First Photometric Study of the Short Period Solar Type Binary V1073 Herculis and the Possible Detection of a Dwarf Companion

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Abstract V1073 Herculis is a very short period, P = 0.294281673(4) day, active solar type eclipsing binary. It was observed in May 2012 with the Lowell Observatory 31-inch NURO reflector. This period study consists of some 54 times of minimum light covering nearly 18,000 orbits. A very low amplitude, 0.002-day sinusoidal variation is detected with a period of 11.25 years, which may indicate the presence of a dwarf third component. The temperature of the binary is ~5200K. A preliminary simultaneous Wilson-Devinney Program solution including a q-search reveals that the system has a mass ratio of 0.4, nearly identical component temperatures, and a cool magnetic spot with a T-factor of 0.86 with a spot radius of 22 degrees. The Roche Lobe fill-out is 0.18. The inclination is 82 degrees which results in a brief total eclipse.

1. Introduction

This paper represents the first precision and multicolor photometric study of the interesting, high amplitude solar type W UMa eclipsing binary, V1073 Her.

2. History and observations

V1073 Her (GSC 2625.1563, ROTSE1 J180835.74+334205.7) was imaged in test fields of the ROTSE all-sky survey (Akerlof *et al.* 2000). The first unfiltered CCD light curves were taken by Blätter and Diethelm (2000). These curves are shown in Figure 1. It was included in the NSVS survey (Hoffman *et al.* 2009) and is classified as a W UMa variable. Eclipse timings have been given in Diethelm (2003, 2004, 2006), Brát *et al.* (2007), Nelson (2008, 2009), Brát *et al.* (2008, 2011), Hübscher (2007), Diethelm (2012), Hübscher (2009), Hübscher *et al.* (2012), and Hoňková *et al.* (2013). It was included in the "77th Name list of variable stars" (Kazarovets *et al.* 2003), and also appeared in the catalog of field contact binary stars, (Pribulla *et al.* 2003). Updated elements were given by Kreiner (2004). It was listed in "A Catalog of 1022 Bright Contact Binary Stars" by Gettel *et al.* (2006). Its period was listed as 0.294283d along with color indices J–H = 0.352, H–K = 0.100.

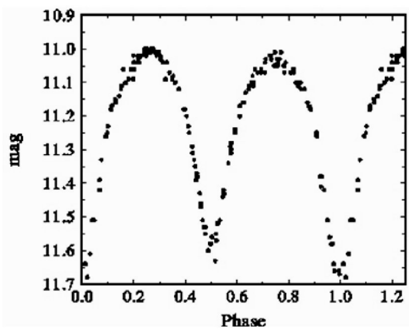

Figure 1. The first unfiltered CCD light curves ov V1073 Her were taken by Blätter and Diethelm (2000).

This system was observed as a part of our student/professional collaborative studies of interacting binaries from data taken from NURO observations (National Undergraduate Research Observatory). The observations were taken by Ron Samec, Justin Benkendorf, and James Dignan. Reduction and analyses were mostly done by Ron Samec and James Kring.

Our 2012 BVRI light curves were taken with the Lowell 0.81-m reflector in Flagstaff on 7, 9, 11, and 12, May 2012, with CRYOTIGER cooled (–100C) 2048 × 2048 NASACAM and standard $UBVR_cI_c$ Johnson-Cousins filters. Individual observations included 265 in B, 247 in V, and 254 in both R and I. The probable error of a single observation was 5 mmag in B and 3 mmag in V, R, and I. The stars in this study (Table 1) were chosen in the same field (V−C has |Δ(B−V)| < 0.2) as designated on the finding chart included for the convenience of future observers (Figure 2). Figures 3a and 3b show sample observations and color curves on 9 and 11 May 2012. Our observations are given in Tables 2a, 2b, 2c, and 2d, in delta magnitudes, ΔB, ΔV, ΔR, and ΔI, in the sense of variable minus comparison star.

Table 1. The variable (V), comparison (C), and check (K) stars in this study.

