

## ON THE PERIOD AND LIGHT CURVE OF THE A-TYPE W UMa BINARY GSC 3208 1986

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### Abstract

We present a new period study and light-curve solutions for the A-Type W UMa binary GSC 3208 1986. Contrary to a previous claim by R. G. Samec et al. of a rapidly decreasing period, the system's period is *increasing* moderately on a timescale of  $2 \times 10^6$  years. The light curve is variable on the time scale of years, which can be understood by changes in how much it overfills its Roche lobe.

Contact binaries are binaries close enough that their components are enclosed in a common, probably convective envelope (Lucy 1968). The best known members of this class are the W Ursae Majoris systems (Binnendijk 1970), although there are other rarer binaries that may be in marginal contact (e.g., Kałużny 1983, 1986a–d; Siwak et al. 2010). Binnendijk (pp. 218–221) defined two varieties of these W UMa systems, A-types, with transit primary eclipses, and W-types, with occultation primaries. Given the direct dependence of the ratio of radii on mass ratio in contact binaries, these A- and W-type classes correspond to  $q=M_2/M_1$  less than and greater than 1.0, respectively.

GSC 3308 1986 ( $\alpha(2000)=22^{\text{h}}25^{\text{m}}16^{\text{s}}.0$ ,  $\delta(2000)=+41^{\circ}27'51''.9$ ) is a faint A-type W UMa binary observed and analyzed by Samec et al. (2015a; hereafter SAMEC). SAMEC obtained four nights of photometry ( $\sigma_B \approx 0.006$ ) and found an F3 V spectral type from a spectrum taken at the Dominion Astrophysical Observatory, a mass ratio of  $q=0.24$ , and that the star overfills its Roche lobe by 39%. These properties are not surprising for such a system, but SAMEC also derived a very rapid period *decrease*, corresponding to a timescale of  $3 \times 10^5$  years. This seems unlikely for what they claim is an “ancient” contact system, especially if caused by magnetic braking, their favored period-change mechanism.

## 1 Ephemeris

Suspecting that the radical period decrease might result from R. G. Samec's previously documented (Odell et al. 2011) error of confusing Modified Julian Date (Heliocentric Julian Date – 2,400,000.5) with Reduced Julian Date (HJD – 2,400,000.0) in data from the Northern Sky Variability Survey (NSVS, see Wozniak et al. 2004), we obtained the archival data from the NSVS and SuperWASP (SWASP, see Butters et al. 2010) web sites. We have subsequently obtained new light curves for 2017 and 2018 (Polakis; *BVRI* on the

*UBV/Cousins* system; Table 1, provided as online table 6263-t1.txt at the IBVS web site) and added the published photometry of Liakos & Niarchos (2011) and SAMEC to give nine seasonal light curves. Using these, we find a very different result than SAMEC. We have derived new effective times of minimum for these nine epochs by fitting those seasonal light curves with the Wilson-Devinney code to measure phase shifts with respect to the ephemeris of Eq. 1. These are listed in Table 2; the errors given are the  $\sigma$ 's calculated by the W-D code multiplied by a factor of three per Popper (1984).

**Table 2.** O-C Residuals for linear and quadratic elements (days).

Epoch (Obs) RJD	Cycle (N)	(Obs-Calc) linear (Eq. 1)	(Obs-Calc) quadratic (Eq. 2)	Source of data
51464.1096 $\pm$ 0.0010	-11693	0.0022	-0.0017	NSVS
53247.4351 $\pm$ 0.0003	-7285	-0.0005	0.0003	SWASP 2004
53989.8134 $\pm$ 0.0006	-5450	-0.0014	0.0003	SWASP 2006
54324.7939 $\pm$ 0.00011	-4622	-0.0018	0.0000	SWASP 2007 Epoch1
54374.1509 $\pm$ 0.00013	-4500	-0.0019	-0.0001	SWASP 2007 Epoch2
55410.2457 $\pm$ 0.0005	-1939	-0.0013	-0.0001	Liakos&Niarchos
56194.7011 $\pm$ 0.0003	0	0.0000	-0.0001	Samec
57925.8458 $\pm$ 0.0003	4279	0.0055	-0.0003	Polakis 2017
58415.7787 $\pm$ 0.0002	5490	0.0081	0.0001	Polakis 2018

