.

No photometric solution is found in any reference, so GZ And was included in the program of short period eclipsing binaries running at the Yunnan Observatory using a 100-cm reflector telescope and a CCD photometric system.

Send offprint requests to: Y. Yang, e-mail: `bily@public.km.yn.cn`

2. Observation

The observations of GZ And in *B* and *V* bands were carried out on November 15, 2001, with the PI1024 TKB CCD photometric system attached to the 100-cm reflector telescope at the Yunnan Observatory in China. The effective field of view of the photometric system is 6.5×6.5 square arc minute at the Cassegrain focus and the size of each pixel is 0.38 arcsec. The *BV* color system used approximates the standard Johnson *BV* photometric system (Yang & Li 1999). The comparison and check stars used are so close to the variable that they are in the same field of the observation together with the program star. The coordinates of the variable, the comparison star and the check star are given in Table 1.

The integration time for each image is 100 s. A total of 101 images in *V* and 99 images in *B* were obtained on one night in November, 2001. The aperture photometry package of the IRAF was used to reduce the images. The reduced results show that the difference between the magnitude of the check star and that of the comparison star is constant within a probable error of ±0.006 mag in *V* and ±0.008 mag in *B*. Extinction correction is not made as the comparison star is very close to the variable.

From the observations, one primary and one secondary time of minimum light were derived by means of the parabola fitting. The new times of the minimum light with those collected from the references are listed in Table 2, in which the symbol “pe” indicates the photoelectric method and “s”

Table 1. The coordinates of the variable, comparison star and check star.

star	RA(2000.0)	Dec(2000.0)
variable	$06^h38^m34^s$	$03^o36'21''$
comparison	06 38 38	03 35 13
check	06 38 19	03 33 45

shows the visual one. The $(O–C)_1$ values are calculated by means of the light element formula consisting of an epoch determined in the present study and a period given by Liu et al. (1987).

$$\text{Min. } I = \text{HJD } 2\,452\,229.2658 + 0\overset{d}{.}3050067E. \quad (1)$$

From 23 times of minimum light collected from the references and the new ones in the present article, the $(O–C)_1$ values of the minima computed with the above-mentioned ephemeris are plotted in Fig. 1. This diagram shows that the orbital period of GZ And has increased continuously since 1973. The photoelectric epochs of minimum light listed in Table 2, except JDH 2441993.9981 (unusual large scatter), were introduced into a least squares solution for a redetermination the ephemeris. A quadratic ephemeris was determined as follows:

$$\text{Min.}I = \text{HJD} \quad 2\,452\,229.2661(3) + 0\overset{d}{.}30501269(9)E$$
$$+1\overset{d}{.}00(9) \times 10^{-10}E^2, \quad (2)$$

which is used to compute the phases of the present observations and the $(O–C)_2$ values in Table 2. Using the coefficient of the square term, we calculate a continuous period increase of $\frac{dp}{p} = 2.00 \times 10^{-10}$, i.e. $\frac{\mathrm{d}p}{\mathrm{d}t} = 2.40 \times 10^{-7}$ days yr^{-1}.

101 individual observations in V band and 99 individual observations in B band were obtained. The magnitude differences in the sense of the variable minus the comparison star together with their heliocentric Julian dates are listed, respectively, in Table 3 for V and Table 4 for B. The light curves of the system are shown in Fig. 2 with full circles.

3. Photometric solutions and absolute dimension

Photometric solutions were obtained by means of the Wilson-Devinney program which includes a new reflection treatment, the option of using non-linear limb-darkening laws and the ability to adjust spot parameters. All the observations are used in computing the solutions. The convergence of the minimization procedure was obtained by means of the method of multiple subsets (Wilson & Biermann 1976).

The adopted parameters in the solutions are described as follows: a temperature of 5260 K for Star 1 (the star eclipsed at the Min.I), which corresponds to the color $B - V = 0.77$ (Liu et al. 1987; Walker 1973; Donald & Thomas 1968), Claret et al.'s (1990) values of the limb darkening coefficient ($x_1 = x_2 = 0.700$ for V band and 0.840 for B band), Lucy's (1967) values of the gravity darkening coefficient ($g_1 = g_2 = 0.320$) and Rucinski's (1969) values of the albedo ($A_1 = A_2 = 0.500$). The adjustable parameters are the orbital inclination, i, the mean temperature of Star 2, T_2, the potential of the components, Ω_1 and Ω_2 , and the monochromatic luminosity of Star 1, L_1 (the Planck function was used in computing the luminosity).