Star	*Name*	*R.A. (2000)* h m s	*Dec. (2000)* ° ′ ″	*V*	*B–V*	*Source**
V	V1073 Her	18 08 35.766	+33 42 05.45	11.616	0.936	*Guide 9*
C	TYC 2625 1672	18 08 22.876	+33 38 26.14	11.24	0.763	*Guide 9*
K	TYC 2629 1443	18 08 39.323	+33 48 14.38	10.98	0.757	*Guide 9*

**Guide 9 (Project Pluto 2012).*

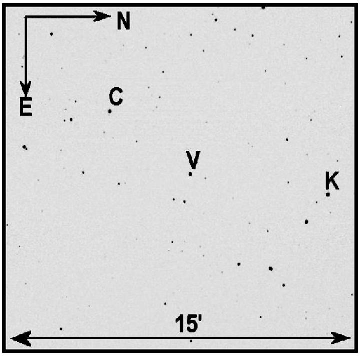

Figure 2. Finding Chart, V1073 Her. Variable (V), Comparison (C), and Check (K).

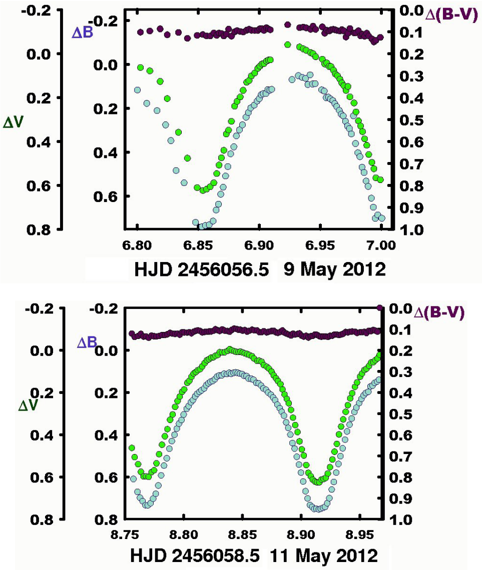

Figure 3. (a, top panel) B,V delta magnitudes from sample observations and color curves on May 9, 2012. (b, bottom panel). B,V delta magnitudes and color curves on May 11, 2012.

Table 2a. V1073 Her observations ΔB, variable minus comparison star.

ΔB	BHJD 2455800+	ΔB	BHJD 2455800+	ΔB	BHJD 2455800+	ΔB	BHJD 2455800+
0.411	4.9655	0.114	6.9070	0.715	8.7651	0.105	8.8443
0.327	4.9726	0.117	6.9086	0.734	8.7674	0.108	8.8461
0.289	4.9766	0.113	6.9102	0.735	8.7695	0.111	8.8479
0.252	4.9805	0.069	6.9269	0.725	8.7719	0.113	8.8498
0.223	4.9845	0.051	6.9321	0.703	8.7741	0.122	8.8516
0.196	4.9884	0.059	6.9353	0.680	8.7763	0.123	8.8536
0.155	4.9932	0.063	6.9380	0.641	8.7785	0.134	8.8553
0.144	5.0017	0.091	6.9398	0.593	8.7809	0.136	8.8577
0.177	6.8079	0.089	6.9437	0.547	8.7833	0.140	8.8595
0.210	6.8163	0.087	6.9458	0.512	8.7856	0.155	8.8620
0.275	6.8233	0.115	6.9512	0.467	8.7879	0.157	8.8638
0.347	6.8276	0.121	6.9533	0.431	8.7900	0.168	8.8660
0.483	6.8319	0.151	6.9549	0.401	8.7922	0.181	8.8678
0.539	6.8385	0.149	6.9567	0.372	8.7942	0.188	8.8702
0.719	6.8478	0.157	6.9583	0.348	8.7961	0.201	8.8720
0.739	6.8530	0.164	6.9603	0.331	8.7982	0.211	8.8744
0.733	6.8560	0.178	6.9619	0.305	8.8000	0.224	8.8762
0.730	6.8590	0.191	6.9635	0.278	8.8026	0.237	8.8780
0.713	6.8622	0.209	6.9656	0.265	8.8043	0.258	8.8798
0.663	6.8647	0.234	6.9688	0.247	8.8062	0.275	8.8819
0.636	6.8666	0.259	6.9706	0.236	8.8080	0.292	8.8836
0.591	6.8685	0.280	6.9723	0.219	8.8098	0.310	8.8855
0.559	6.8705	0.292	6.9739	0.206	8.8116	0.342	8.8873
0.508	6.8724	0.316	6.9755	0.198	8.8135	0.368	8.8891
0.465	6.8743	0.360	6.9789	0.190	8.8153	0.400	8.8909
0.407	6.8766	0.402	6.9808	0.181	8.8175	0.440	8.8927
0.375	6.8792	0.420	6.9825	0.166	8.8193	0.466	8.8945
0.325	6.8813	0.468	6.9842	0.157	8.8211	0.505	8.8964
0.298	6.8838	0.492	6.9859	0.150	8.8229	0.542	8.8982
0.275	6.8863	0.531	6.9876	0.146	8.8248	0.580	8.9000
0.240	6.8892	0.555	6.9892	0.138	8.8266	0.622	8.9018
0.219	6.8911	0.609	6.9918	0.125	8.8285	0.668	8.9038
0.198	6.8930	0.650	6.9935	0.120	8.8303	0.702	8.9056
0.185	6.8959	0.701	6.9951	0.120	8.8324	0.733	8.9076
0.166	6.8984	0.685	6.9971	0.112	8.8345	0.742	8.9094
0.155	6.9001	0.700	7.0004	0.113	8.8369	0.752	8.9112
0.138	6.9017	0.610	8.7573	0.108	8.8388	0.751	8.9130
0.133	6.9033	0.671	8.7607	0.112	8.8405	0.754	8.9150
0.132	6.9055	0.699	8.7629	0.108	8.8425	0.751	8.9168