In analyzing the period, we first used a preliminary linear ephemeris derived by Odell from the NSVS plus Polakis' 2017 data, namely

$$\text{HJD } T_{\min} \text{ I} = 2, 456, 194.7011 + 0.4045663 \times N, \quad (1)$$

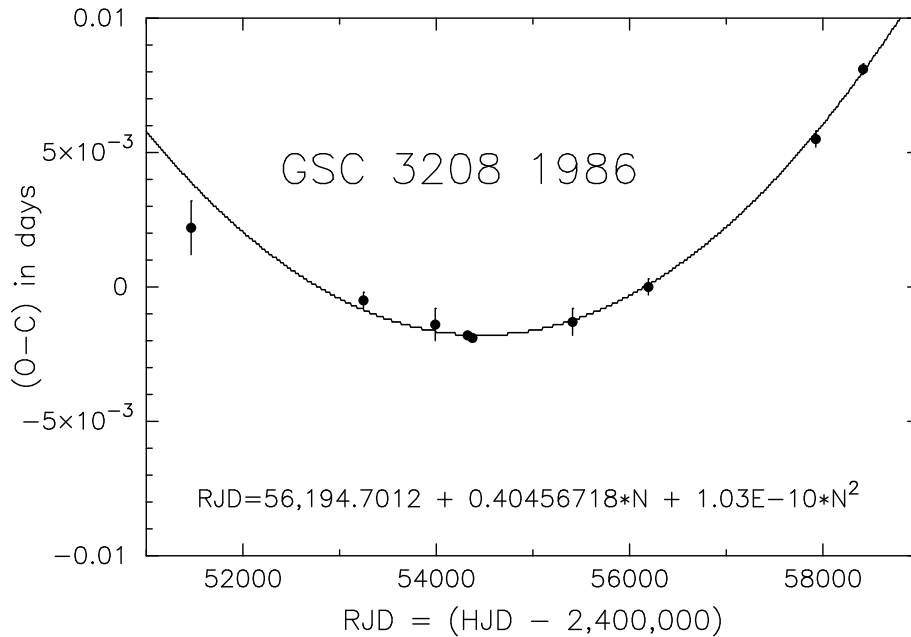
to phase all the data into annual/seasonal light curves. Then we derived the deviations of the phases from this linear ephemeris with the W-D code as noted above, and then fit those deviations with a second-order polynomial to determine the following quadratic ephemeris:

$$\text{HJD } T_{\min} \text{ I} = 2, 456, 194.7012(1) + 0.40456718(1) \times N + 1.03(5) \times 10^{-10} \times N^2. \quad (2)$$

In this equation the numbers in parentheses are errors in the last decimal place, and  $N$  is the cycle number. Fig. 1 shows the deviations from Eq. 1 and the quadratic fit.

## 2 Spectra

Odell obtained two spectra of GSC 3208 1986 with the Boller&Chivens Spectrograph on the Steward Observatory 90-inch telescope around 1 June 2015, specifically at HJD 2,457,173.9734 (phase 0.55) and HJD 2,457,174.8694 (phase 0.76). These spectra covered the wavelength range 3900–4750 Å and are consistent with the F3V spectral type of SAMEC. They give radial velocities for the components of  $RV_1 = 22.1 \pm 7.2 \text{ km s}^{-1}$  for the phase near conjunction and  $RV_1 = 86.9 \pm 8.2 \text{ km s}^{-1}$  and  $RV_2 = -298 \pm 25 \text{ km s}^{-1}$  for the quadrature. These values give a crude indication of the velocity amplitudes of the components,  $K_1 = 91 \pm 16 \text{ km s}^{-1}$  and  $K_2 = 294 \pm 25 \text{ km s}^{-1}$  with  $\gamma = -4 \text{ km s}^{-1}$ . The resulting spectroscopic mass ratio  $q = 0.30 \pm 0.03$  is  $\sim$  consistent with the photometric mass ratio.

