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ANOTHER COMPONENT IN THE V523 CASSIOPEIAE ECLIPSING BINARY SYSTEM

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V523 Cassiopeiae is a W UMa type eclipsing binary. Samec et al. (2004) used 160,000 orbits measured over a period of 102 years for a comprehensive period study. Their O–C diagram strongly suggests a sinusoidal term which is indicative of a third star in the binary system. According to Samec et al. (2004), if a third star were present, it would be about 0.41 solar masses with a period of 101 ± 5 years. However, the difference in the O–C curve calculated from linear light elements and from light elements that include the sinusoidal term could not be clearly distinguished in their O–C diagram. Extrapolating the Samec et al. (2004) linear and sinusoidal ephemerides from 2004 to 2013 shows that a departure from their O–C curves will begin in 2013, after 40,000 orbits since 2004, if a third component exists. We set out to observe the V523 Cas light curve through many orbits in 2012 and 2013 and calculated the O–C diagram through 2013. If a third component is present, it should be clear from the new O–C diagram.

V523 Cas is located at $\alpha_{2000} = 0^{\rm h}40^{\rm m}06\overset{\rm s}{.}2$, $\delta_{2000} = +50^\circ 14' 16\overset{''}{.}0$ and is fairly bright with $V \sim 10.9$ magnitudes and about 1.0 magnitude difference between minimum and maximum. The system was observed using the Pisgah Astronomical Research Institute 0.4-m telescope equipped with an Apogee E42 2048×2048 CCD camera and VRI filters. Exposure times were 40 seconds in each filter. The number of images per filter per night varied from 80 to 120. Observations were made on UT 2012 October 22, 23, 24, 25, November 2, 9, 11, 14, 16, 18, 19, 21, 22, 25, 26, 29, and UT 2013 October 10, 11, 12, 24, November 4, 8, 11, 14, 15. A total of 1,833 images were made in each filter over the two year period.

The telescope and camera have a 30 arcminute field of view. Three stars in this field of view were selected as the comparison and check stars. Table 1 lists the coordinates and magnitudes of these stars and Figure 1 is the finding chart. The V magnitudes are from the Tycho-2 Catalog (Hog et al. 2000) and the R and I magnitudes are from the USNO B1.0 Catalog (Monet et al. 2003).

Table 1. Comparison and check stars.

Star	RA (J2000)	Dec (J2000)	V	R	I
BD+49 151 (Comparison)	00 40 15.01	+50 07 14.6	9.75	9.63	9.53
BD+49 154 (Check 1)	00 40 26.17	+50 06 16.0	9.84	9.69	9.56
TYC 3257-747-1 (Check 2)	00 40 49.02	+50 22 49.13	10.27	9.93	9.67

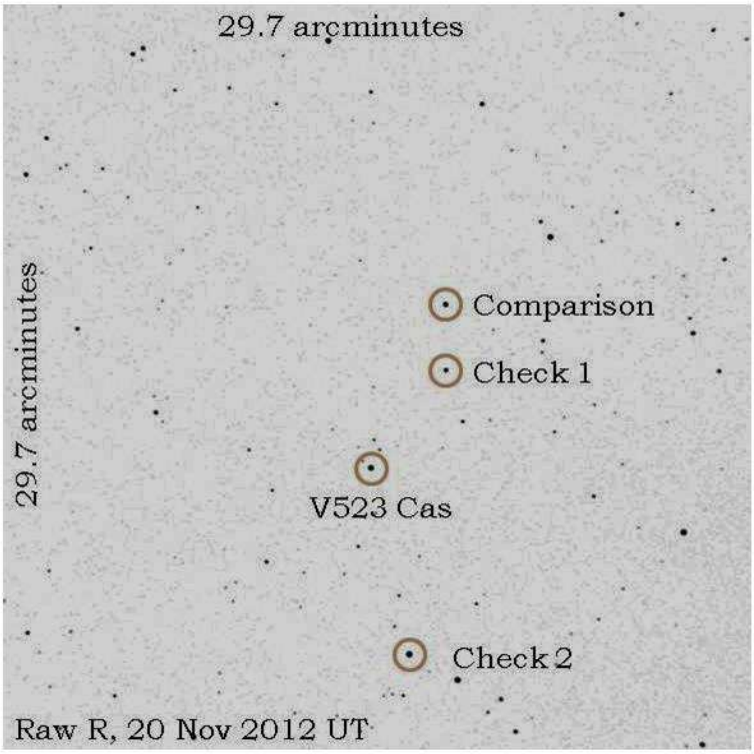

Figure 1. Finding chart for V523 Cas.