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Table 2a. V1073 Her observations ΔB, variable minus comparison star, cont.

ΔB	BHJD 2455800+	ΔB	BHJD 2455800+	ΔB	BHJD 2455800+	ΔB	BHJD 2455800+
0.747	8.9186	0.155	8.9627	0.101	9.8837	0.470	9.9264
0.742	8.9204	0.149	8.9646	0.103	9.8855	0.507	9.9284
0.725	8.9223	0.140	8.9664	0.117	9.8874	0.544	9.9302
0.701	8.9241	0.183	9.8411	0.123	9.8892	0.582	9.9320
0.660	8.9261	0.152	9.8464	0.127	9.8911	0.618	9.9339
0.624	8.9279	0.148	9.8484	0.129	9.8929	0.663	9.9357
0.580	8.9300	0.138	9.8502	0.146	9.8947	0.689	9.9376
0.539	8.9318	0.125	9.8526	0.157	9.8965	0.730	9.9416
0.502	8.9336	0.125	9.8544	0.166	9.8984	0.740	9.9487
0.465	8.9354	0.100	9.8578	0.177	9.9002	0.728	9.9505
0.424	8.9374	0.106	9.8596	0.192	9.9021	0.709	9.9523
0.385	8.9392	0.099	9.8616	0.203	9.9039	0.678	9.9541
0.353	8.9413	0.092	9.8634	0.217	9.9057	0.639	9.9559
0.324	8.9431	0.086	9.8654	0.228	9.9075	0.608	9.9577
0.293	8.9454	0.086	9.8672	0.249	9.9095	0.574	9.9596
0.272	8.9472	0.083	9.8690	0.254	9.9113	0.544	9.9614
0.250	8.9496	0.079	9.8708	0.281	9.9133	0.504	9.9633
0.231	8.9514	0.082	9.8726	0.302	9.9151	0.481	9.9651
0.214	8.9533	0.080	9.8744	0.327	9.9169	0.449	9.9670
0.203	8.9551	0.080	9.8762	0.350	9.9188	0.421	9.9688
0.197	8.9573	0.087	9.8780	0.377	9.9208	0.394	9.9706
0.172	8.9591	0.091	9.8798	0.412	9.9226	0.372	9.9724
0.168	8.9609	0.095	9.8816	0.442	9.9246		

Table 2b. V1073 Her observations ΔV, variable minus comparison star.