Solutions were made for a series of fixed values of the mass ratio $q = m_2/m_1$ (0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.20, 1.40, 1.60, 1.80, 2.00, 2.40 and 3.00). Assuming that initially it is

Table 2. The times of minimum light of GZ And.

HJD2400000+	way	E	$(O–C)_1$	$(O–C)_2$	Ref.
41976.8470	pe	−33613.5	−0.0761	0.0007	[1]
41977.7605	pe	−33610.5	−0.0776	−0.0008	[1]
41977.9146	pe	−33610	−0.0760	0.0008	[1]
41992.8599	pe	−33561	−0.0760	0.0008	[1]
41993.9981	pe	−33557.5	−0.0054	0.0715	[1]
45950.93175	pe	−20584	−0.07614	0.00025	[2]
45951.84676	pe	−20581	−0.07615	0.00024	[2]
45984.93999	pe	−20472.5	−0.07614	0.00008	[2]
45985.70251	pe	−20470	−0.07614	0.00008	[2]
45985.85502	pe	−20469.5	−0.07613	0.00009	[2]
45986.77004	pe	−20466.5	−0.07613	0.00008	[2]
45986.61753	pe	−20467	−0.07614	0.00008	[2]
46007.66299	pe	−20398	−0.07614	−0.00003	[2]
46008.57802	pe	−20395	−0.07613	−0.00002	[2]
46009.64554	pe	−20391.5	−0.07614	−0.00003	[2]
46012.54310	pe	−20382	−0.07614	−0.00005	[2]
46013.61063	pe	−20378.5	−0.07613	−0.00005	[2]
46015.59317	pe	−20372	−0.07614	−0.00006	[2]
49732.261	s	−8186.5	−0.068	−0.046	[3]
50390.447	s	−6028.5	−0.046	−0.034	[4]
50925.323	s	−4275	−0.039	−0.016	[5]
51384.522	s	−2769.5	−0.028	−0.012	[6]
51440.337	s	−2586.5	−0.029	−0.015	[7]
52229.1138	pe	−0.5	0.0005	0.0002	[8]
52229.2658	pe	0	0	−0.0003	[8]

[1] = Walker (1973); [2] = Liu et al. (1987); [3] = Locher (1995) [4] = Locher (1997); [5] = Locher (1998); [6] = Locher (1999) [7] = Locher (2000); [8] = this paper.

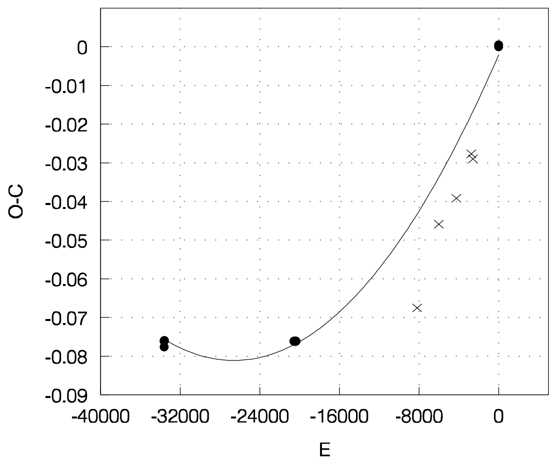

Fig. 1. The period change for GZ And. The full circles: photoelectric observations; the crosses: visual ones; the curve: fit to the observations (see text).

Table 3. The CCD observations in *V* band for GZ And.

JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*
2 452 220+		2 452 220+		2 452 220+		2 452 220+	2 452 220+		
8.9808	−1.379	9.0540	−1.798	9.1200	−1.172	9.1861	−1.828	9.2555	−1.143
.9866	−1.500	.0571	−1.786	.1231	−1.247	.1892	−1.826	.2586	−1.069
.9899	−1.556	.0604	−1.768	.1262	−1.317	.1923	−1.829	.2620	−1.036
.9934	−1.604	.0635	−1.752	.1294	−1.389	.1954	−1.817	.2652	−1.036
.9999	−1.673	.0666	−1.746	.1325	−1.451	.1985	−1.807	.2746	−1.106
9.0033	−1.690	.0697	−1.732	.1355	−1.507	.2017	−1.806	.2779	−1.191
.0064	−1.709	.0729	−1.715	.1386	−1.559	.2051	−1.796	.2829	−1.330
.0095	−1.732	.0760	−1.694	.1418	−1.601	.2083	−1.784	.2860	−1.404
.0128	−1.744	.0792	−1.666	.1451	−1.637	.2131	−1.769	.2894	−1.463
.0160	−1.757	.0823	−1.633	.1483	−1.670	.2226	−1.744	.2951	−1.572
.0193	−1.780	.0854	−1.592	.1514	−1.693	.2195	−1.721	.2982	−1.601
.0225	−1.784	.0885	−1.550	.1545	−1.719	.2229	−1.707	.3014	−1.639
.0257	−1.796	.0916	−1.504	.1576	−1.732	.2261	−1.685	.3045	−1.669
.0288	−1.797	.0948	−1.445	.1610	−1.757	.2294	−1.661	.3078	−1.705
.0319	−1.780	.0980	−1.376	.1640	−1.771	.2326	−1.619	.3110	−1.712
.0351	−1.819	.1011	−1.308	.1671	−1.784	.2357	−1.579	.3141	−1.727
.0383	−1.814	.1042	−1.239	.1704	−1.794	.2389	−1.537	9.3173	−1.734
.0414	−1.813	.1074	−1.160	.1735	−1.809	.2420	−1.475		
.0446	−1.815	.1105	−1.135	.1766	−1.819	.2453	−1.401		
.0477	−1.809	.1136	−1.124	.1797	−1.821	.2486	−1.324		
9.0509	−1.802	9.1167	−1.132	9.1828	−1.827	9.2519	−1.239		

Table 4. The CCD observations in *B* band for GZ And.

JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*	JD.(HEL)	Δ*m*
2 452 220+		2 452 220+		2 452 220+		2 452 220+		2 452 220+	
8.9848	−1.410	9.0555	−1.762	9.1182	−1.085	9.1812	−1.788	9.2470	−1.289
.9883	−1.472	.0587	−1.749	.1215	−1.150	.1845	−1.787	.2503	−1.226
.9918	−1.535	.0620	−1.721	.1247	−1.228	.1876	−1.793	.2535	−1.126
.9949	−1.577	.0651	−1.715	.1278	−1.299	.1908	−1.798	.2570	−1.028
9.0016	−1.635	.0682	−1.701	.1309	−1.377	.1939	−1.791	.2602	−.952
.0048	−1.670	.0713	−1.682	.1340	−1.430	.1970	−1.783	.2636	−.959
.0111	−1.713	.0745	−1.660	.1371	−1.488	.2001	−1.773	.2730	−.987
.0144	−1.719	.0776	−1.634	.1402	−1.537	.2035	−1.781	.2761	−1.070
.0175	−1.736	.0808	−1.615	.1435	−1.585	.2067	−1.748	.2796	−1.162
.0209	−1.758	.0839	−1.571	.1467	−1.603	.2099	−1.742	.2844	−1.322
.0241	−1.769	.0869	−1.526	.1498	−1.631	.2147	−1.721	.2877	−1.385
.0273	−1.783	.0900	−1.488	.1529	−1.676	.2179	−1.705	.2933	−1.474
.0303	−1.773	.0932	−1.423	.1560	−1.687	.2210	−1.678	.2967	−1.553
.0335	−1.793	.0964	−1.363	.1594	−1.710	.2245	−1.663	.2998	−1.589
.0367	−1.798	.0996	−1.288	.1625	−1.722	.2278	−1.631	.3030	−1.621
.0398	−1.793	.1026	−1.208	.1656	−1.735	.2310	−1.598	.3062	−1.658
.0430	−1.799	.1058	−1.134	.1687	−1.753	.2341	−1.560	.3094	−1.653
.0461	−1.790	.1089	−1.086	.1719	−1.767	.2373	−1.501	.3125	−1.700
.0492	−1.772	.1120	−1.063	.1751	−1.779	.2404	−1.458	.3157	−1.706
9.0524	−1.774	9.1151	−1.056	9.1781	−1.783	9.2437	−1.381		

a detached system, the differential corrections started from the mode 2, but the converged solutions were always obtained at the contact mode 3. The resulting sum Σ of the square deviations of the converged solutions for each value of q shows that the fitting is best for $q = 2.00$. At this point, the set of the adjustable parameters were expanded to include q. The mass ratio converged to a value of $q = 1.95891$ in the final solution. The photometric parameters are listed in Table 5, where Star 1 indicates a more massive component and Star 2 is of lesser mass. In the final solution with the application of the WD