The images were bias, dark, and flat field corrected. Photometry of V523 Cas and comparison and check stars was done with an aperture radius of 12 arcseconds for star brightness measurement, and a concentric outer annulus from 14 arcseconds to 17 arcseconds for sky measurements. The magnitude measurement error was 0.010, 0.008, and 0.006 in V, R, and I, respectively. The time of measurement was converted to heliocentric Julian date. Phase was calculated from the ephemeris $2446708.786 + 0.^{\mathrm{d}}233691049E$ (Samec et al. 2004). Figure 2 shows the light curve of V523 Cas from all observations made in 2012 and 2013. The V, R, and I observations are given in Tables 2, 3 and 4 as HJD, orbital phase (based on the ephemeris) and magnitude. (The tables are available through the IBVS website as `6120-t1.txt`, `6120-t2.txt`, and `6120-t3.txt`.)

Over the total of 25 days of observations in two years, 30 primary minima were measured. Two primary minima were observed in one night on 2012 October 23, November 11, 14, 18 and 2013 October 12, 24, and November 14. On all other days, only one primary minimum was observed. The opportunity exists to precisely measure the period of the V523 Cas directly on 7 separate occasions. In order to measure the period and calculate the O–C curve, the time of minimum must be determined. Table 5 lists the dates of observations, times of minima measured with bisector of chords method of Kwee and van Woerden (1956) and the error in determining the primary minima. Also included in Table 5 are all (48) published primary minima measured between 2004 and the observations presented here. Note that the bisector of chords method was used by Samec et al. (2004) in their period analysis that led to the suggestion of a third component in the system.

The linear light ephemeris used to calculate times of minima without a third component was determined from Samec et al. (2004) and is

HJD min. I $= 2446708.7773 + 0.^{\mathrm{d}}233689935E$

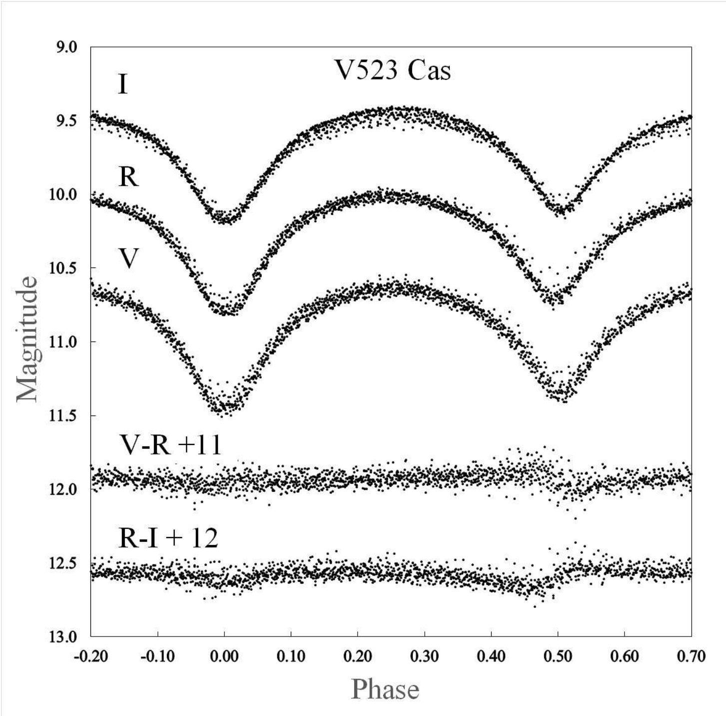

Figure 2. V523 Cas *VRI* light curves.

The linear light ephemeris was applied to all recorded times of primary minima given in the Brno Regional Network of Observers O–C Gateway database (Paschke & Brat 2006), plus the current set of observed primary minima. Figure 3 shows the O–C values. The best fit which includes the effect of a third component to the O–C values is given by the ephemeris with a sinusoidal term (Samec et al. 2004):

HJD min. I $= 2446708.8030 + 0\overset{d}{.}233691049E + 1.1\cdot10^{-11}E^2 + (0\overset{d}{.}041)[\sin(3.90\cdot10^{-5}E - 1.04]$

The sinusoidal fit, as well as a parabolic fit, are shown in Figure 3. Figure 4 is the same O–C diagram, but showing the data only from 2004 through 2013. Figure 4 clearly shows the deviation between the parabolic and sinusoidal models of the O–C diagram. Table 5 lists the current O–C residuals and those measured since 2004 for both the parabolic and sinusoidal models. (Table 5 is available through the IBVS website as `6120-t4.txt`.)