ΔV	BHJD 2455800+	ΔV	BHJD 2455800+	ΔV	BHJD 2455800+	ΔV	BHJD 2455800+
0.404	4.9582	0.058	6.9005	0.566	6.9956	0.034	8.8254
0.282	4.9661	0.048	6.9022	0.538	6.9976	0.027	8.8271
0.183	4.9730	0.046	6.9038	0.575	6.9992	0.023	8.8291
0.149	4.9770	0.035	6.9059	0.573	7.0009	0.010	8.8308
0.123	4.9809	0.030	6.9075	0.555	7.0026	0.010	8.8350
0.098	4.9849	0.029	6.9091	0.595	7.0059	–0.004	8.8393
0.070	4.9889	0.018	6.9106	0.463	8.7559	0.005	8.8431
0.043	4.9936	–0.001	6.9193	0.507	8.7583	0.008	8.8448
0.030	4.9976	–0.030	6.9331	0.540	8.7613	0.009	8.8467
0.020	5.0021	–0.021	6.9361	0.576	8.7636	0.007	8.8484
0.018	6.7960	–0.015	6.9385	0.598	8.7658	0.011	8.8503
0.064	6.8027	–0.004	6.9421	0.598	8.7680	0.015	8.8521
0.079	6.8104	0.001	6.9441	0.600	8.7702	0.019	8.8541
0.127	6.8188	0.015	6.9462	0.578	8.7726	0.023	8.8559
0.205	6.8246	0.026	6.9517	0.569	8.7748	0.029	8.8583
0.245	6.8289	0.047	6.9537	0.536	8.7769	0.040	8.8600
0.359	6.8338	0.043	6.9553	0.493	8.7791	0.051	8.8626
0.477	6.8412	0.059	6.9572	0.448	8.7816	0.050	8.8644
0.611	6.8492	0.059	6.9588	0.408	8.7840	0.055	8.8665
0.624	6.8538	0.076	6.9608	0.374	8.7862	0.071	8.8683
0.618	6.8568	0.093	6.9624	0.330	8.7885	0.079	8.8708
0.607	6.8598	0.101	6.9640	0.305	8.7907	0.087	8.8726
0.589	6.8628	0.117	6.9661	0.269	8.7928	0.102	8.8749
0.547	6.8652	0.134	6.9677	0.241	8.7948	0.119	8.8767
0.508	6.8671	0.146	6.9693	0.220	8.7967	0.133	8.8786
0.475	6.8690	0.168	6.9711	0.198	8.7987	0.146	8.8804
0.441	6.8710	0.150	6.9727	0.186	8.8005	0.161	8.8824
0.367	6.8730	0.197	6.9743	0.155	8.8031	0.186	8.8842
0.349	6.8749	0.243	6.9760	0.145	8.8049	0.210	8.8860
0.309	6.8772	0.225	6.9777	0.126	8.8067	0.231	8.8878
0.240	6.8798	0.266	6.9793	0.111	8.8085	0.252	8.8896
0.218	6.8819	0.307	6.9813	0.104	8.8104	0.283	8.8914
0.198	6.8844	0.330	6.9830	0.095	8.8121	0.320	8.8932
0.168	6.8868	0.356	6.9846	0.090	8.8140	0.355	8.8950
0.131	6.8897	0.389	6.9864	0.077	8.8158	0.388	8.8970
0.123	6.8916	0.418	6.9881	0.061	8.8180	0.432	8.8987
0.102	6.8936	0.460	6.9897	0.048	8.8198	0.470	8.9006
0.089	6.8963	0.496	6.9923	0.043	8.8217	0.499	8.9024
0.067	6.8989	0.525	6.9940	0.036	8.8234	0.544	8.9044

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Table 2b. V1073 Her observations ΔV, variable minus comparison star, cont.