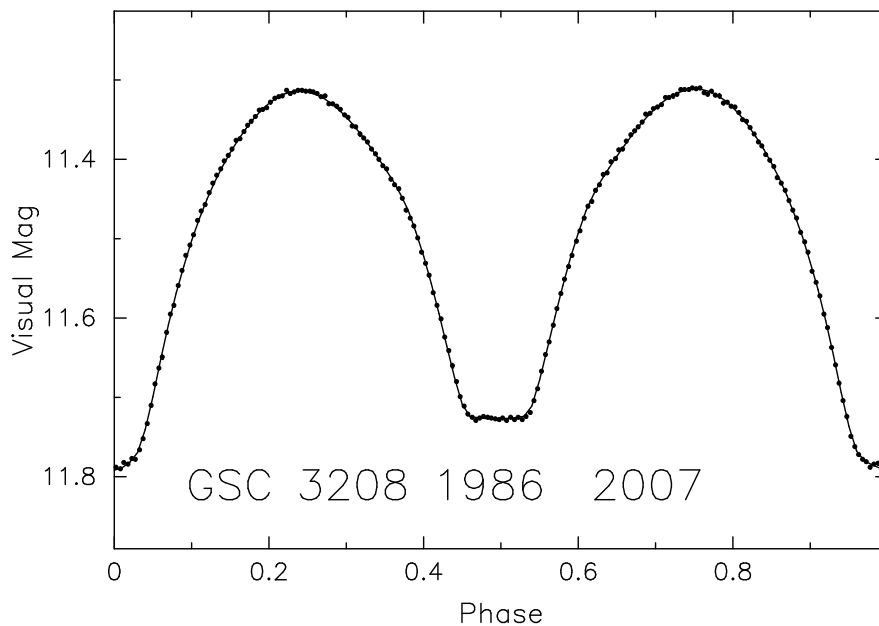


**Figure 1.** O-C Diagram for GSC 3208 1986.

### 3 Light curve

The extensive observations from SWASP give us the opportunity to solve well-defined light curves for the three years, 2007, 2006, and 2004. The data for 2007 are by far the best and most numerous, so we will concentrate on them. Consequently, we have formed 200 normal points derived from the roughly 11,300 SWASP observations for 2007, giving them in online Table 3 (available through the IBVS website as `6263-t3.txt`) as orbital phase (based on Eq. 1), magnitude, and a standard deviation of the mean for each magnitude. The typical normal point has an uncertainty of  $\sigma = 0.0019$  mag (S.D.), nominally giving about the same total weight as the photometry published by SAMEC, but the SWASP data cover enough time to average out the typical wavelength-independent observational errors of data taken on a mere four nights. These data represent a broad band in the optical, corresponding roughly to  $V$  of the  $UBV$  system. Fig. 2 shows the SWASP light curves for 2007 (Table 3) with a representation of the solution of Table 4 plotted as a solid line.

We have solved this light curve with the Wilson-Devinney code [2003 version; see Wilson & Devinney (1971); Wilson (1990,94)], finding the elements in the second column of Table 4. These are roughly consistent with SAMEC's solution (Table 4, Col. 4). In calculating this solution we adopted SAMEC's temperature of the primary, convective gravity darkening (Lucy 1967), convective reflection effect (Rucinski 1969), the Kurucz-atmospheres option in the W-D code, and a linear limb-darkening coefficient from Van Hamme (1993). We accounted for a slight O'Connell effect in the normal points with a small dark spot on the leading hemisphere of the primary component. The small  $\chi^2$  indicates the model fits the data as well as can be expected. For completeness, we calculated a solution for 2007 with radiative gravity darkening and reflection effect, because in the past there was some inkling that these hotter A-type systems might be radiative, but the fit was much worse, by a factor of two in  $\chi^2$ . This radiative solution had a significantly lower fillout, 13%, as expected from the well-known correlation between fillout and gravity



**Figure 2.** Light curve solution for SWASP, normal points for 2007.

darkening.