The sinusoidal fit of the O–C residuals does not deviate and represents a better model than a parabolic fit, strongly suggesting the presence of a third component. We adopt the sinusoidal ephemeris as best predicting the times of minima of V523 Cas.

Kepler's third law and using the sinusoidal component with an amplitude of 0.041 days implies the mass of the third component according to this ephemeris is 0.6 solar masses and the orbital period of the larger system is 70 years, assuming all three stars are in the same orbital plane.

An orbital period of 70 years implies a semimajor axis of 17 AU or a maximum angular separation of 0.25 arcseconds at the distance of V523 Cas of 69 pc (Samec et al. 2004). Rucinski et al. (2007) searched eclipsing binaries for companions using an adaptive optics method. Their resolution was 0.07–0.08 arcseconds in separation and magnitude difference in the K filter up to 6 magnitudes. V523 Cas was included in their search. They did not

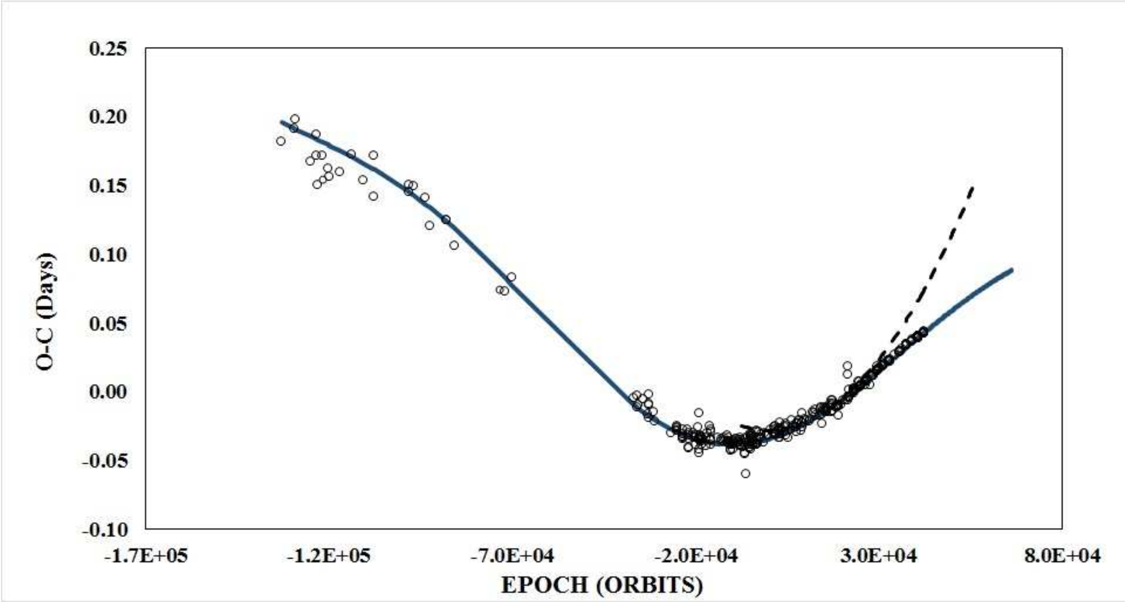

Figure 3. V523 Cas O–C diagram from to 2013. The circles represent the O–C values, the dashed line is the ephemeris without a third component and the solid line is the ephemeris that includes a third component.