ΔV	*BHJD 2455800+*	*ΔV*	*BHJD 2455800+*	*ΔV*	*BHJD 2455800+*	*ΔV*	*BHJD 2455800+*
0.581	8.9062	0.094	8.9539	–0.024	9.8786	0.322	9.9252
0.597	8.9082	0.088	8.9557	–0.019	9.8804	0.353	9.9270
0.613	8.9100	0.075	8.9578	–0.014	9.8822	0.389	9.9289
0.622	8.9118	0.059	8.9596	–0.012	9.8843	0.413	9.9307
0.626	8.9136	0.057	8.9615	–0.001	9.8860	0.451	9.9326
0.626	8.9156	0.048	8.9632	0.005	9.8879	0.504	9.9344
0.613	8.9173	0.039	8.9652	0.006	9.8897	0.526	9.9363
0.610	8.9192	0.022	8.9670	0.013	9.8916	0.558	9.9381
0.605	8.9210	0.061	9.8422	0.029	9.8934	0.589	9.9422
0.584	8.9228	0.042	9.8470	0.038	9.8953	0.604	9.9473
0.554	8.9246	0.030	9.8490	0.040	9.8971	0.595	9.9492
0.518	8.9267	0.030	9.8508	0.055	9.8990	0.573	9.9510
0.481	8.9285	0.017	9.8531	0.066	9.9008	0.552	9.9529
0.444	8.9305	0.006	9.8549	0.071	9.9027	0.532	9.9547
0.399	8.9323	–0.002	9.8584	0.089	9.9044	0.494	9.9565
0.362	8.9341	–0.008	9.8602	0.102	9.9063	0.466	9.9583
0.328	8.9359	–0.009	9.8622	0.104	9.9081	0.434	9.9602
0.292	8.9380	–0.022	9.8640	0.128	9.9101	0.397	9.9620
0.261	8.9398	–0.025	9.8660	0.147	9.9118	0.370	9.9638
0.228	8.9418	–0.024	9.8678	0.170	9.9138	0.330	9.9656
0.204	8.9436	–0.031	9.8696	0.185	9.9156	0.312	9.9675
0.174	8.9459	–0.029	9.8714	0.211	9.9175	0.283	9.9693
0.153	8.9477	–0.027	9.8732	0.229	9.9193	0.259	9.9712
0.126	8.9502	–0.029	9.8750	0.260	9.9213	0.231	9.9729
0.111	8.9520	–0.022	9.8768	0.290	9.9232		

Table 2c. V1073 Her observations ΔR, variable minus comparison star.