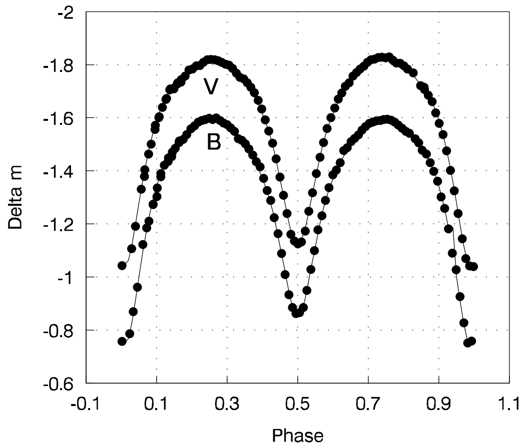

Fig. 2. The light curves for GZ And. The full circles show the observations, and the lines indicat the computed light curves with the model (see text).

Table 5. The photometric solutions of GZ And.

color	V	B
$L_1/(L_1+L_2)$	0.5913 ± 0.0006	0.5754 ± 0.0007
$x_1 = x_2$	0.700	0.840
$q = m_2/m_1$	0.5105 ± 0.0007	
i	85.86 ± 0.20	
$A_1 = A_2$	0.500	
$g_1 = g_2$	0.320	
Ω	2.8876 ± 0.0016	
f	0.027	
Σ	0.01255	
component	1	2
T(K)	5021±3	5260
r(pole)	0.4186 ± 0.0003	0.3077 ± 0.0003
r(side)	0.4458 ± 0.0003	0.3222 ± 0.0003
r(back)	0.4764 ± 0.0005	0.3588 ± 0.0005

program, the mass ratio of $q = 1.95891$ suggests that the less massive component is eclipsed at the primary eclipse. Since a mass ratio of binary systems is often shown as less than 1, the mass ratio of GZ And was changed to that in Table 5. The fit of the computed light curves is shown in Fig. 2 with solid lines.

The present photometric solution indicates that GZ And is a W-subtype W UMa contact binary with a shallow contact. The degree of geometrical contact is only about 2.7%, which has here the expression $(\Omega_{\rm in} - \Omega)/(\Omega_{\rm in} - \Omega_{\rm out})$. The photometrically derived mass ratio is in agreement with that spectroscopically determined by Lu & Rucinski (1999). This suggests that the solution listed in Table 5 is satisfactory.

Adopting the spectroscopic orbital elements obtained by Lu & Rucinski (1999) and combining the present photometric solution, we determined absolute dimensions of GZ And as follows: $M_1 = 1.25(4)\, M_\odot$, $M_2 = 0.65(1)\, M_\odot$, $R_1 = 1.06(1)\, R_\odot$, $R_2 = 0.78(1)\, R_\odot$, $L_1 = 0.63(5)\, L_\odot$, $L_2 = 0.41(3)\, L_\odot$. These physical parameters suggest that GZ And is an unevolved contact binary with both of the two components in the evolution stage of main-sequence stars, but the determined luminosity of the primary is abnormally low for the same mass main-sequence stars.

4. Explanation of abnormal luminosity

The observed abnormally low luminosity of the primary of GZ And may be explained by transformation between gravitational energy and thermal energy of the system. The analyses show that the orbital period of GZ And continuously increased at a rate of $\frac{{\rm d}p}{p} = 2.00 \times 10^{-10}$. It may be imagined that the observed long-term orbital period increase of GZ And could be explained by the mass transfer from the less to more massive component.In the case of conservative mass transfer, referring to the works of Kruszewski (1966), Plavec (1968), Rucinski (1974), Pribulla et al. (1999) and many other papers, the rate of mass transfer can be estimated using the formula:

$$\frac{{\rm d}m}{{\rm d}t} = \frac{mq}{3p(1-q^2)}\frac{{\rm d}p}{{\rm d}t} \quad (3)$$

where m indicates the total mass of the two components. The observed orbital period increase of GZ And may be explained by a mass transfer rate from the less to more massive component $\Delta m = 1.05 \times 10^{-7}\, M_\odot {\rm yr}^{-1}$. In the case of conservative mass transfer, one may have

$$\frac{{\rm d}m}{{\rm d}t} = \frac{-m}{(1+q)^2}\frac{{\rm d}q}{{\rm d}t}. \quad (4)$$

Combining the Eqs. (3) and (4), one has

$$\frac{{\rm d}q}{{\rm d}t} = \frac{-q(1+q)}{3p(1-q)}\frac{{\rm d}p}{{\rm d}t}. \quad (5)$$

The rate of change of the mass ratio of GZ And was found to be 1.26×10^{-7} yr^{-1}.