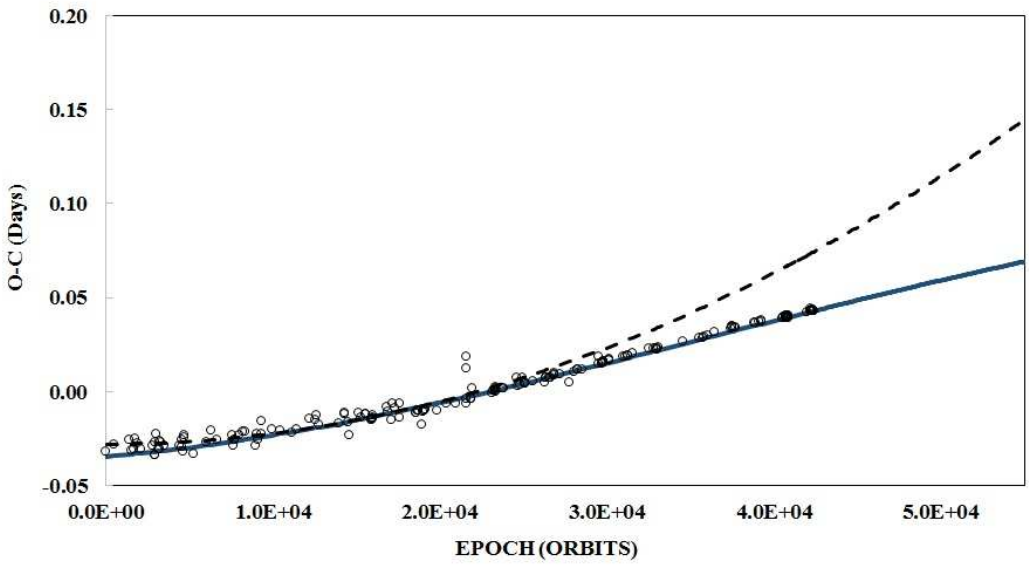

Figure 4. V523 Cas O–C diagram from 2004 to 2013. The circles represent the O–C values, the dashed line is the ephemeris without a third component and the solid line is the ephemeris that includes a third component

detect the third component which implies that the third component must be nearly along the line of sight to the eclipsing binary system of V523 Cas. However, a quarter of a period later, or in about 18 years, the third component should be clearly visible with current spatial resolution imaging capabilities.

Table 5. Times of Minima and O–C residuals.

Date	Primary Minimum (HJD 2450000+)	Error[a] (days)	Parabolic O–C residuals	Sinusoidal O–C residuals	Ref[b]
2004 Feb 20	3056.3286	0.008	−0.00473	0.00042	1
2004 Jul 07	3193.501	—	−0.01081	−0.00512	2
2004 Sep 14	3263.1465	—	−0.00619	−0.00021	3
2004 Nov 06	3316.429	—	−0.00598	0.00023	3
2004 Nov 07	3316.6628	—	−0.00587	0.00033	3
2004 Dec 29	3369.0099	0.0003	−0.00629	0.00014	4
2005 Aug 16	3599.436	—	−0.00283	0.00467	2
2005 Aug 19	3602.2365	—	−0.00666	0.00085	3
2005 Oct 05	3648.508	—	−0.00666	0.00108	3
2005 Oct 06	3650.3771	—	−0.00711	0.00063	3
2005 Oct 07	3651.3117	—	−0.00729	0.00046	1
2005 Oct 07	3661.5948	—	−0.00675	0.00105	3
2005 Oct 08	3662.2965	—	−0.00613	0.00167	3
2005 Oct 08	3662.5295	—	−0.00682	0.00098	3
2005 Oct 25	3669.307	—	−0.00646	0.00137	4
2006 Jan 09	3745.2573	—	−0.00686	0.00135	1
2006 Jan 09	3745.4916	0.0011	−0.00626	0.00196	3
2006 Jul 26	3943.4294	0.0001	−0.00772	0.00153	5
2006 Sep 08	3987.3632	0.0001	−0.00851	0.00099	6
2006 Oct 09	4018.211	0.0001	−0.00839	0.00127	3
2006 Oct 10	4019.3796	—	−0.00827	0.00141	7
2006 Dec 16	4086.4499	0.0004	−0.00833	0.00173	6
2007 Aug 02	4314.5347	—	−0.00956	0.00185	5
2007 Sep 22	4366.4144	—	−0.01010	0.00163	3
2007 Oct 27	4401.2344	—	−0.01062	0.00133	3
2007 Nov 17	4422.0319	—	−0.01196	0.00012	3
2007 Nov 24	4429.0432	—	−0.01150	0.00062	3
2007 Dec 07	4441.6632	0.0001	−0.01102	0.00118	8
2008 Nov 08	4779.3502	0.0001	−0.01316	0.00132	9
2009 Jul 04	5017.4829	0.0001	−0.01571	0.00051	10
2009 Aug 10	5054.4066	0.0001	−0.01584	0.00066	10
2009 Sep 02	5076.6077	—	−0.01577	0.00090	10
2009 Oct 21	5126.3843	0.0001	−0.01624	0.00082	3
2010 Jan 24	5221.2646	—	−0.01618	0.00162	10
2010 Sep 21	5461.0338	—	−0.01832	0.00146	3
2010 Sep 28	5468.2785	—	−0.01817	0.00167	3
2010 Oct 08	5478.3278	—	−0.01777	0.00216	3
2010 Oct 09	5478.5615	0.0001	−0.01777	0.00216	3
2010 Oct 30	5500.2942	0.0003	−0.01873	0.00138	10
2010 Nov 17	5517.5877	0.0002	−0.01869	0.00158	11
2011 Aug 04	5778.3891	—	−0.02137	0.00122	12
2011 Aug 21	5794.514	—	−0.02145	0.00128	3
2011 Oct 15	5850.3669	—	−0.02178	0.00148	3
2011 Nov 17	5883.0837	—	−0.02235	0.00121	3
2011 Nov 17	5883.3178	0.0002	−0.02195	0.00162	3
2012 Sep 12	6183.3786	0.0002	−0.02629	0.00020	12
2012 Sep 18	6189.4547	—	−0.02628	0.00027	12
2012 Sep 19	6219.6015	—	−0.02622	0.00064	3
2012 Oct 22	6222.63863	0.00022	−0.02761	−0.00072	13
2012 Oct 23	6223.57480	0.00175	−0.02587	0.00103	13
2012 Oct 23	6223.80757	0.00014	−0.02697	−0.00006	13
2012 Oct 24	6224.74323	0.00059	−0.02661	0.00030	13