ΔR	BHJD 2455800+	ΔR	BHJD 2455800+	ΔR	BHJD 2455800+	ΔR	BHJD 2455800+
0.173	4.9664	–0.025	6.9009	0.467	6.9960	0.051	9.9104
0.105	4.9734	–0.033	6.9025	0.470	6.9979	0.067	9.9122
0.066	4.9773	–0.041	6.9042	0.481	6.9996	0.086	9.9142
0.038	4.9813	–0.050	6.9063	0.496	7.0012	0.104	9.9160
0.011	4.9852	–0.051	6.9078	0.506	7.0029	0.134	9.9179
–0.006	4.9892	–0.067	6.9094	–0.025	9.8429	0.148	9.9197
–0.030	4.9940	–0.070	6.9110	–0.047	9.8473	0.173	9.9217
–0.052	4.9979	–0.109	6.9196	–0.056	9.8493	0.201	9.9235
–0.062	5.0025	–0.113	6.9237	–0.058	9.8511	0.240	9.9255
–0.052	5.0064	–0.107	6.9339	–0.072	9.8535	0.266	9.9274
–0.035	6.7967	–0.102	6.9367	–0.078	9.8553	0.312	9.9293
–0.026	6.8043	–0.094	6.9388	–0.082	9.8588	0.335	9.9311
–0.018	6.8120	–0.116	6.9406	–0.098	9.8605	0.379	9.9330
0.062	6.8204	–0.099	6.9425	–0.097	9.8626	0.407	9.9348
0.136	6.8255	–0.078	6.9445	–0.102	9.8642	0.433	9.9367
0.182	6.8298	–0.071	6.9466	–0.105	9.8663	0.465	9.9385
0.271	6.8353	–0.049	6.9520	–0.103	9.8681	0.498	9.9426
0.424	6.8432	–0.019	6.9541	–0.101	9.8699	0.514	9.9477
0.510	6.8503	–0.048	6.9557	–0.108	9.8717	0.495	9.9496
0.515	6.8545	–0.029	6.9575	–0.104	9.8736	0.476	9.9514
0.520	6.8575	–0.019	6.9591	–0.102	9.8753	0.448	9.9532
0.493	6.8604	–0.005	6.9612	–0.108	9.8771	0.422	9.9550
0.468	6.8632	0.008	6.9628	–0.101	9.8789	0.394	9.9569
0.427	6.8656	0.016	6.9644	–0.098	9.8808	0.368	9.9586
0.395	6.8675	0.024	6.9664	–0.091	9.8825	0.334	9.9605
0.365	6.8695	0.050	6.9680	–0.081	9.8846	0.299	9.9623
0.318	6.8714	0.059	6.9696	–0.082	9.8864	0.267	9.9642
0.238	6.8734	0.114	6.9715	–0.081	9.8883	0.240	9.9660
0.248	6.8753	0.130	6.9731	–0.071	9.8901	0.212	9.9679
0.205	6.8776	0.116	6.9747	–0.062	9.8920	0.182	9.9697
0.169	6.8802	0.162	6.9780	–0.055	9.8938	0.169	9.9715
0.135	6.8823	0.183	6.9797	–0.041	9.8956	0.144	9.9733
0.095	6.8848	0.214	6.9817	–0.028	9.8974	0.461	8.7618
0.073	6.8872	0.249	6.9833	–0.021	9.8993	0.467	8.7640
0.042	6.8901	0.259	6.9850	–0.020	9.9011	0.502	8.7662
0.027	6.8920	0.312	6.9868	–0.004	9.9030	0.497	8.7684
0.018	6.8940	0.336	6.9884	0.006	9.9048	0.483	8.7730
0.003	6.8967	0.359	6.9901	0.012	9.9066	0.445	8.7752
–0.018	6.8993	0.441	6.9943	0.031	9.9084	0.423	8.7774

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Table 2c. V1073 Her observations ΔR, variable minus comparison star, cont.

ΔR	BHJD 2455800+	ΔR	BHJD 2455800+	ΔR	BHJD 2455800+	ΔR	BHJD 2455800+
0.391	8.7796	–0.063	8.8294	0.053	8.8789	0.455	8.9250
0.348	8.7820	–0.066	8.8312	0.058	8.8807	0.414	8.9271
0.310	8.7843	–0.068	8.8333	0.084	8.8828	0.375	8.9288
0.272	8.7866	–0.075	8.8354	0.101	8.8846	0.333	8.9309
0.241	8.7889	–0.085	8.8378	0.128	8.8864	0.294	8.9327
0.199	8.7911	–0.085	8.8397	0.150	8.8882	0.260	8.9345
0.165	8.7931	–0.074	8.8415	0.178	8.8900	0.230	8.9363
0.141	8.7952	–0.073	8.8434	0.195	8.8918	0.191	8.9383
0.128	8.7971	–0.078	8.8452	0.232	8.8936	0.167	8.9401
0.101	8.7991	–0.074	8.8470	0.266	8.8954	0.129	8.9422
0.085	8.8009	–0.070	8.8488	0.302	8.8973	0.110	8.9440
0.061	8.8035	–0.065	8.8507	0.343	8.8991	0.082	8.9463
0.047	8.8053	–0.068	8.8525	0.387	8.9009	0.060	8.9481
0.037	8.8071	–0.065	8.8545	0.417	8.9027	0.040	8.9505
0.030	8.8089	–0.055	8.8563	0.451	8.9047	0.027	8.9523
0.011	8.8107	–0.049	8.8586	0.485	8.9065	0.008	8.9543
–0.007	8.8125	–0.044	8.8604	0.509	8.9085	–0.003	8.9560
–0.005	8.8144	–0.036	8.8630	0.522	8.9103	–0.011	8.9582
–0.016	8.8162	–0.029	8.8647	0.522	8.9122	–0.022	8.9600
–0.028	8.8184	–0.021	8.8669	0.524	8.9139	–0.030	8.9618
–0.031	8.8202	–0.007	8.8687	0.522	8.9159	–0.040	8.9636
–0.044	8.8220	0.002	8.8712	0.516	8.9177	–0.046	8.9655
–0.044	8.8238	0.014	8.8730	0.512	8.9196	–0.054	8.9673
–0.047	8.8257	0.026	8.8753	0.500	8.9213		
–0.063	8.8275	0.032	8.8771	0.480	8.9232		