In the case of conservative mass transfer, the orbital period increase suggests an increase in the radius of the primary. According to Kepler's third law, one has

$$A^3 = 74.5mp^2 \quad (6)$$

where A and m are the separation between the two components and the total mass of the system, respectively, in solar units; p represents the orbital period in days. From the definition of the relative radius of one of the two components, one may have

$$A = \frac{R_1 + R_2}{r_1 + r_2}. \quad (7)$$

According to Binnendijk (1970) and Kuiper (1941), one has

$$r_1 + r_2 = 0.76 \quad (8)$$

and

$$\frac{R_2}{R_1} = q^{0.46}. \quad (9)$$

Inserting Eqs. (7), (8) and (9) into Eq. (6), one may acquire

$$R_1^3(1+q^{0.46})^3 = 32.7mp^2. \quad (10)$$

Assuming conservation of total mass of the system, from Eq. (10), one can obtain

$$\frac{{\rm d}R_1}{{\rm d}t} = \frac{2R_1}{3p}F(q)\frac{{\rm d}p}{{\rm d}t}, \quad (11)$$

where

$$F(q) = 1 + \frac{0.23q^{0.46}(1+q)}{(1-q)(1+q^{0.46})}\cdot \quad (12)$$

Equation (11) shows a swelling rate of the primary due to an orbital period increase and mass transfer from the less to the more massive component. For GZ And, the swelling velocity of the primary was found to be 4.69×10^{-4} cm s^{-1}.

When the primary expands, the gravitational energy must be overcome by the luminosity of the primary. In other words, part of the nuclear luminosity of the primary could have transformed into the gravitational energy to support the primary expansion. Here, we only care about the results of the transformation, rather than the detailed process. Suppose the primary is spherically symmetric with mass m_1 and radius R_1, then its gravitational energy E_g is written (Kippenhahn & Weigert 1990):

$$E_g = \frac{3Gm_1^2}{(n-5)R_1}, \quad (13)$$

where $n = 3$ for the main-sequence stars. Equation (13) may be rewritten as

$$E_g = \frac{3Gm^2}{(n-5)(1+q)^2R_1^2}\cdot \quad (14)$$

From Eq. (14), the following equation can be derived

$$\frac{dE_g}{dt} = \frac{3Gm^2}{(5-n)(1+q)^2R_1^2}\left(\frac{dR_1}{dt} + \frac{2R_1}{1+q}\frac{dq}{dt}\right)\cdot \quad (15)$$

Inserting Eqs. (5) and (11) into Eq. (15), one may have

$$\frac{dE_g}{dt} = \frac{3Gm^2}{(5-n)(1+q)^2R_1p}\left[F(q) - \frac{q}{1-q}\right]\frac{dp}{dt}\cdot \quad (16)$$

From Eq. (16), one can find that a gravitational luminosity of 1.64 $L_\odot$ is necessary to support the swelling velocity of 4.69×10^{-4} cm s^{-1} of the primary of GZ And. The primary of the system is a main-sequence star and thus the luminosity generated from the nuclear reactions of the primary component with a mass of 1.25 $M_\odot$ is about 2.44 $L_\odot$. The observed luminosity of the primary, however, is only 0.63 $L_\odot$. The luminosity generated from the nuclear reactions could taken in three parts. The first, about 0.63 $L_\odot$, may be radiated through the surface of the primary component. The second, about 1.64 $L_\odot$, may be transformed into gravitational energy of the system to support the swell of the primary. The third, about 0.17 $L_\odot$, may be transferred to the secondary component.

5. Discussion

The supposition of the conservation of total mass of the system may be a valid approximation in the present study, though mass loss through L_2 and angular momentum loss could be possible because of possible magnetic activity and/or star wind. Mass loss may result in a decrease of the orbital period of the system, and then the observed increase of the orbital period of GZ And may be combined from two physics processes: the mass transfer from the secondary to the primary and the mass loss through L_2. However, the mass transfer, which can cause an increase in the orbital period, must be dominant because the observed effect is the increase of the orbital period but also a decrease caused by the mass loss. Furthermore, quantitative estimations suggest that neglecting the mass loss should be allowable for the present study. Since it is difficult to estimate the amount of mass loss of GZ And, we adopt a mass loss rate of 10^{-9} $M_\odot$, which may be an average value of mass loss rate for W UMa-type binaries. According to Pribulla et al. (1999), a decreased rate of the orbital period can be calculated to be $\frac{dp}{p} = 7{\times}10^{-12}$. This is 28 times less than the observed increased rate of the orbital period. Therefore, neglecting possible mass loss through L_2, i.e., adopting the supposition of conservation of total mass of the system, should be feasible.