Table 5. Continued Times of Minima and O–C residuals.

Date	Primary Minimum (HJD 2450000+)	Error[a] (days)	Parabolic O–C residuals	Sinusoidal O–C residuals	Ref[b]
2012 Nov 02	6233.62264	0.00022	−0.02747	−0.00047	13
2012 Nov 09	6240.63314	0.00011	−0.02718	−0.00010	13
2012 Nov 11	6242.50281	0.00015	−0.02714	−0.00005	13
2012 Nov 11	6242.73649	0.00014	−0.02703	0.00007	13
2012 Nov 14	6245.54068	0.00053	−0.02750	−0.00038	13
2012 Nov 14	6245.77544	0.00043	−0.02671	0.00041	13
2012 Nov 16	6247.64421	0.00014	−0.02755	−0.00040	13
2012 Nov 18	6249.51396	0.00026	−0.02693	0.00023	13
2012 Nov 18	6249.74730	0.00007	−0.02720	−0.00003	13
2012 Nov 19	6250.68245	0.00025	−0.02707	0.00011	13
2012 Nov 21	6252.55234	0.00012	−0.02671	0.00049	13
2012 Nov 22	6253.48601	0.00048	−0.02767	−0.00046	13
2012 Nov 25	6256.52497	0.00029	−0.02702	0.00021	13
2012 Nov 29	6260.49747	0.00021	−0.02720	0.00008	13
2013 Aug 14	6519.4294	—	−0.02999	0.00002	3
2013 Oct 10	6575.74935	0.00016	−0.03074	−0.00012	13
2013 Oct 11	6576.68531	0.0004	−0.02956	0.00108	13
2013 Oct 12	6577.61881	0.00021	−0.03083	−0.00018	13
2013 Oct 12	6577.85236	0.00008	−0.03096	−0.00031	13
2013 Oct 24	6589.53704	0.00024	−0.03092	−0.00014	13
2013 Oct 24	6589.77115	0.00025	−0.03047	0.00032	13
2013 Nov 04	6600.75474	0.00015	−0.03058	0.00032	13
2013 Nov 08	6604.72680	0.00015	−0.03127	−0.00032	13
2013 Nov 11	6607.76530	0.00001	−0.03103	−0.00005	13
2013 Nov 14	6610.56932	0.00014	−0.03126	−0.00025	13
2013 Nov 14	6610.80309	0.00021	−0.03147	−0.00045	13
2013 Nov 15	6611.50413	0.00055	−0.03120	−0.00018	13

[a] Errors are stated when given in the reference.
[b] 1) Brat et al. 2007, 2) Locher 2005, 3) Paschke & Brat 2006, 4) Kim et al. 2006, 5) Parimucha et al. 2007, 6) Dogru et al. 2007a, 7) Csizmadia 2006, 8) Dogru et al. 2007b, 9) Hübscher et al. 2009, 10) Parimucha et al. 2011, 11) Diethelm 2011, 12) Parimucha et al. 2013, 13) This paper.

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