Table 2d. V1073 Her observations ΔI, variable minus comparison star, cont.

ΔI	BHJD 2455800+	ΔI	BHJD 2455800+	ΔI	BHJD 2455800+	ΔI	BHJD 2455800+
0.075	4.9667	–0.122	6.9013	0.369	6.9963	–0.041	9.9126
0.009	4.9737	–0.129	6.9029	0.353	6.9983	–0.019	9.9145
–0.032	4.9776	–0.131	6.9045	0.391	6.9999	0.008	9.9164
–0.063	4.9816	–0.160	6.9066	0.349	7.0033	0.030	9.9182
–0.082	4.9855	–0.146	6.9082	–0.123	9.8435	0.056	9.9200
–0.101	4.9895	–0.135	6.9097	–0.151	9.8477	0.080	9.9221
–0.118	4.9943	–0.177	6.9113	–0.149	9.8497	0.108	9.9239
–0.146	4.9982	–0.192	6.9345	–0.159	9.8515	0.135	9.9259
–0.170	5.0027	–0.191	6.9374	–0.168	9.8538	0.170	9.9277
–0.171	5.0067	–0.182	6.9391	–0.171	9.8556	0.202	9.9296
–0.166	6.7974	–0.175	6.9409	–0.187	9.8591	0.231	9.9315
–0.106	6.8057	–0.186	6.9428	–0.188	9.8609	0.262	9.9333
–0.090	6.8133	–0.170	6.9449	–0.195	9.8629	0.303	9.9352
–0.024	6.8217	–0.146	6.9470	–0.190	9.8647	0.330	9.9370
–0.007	6.8263	–0.143	6.9524	–0.198	9.8667	0.346	9.9389
0.035	6.8305	–0.130	6.9544	–0.196	9.8685	0.388	9.9429
0.121	6.8363	–0.123	6.9560	–0.196	9.8703	0.377	9.9480
0.338	6.8451	–0.120	6.9578	–0.203	9.8721	0.364	9.9499
0.396	6.8514	–0.108	6.9595	–0.197	9.8739	0.354	9.9518
0.400	6.8551	–0.094	6.9615	–0.197	9.8757	0.323	9.9536
0.402	6.8581	–0.084	6.9631	–0.202	9.8775	0.295	9.9554
0.387	6.8611	–0.074	6.9647	–0.185	9.8793	0.271	9.9572
0.362	6.8636	–0.063	6.9668	–0.185	9.8811	0.243	9.9590
0.313	6.8660	–0.045	6.9683	–0.185	9.8829	0.200	9.9609
0.275	6.8679	–0.037	6.9700	–0.183	9.8850	0.177	9.9627
0.244	6.8699	–0.030	6.9718	–0.172	9.8868	0.147	9.9645
0.199	6.8718	0.004	6.9734	–0.172	9.8886	0.123	9.9663
0.145	6.8738	0.024	6.9750	–0.165	9.8904	0.092	9.9682
0.139	6.8757	0.050	6.9767	–0.162	9.8923	0.069	9.9700
0.090	6.8780	0.057	6.9784	–0.152	9.8941	0.047	9.9719
0.059	6.8806	0.093	6.9800	–0.139	9.8960	0.313	8.7597
0.021	6.8827	0.128	6.9820	–0.132	9.8978	0.348	8.7622
–0.010	6.8852	0.144	6.9837	–0.118	9.8997	0.362	8.7645
–0.027	6.8876	0.172	6.9853	–0.113	9.9015	0.380	8.7667
–0.059	6.8905	0.198	6.9871	–0.106	9.9034	0.370	8.7689
–0.073	6.8924	0.239	6.9888	–0.090	9.9052	0.374	8.7711
–0.084	6.8944	0.272	6.9904	–0.085	9.9070	0.358	8.7734
–0.096	6.8970	0.315	6.9930	–0.069	9.9088	0.334	8.7756
–0.122	6.8996	0.333	6.9947	–0.052	9.9108	0.296	8.7778

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Table 2d. V1073 Her observations Δi, variable minus comparison star, cont.