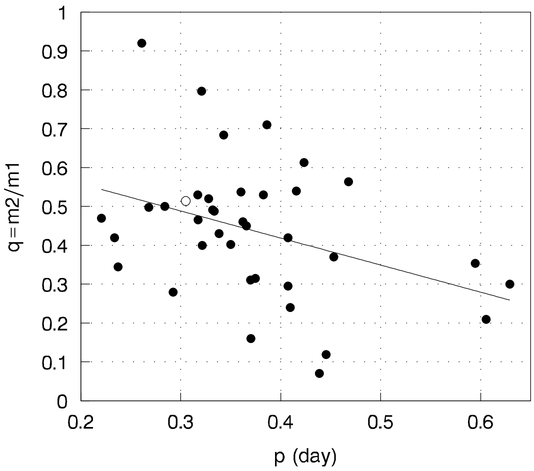

Fig. 3. Mass ratios versus orbital periods for W UMa contact systems. Full circles: the systems with the spectroscopic mass ratios from Maceroni & Veer (1996); open circle: GZ And; line: fit to the full cirlce points.

A long-term continuous increase or decrease in the orbital period is common for many W UMa-type contact systems. This kind of period change may be caused by mass exchange between the two components of a contact system and thus a long-term change of mass ratios of many W UMa-type contact systems may be expected. For GZ And, the mass transfer of $\Delta m = 1.05 \times 10^{-7}$ $M_\odot$yr^{-1} results in a mass ratio decrease of $\Delta q = 1.26 \times 10^{-7}$ yr^{-1}.

As shown from GZ And, it seems to be common for many W UMa type systems that mass transfer between the two components of a W UMa type system must cause mass ratio changes and thus results in orbital period changes. Adopting parameters for 38 W UMa systems with spectroscopic mass ratios listed by Maceroni & Veer (1996), we plotted the spectroscopic mass ratios versus the orbital periods of the systems in Fig. 3, in which the full circles indicate the systems listed by Maceroni & Veer (1996), the line is a fit to these systems and the open circle is GZ And. In despite of the large scatter, from Fig. 3 one can see that mass ratios of W UMa type systems have a linear relation with orbital period. The data of 38 systems were introduced into a least squares solution and the following relation was obtained:

$$q = 0.698 + 0.697p \quad (17)$$

Table 6. W UMa type binaries with long-term continuous increase or decrease of the period.