The other two years of SWASP data had somewhat different light curves which we have solved by varying those elements of the 2007 solution that might conceivably change on the timescale of a few years. Some elements, such as  $q$  and  $i$ , cannot change materially on such a short timescale, so we are left with temperatures and fillout that might change. Keeping  $q$ ,  $i$ ,  $T_1$  fixed, we get the solution in Col. 3 of Table 4 for 2004. A greater depth of both eclipses in 2004 led to a larger overfilling of the Roche lobe. The solution for 2006 had a marginally larger fillout, 39%, for the worst data of the three years ( $\sigma = 0.014$  mag). The differences between 2007 and 2004 might conceivably result from a change in the photometric band of the observations, but it would require a shift at least as great as from  $V$  to  $B$  between the two years. A shift of this magnitude is rather unlikely (see Butters et al. 2010, Fig. 1).

All of these solutions imply that the standard overcontact model fits GSC 3208 1986 well. Values of  $T_{\text{mult}}$ , which measures the ratio of  $T_2$  as measured in W-D, Mode 3, to its value for W-D, Mode 1, (no break in temperature at the neck between the components), are 1.0 for all practical purposes, so the temperature varies smoothly over the surface as determined by the gravity-darkening law. The solution for a radiative envelope, however, does not have this property and gives a significantly worse fit, so the envelope is not likely to be radiative.

You may have noticed that the quoted errors of our solution for 2007 and SAMEC's solution for 2012 are inconsistent, although the two data sets have roughly the same weight ( $\#\text{points}/\sigma^2$ ). This probably results from the way such uncertainties are calculated. If we calculate the uncertainty of each element independently of all the others, we get values for the 2007 SWASP solution similar to those quoted by SAMEC. However, if we let elements  $q$ ,  $i$ ,  $\Omega$ ,  $T_2$ , and the  $x$ 's vary simultaneously, we get the uncertainties listed. Adding  $g$  and  $A_{\text{bol}}$  to the mix gives even bigger uncertainties, doubling the reported uncertainty of  $\Omega$ . This result confirms Popper's (1984) insinuation that the uncertainties derived by the

**Table 4.** GSC 3208 1986: Light curve solutions

Parameter (1)	2007-SWASP (2)	2004-SWASP (3)	2012-SAMEC (4)	2017-Polakakis (5)	2018-Polakakis (6)
$x_1=x_2$ (fixed)	0.51	0.51	Non-linear	0.63,0.51,0.41,0.33	0.63,0.51,0.41,0.33
$g$ (fixed)	0.32	0.32	0.32	0.32	0.32
$A_{\text{bol}}$ (fixed)	0.50	0.50	0.50	0.50	0.50
$i$ (deg)	$85.60 \pm 0.27$	85.60 (fixed)	$85.8 \pm 0.1$	85.60 (fixed)	85.60 (fixed)
$q$ ( $M_2/M_1$ )	$0.2424 \pm 0.0011$	0.2424 (fixed)	$0.2374 \pm 0.0002$	0.2424 (fixed)	0.2424 (fixed)
$\Omega$	$2.2811 \pm 0.0020$	$2.269 \pm 0.0020$	$2.261 \pm 0.001$	$2.273 \pm 0.0018$	$2.279 \pm 0.0016$
fillout	$35.3 \pm 1.3\%$	$49.1 \pm 1.3\%$	$39 \pm 0.7\%$	$40.3 \pm 1.2\%$	$36.8 \pm 1.0\%$
$T_1$ (K, fixed)	6875	6875	6875	6875	6875
$T_2$ (K)	$6757 \pm 22$	$6789 \pm 10$	$6760 \pm ?$	$6745 \pm 11$	$6725 \pm 8$
$T_{\text{mult}}$	$0.9950 \pm 0.0032$	$1.0009 \pm 0.0014$	0.9968	0.9948	0.9909
$\sigma$ (mag)	0.0019/point	0.0066/point	$\sim 0.006/\text{point}$	$\sim 0.013/\text{point}$	$\sim 0.013/\text{point}$
$\chi^2/\text{DOF}$	1.2	1.1	$\sim 1.44$	$\sim 2.2$	$\sim 1.0$
Spot on the Primary Component					
lat,long (deg)	0,270	0,270	none	none	none
$r_{\text{spot}}$ (deg)	1.7	1.7			
$T_{\text{spot}}$	(black)	(black)			

W-D code are misleading. It also points to the intuitive truth that our assumptions about limb darkening, gravity darkening, and reflection effect will inevitably bias the results for all these contact and near-contact binaries.

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