System	Period [days]	dp/dE [10^{-10} days/cycle]	dM/dt [10^{-7} $M_\odot$yr^{-1}]	Δq_1	Δq_2	Ref.
AH Vir	0.4075	2.42	1.09	−1.25	−1.51	Hobart et al. (1999)
44i Boo	0.2678	1.24	1.15	−1.76	−1.18	Gherega et al. (1994)
Dk Cyg	0.4707	1.15	0.39	−0.30	−0.62	Wolf et al. (2000)
AD Cnc	0.2827	3.40	1.74	−2.36	−3.06	Yang & Liu (2002)
RZ Com	0.3385	0.74	0.61	−0.86	−0.56	Qian (2001)
RZ Tau	0.5509	−1.52	−1.00	0.87	0.70	Zhai et al. (1980)
CN And	0.4628	−1.96	−1.14	1.32	1.08	Samec et al. (1998)
UZ Leo	0.6180	6.07	1.26	−2.76	−2.50	Hegediis & Jager (1992)
V839 Oph	0.4090	3.46	3.31	−2.63	−2.15	Wolf et al. (1996)
V502 Oph	0.4534	−3.40	−1.50	1.65	1.91	Herczeg (1993)
V1010 Oph	0.6614	−7.20	−1.44	1.49	2.77	Herczeg (1993)
TY Boo	0.3171	0.79	0.86	−1.22	−0.63	Qian (2001)
TX Cnc	0.3829	0.59	0.79	−0.92	−0.39	Qian (2001)
BB Peg	0.3615	0.47	0.34	−0.41	−0.33	Qian (2001)
AA UMa	0.4381	1.16	0.99	−1.22	−0.63	Qian (2001)
BX Peg	0.2804	−1.07	−1.01	1.58	0.98	Samac (1990)
YY Eri	0.3215	0.20	0.16	−0.23	−0.16	Kim et al. (1997)
DF Hya	0.3306	1.50	1.18	−1.55	−1.16	Zhang et al. (1989)
AB And	0.3319	1.06	1.18	−1.68	−0.82	Borkovits & Hegedues (1996)
SW Lac	0.3207	0.53	2.55	−4.53	−0.42	Pribulla et al. (1999)
XY Boo	0.3706	6.20	1.80	−1.65	−4.26	Molik & Wolf (1998)
LS Del	0.3630	2.24	2.82	−4.16	−1.57	Qian (2001)
VW Cep	0.2783	−5.81	−4.04	6.67	5.31	Kaszas et al. (1998)
V417 Aql	0.3701	−0.95	−0.59	0.68	0.65	Qian (2001)
EZ Hya	0.4498	−8.40	−2.67	3.76	4.75	Lipari & Sistero (1989)
GZ And	0.3050	2.00	3.85	−4.68	−1.87	present paper
TZ Boo	0.2972	−0.96	−0.35	0.19	0.82	Qian & Liu (2000a)
V401 Cyg	0.5827	2.20	1.83	−1.89	−0.96	Herczeg (1993)
CE Leo	0.3034	5.98	7.56	−12.1	−5.02	Qian (2002)
RW Com	0.2373	−0.39	−0.40	0.58	0.41	Qian (2002)
CT Eri	0.6342	−1.02	−0.72	0.74	0.41	Lipari & Sistero (1987)
LT Pav	0.3937	−2.71	−1.21	1.48	1.75	Cerruti (1994)
CK Boo	0.355	4.83	5.77	−9.01	−3.46	Qian & Liu (2000b)

and then one can have

$$\Delta q = -0.697\Delta p. \quad (18)$$

These two equations suggest orbital period changes of W UMa type systems may be accompanied by mass ratio variance, which may be caused by mass transfer between the two components of the system. For GZ And, adopting the observed period change rate of $\frac{dp}{dt} = 2.40\times10^{-7}$ days yr^{-1}, from Eq. (18) we obtain $\frac{dq}{dt} = 1.67\times10^{-7}$ yr^{-1} which is very close to 1.26×10^{-7} yr^{-1} obtained from Eq. (5). The long-term increase or decrease in the orbital periods of W UMa systems is typical for other systems such as those listed Table 6, in which Δq_1 are computed from Eq. (5) and Δq_2 are computed by Eq. (18). Δq_1 versus Δq_2 is plotted in Fig. 4. The identity between Δq_1 and Δq_2 for every system in Table 6, as shown by that of GZ And, indicates that the linear relation between mass ratios and orbital periods of W UMa type systems, as shown in Fig. 3 or Eqs. (17) and (18), may result from the mass transfer between the two components of the systems because it can contribute to both changes of the orbital period and the mass ratio of a system.

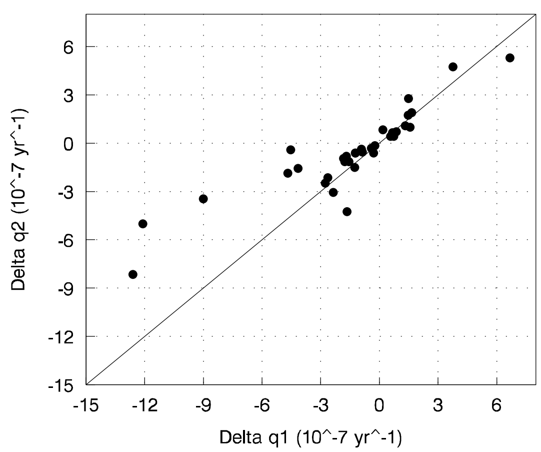

Fig. 4. Mass ratio chang computed from mass transfer vs. ones computed by the Eq. (18) (see text). Delta $q1$ show sones computed from mass transfer and Delta $q2$ indicates ones computed by the Eq. (18).

Both changes of the orbital period and the mass ratio of a system must cause swell or contraction in the component radii of the system and thus gravitational energy of the system must also change. Therefore, an abnormal luminosity of some W UMa-type contact systems may result from transformation between gravitational energy and thermal energy of the systems. If absolute dimensions and a long- term continuous increase or decrease in the orbital period of a system is determined precisely, it is possible to analyze abnormal luminosity of the system by way of the method presented in this paper.

Acknowledgements. The authors would like to thank Mr. J. Li for his assistance in the observations. The authors would also like to express their gratitude for the support from the Yunnan Provincial Science & Technology Department and the Chinese Academy of Sciences.

References

Binnendijk, L. 1970, Vistas Astron., 12, 217
Borkovits, T., & Hegedues, T. 1996, A&AS, 120, 63
Cerruti, M. A. 1994, Acta Astron., 44, 291
Claret, A., & Gimenez, A. 1990, A&A, 230, 412
Donald, C. M., & Thomas, F. A. 1968, ApJ, 151, 611
Eggen, O. J. 1967, MmRAS, 70, 111
Gherega, O., Farkas, L., & Horvath, A. 1994, IBVS No. 4045
Herczeg, T. J. 1993, PASP, 105, 911
Herczeg, T. J., & Jager, Z. 1992, PASP, 104, 733
Hobart, M. A., Pena, J. H., & de La Cniz, C. 1999, Ap&SS, 260, 375
Kaszas, G., Vinko J., Szatmary, K., et al. 1998, A&A, 331, 231
Kim, C. H., Jeong, J. H., Demircan, O., Muyesseroglu, Z., & Budding, E. 1997, AJ, 114, 2753
Kippenhahn, R., & Weigert, A. 1990, Stellar Structure and Evolution (Berlin Springer), 184
Kuiper, G. P. 1941, ApJ, 93, 133
Kruszewski, A. 1966, Adv. Astron. Astrophys., 4, 233
Lipari, S. L., & Sistero, R. F. 1989, AJ, 97, 207
Lipari, S. L., & Sistero, R. F. 1987, AJ, 94, 792
Liu, X., Yang, J., & Tan, H. 1987, IBVS No. 3080
Locher, K. 1995, BBSAG Bull., 108, 3
Locher, K. 1997, BBSAG Bull., 114, 2
Locher, K. 1998, BBSAG Bull., 117, 2
Locher, K. 1999, BBSAG Bull., 120, 2
Locher, K. 2000, BBSAG Bull., 121, 2
Lu, W., & Rucinski, S. M. 1999, AJ, 118, 515
Lucy, L. B. 1967, Z. Astrophys., 65, 89
Maceroni, C., & Veer, F. van't 1996, A&A, 311, 523
Mochnacki, S. W. 1981, ApJ, 245, 650
Molik, P., & Wolf, M. 1998, IBVS No. 4640
Plavec, M. 1968, Adv. Astron. Astrophys., 6, 202
Pribulla, T., Chochol, D., & Parimueha, S. 1999, Contrib. Astron. Obs. Skalnate Pleso, 29, 111
Pribulla, T., Chochol, D., Rovithis-Livaniou, H., & Rovithis, P. 1999, A&A, 345, 137
Qian, S. 2002, A&A, 384, 908
Qian, S. 2001, MNRAS, 328, 635
Qian, S., & Liu, Q. 2000a, A&A, 355, 171
Qian, S., & Liu, Q. 2000b, Ap&SS, 271, 331
Rucinski, S. M. 1969, A&A, 19, 245
Rucinski, S. M. 1974, Acta Astron., 24, 119
Samec, R. G. 1990, AJ, 100, 808
Samec, R. G., Laird, H., Mutzke, M., & Faulkner, D. R. 1998, IBVS No. 4616
Walker, R. L. 1973, IBVS No. 855
Walker, R. L. 1991, BAAS, 23, 881
Walker, R. L. 1996, BAAS, 28, 921
Wilson, R. E., & Biermann 1976, A&A, 48, 349
Wolf, M., & Molik, P. 1996, IBVS No. 4304
Wolf, M., Molik, P., Hornoch, K., & Saronovo, L. 2000, A&A, 147, 243
Yang, Y., & Li, L. 1999, Publication of Yunnan Observatory, 1, 32
Yang, Y., & Liu, Q. 2002, Chin. J. Astron. Astrophys., 2, 369
Zhai, D., & Huang, Y. 1980, Acta Astron. Sin., 21, 158
Zhang, Y., Liu, Q., Yang, Y., Wang, B., & Zhang, Z. 1989, IBVS No. 3349