ΔI	BHJD 2455800+	ΔI	BHJD 2455800+	ΔI	BHJD 2455800+	ΔI	BHJD 2455800+
0.262	8.7800	–0.164	8.8298	–0.052	8.8793	0.322	8.9254
0.226	8.7824	–0.166	8.8316	–0.039	8.8811	0.284	8.9274
0.184	8.7847	–0.175	8.8336	–0.011	8.8831	0.257	8.9292
0.148	8.7870	–0.171	8.8357	0.001	8.8849	0.211	8.9313
0.114	8.7893	–0.186	8.8382	0.020	8.8867	0.178	8.9330
0.086	8.7914	–0.179	8.8400	0.053	8.8885	0.149	8.9349
0.065	8.7935	–0.178	8.8418	0.065	8.8903	0.114	8.9366
0.034	8.7955	–0.180	8.8438	0.103	8.8921	0.075	8.9387
0.011	8.7974	–0.172	8.8455	0.132	8.8939	0.052	8.9405
0.004	8.7995	–0.178	8.8474	0.161	8.8957	0.022	8.9425
–0.033	8.8012	–0.172	8.8491	0.198	8.8977	0.005	8.9443
–0.045	8.8038	–0.167	8.8510	0.229	8.8994	–0.022	8.9466
–0.064	8.8056	–0.168	8.8528	0.264	8.9013	–0.037	8.9484
–0.065	8.8074	–0.160	8.8548	0.301	8.9031	–0.060	8.9509
–0.080	8.8092	–0.155	8.8566	0.333	8.9051	–0.084	8.9527
–0.092	8.8111	–0.139	8.8590	0.361	8.9069	–0.090	8.9546
–0.097	8.8128	–0.143	8.8608	0.378	8.9089	–0.101	8.9564
–0.104	8.8148	–0.134	8.8633	0.392	8.9107	–0.110	8.9585
–0.113	8.8165	–0.126	8.8651	0.399	8.9125	–0.119	8.9603
–0.130	8.8187	–0.113	8.8672	0.398	8.9143	–0.130	8.9622
–0.129	8.8205	–0.102	8.8690	0.398	8.9163	–0.139	8.9639
–0.139	8.8224	–0.097	8.8715	0.395	8.9180	–0.146	8.9659
–0.142	8.8242	–0.086	8.8733	0.390	8.9199	–0.152	8.9677
–0.153	8.8261	–0.074	8.8756	0.376	8.9217		
–0.158	8.8278	–0.063	8.8774	0.345	8.9236		

3. Period study

Four times of minimum light were calculated, 2 primary and 2 secondary eclipses, from our present observations including errors:

HJD I = JD Hel Min I = 2456056.8549±0.0002, 2456058.91485±0.00008 (1)

HJD II = 2456058.7685±0.0002, 2456059.9455±0.0001 (2)

Some 54 timings were used in our period study. A very low amplitude sinusoid was discovered in the calculation of its linear ephemeris. The sinusoidal ephemeris follows the linear one below:

$$\text{JD Hel Min I} = 2451746.5113 \pm 0.0004\text{d} + 0.29428167 \pm 0.00000004 \times \text{E} \quad (3)$$

$$\text{JD Hel Min I} = 2451746.5108 \pm 0.0006\text{d} + 0.294281673 \pm 0.00000004 \times \text{E} + 0.0025(\pm 0.0003) \times sin[(0.00045 \pm 0.00002) \times \text{E} + 2.4 \pm 0.2] \quad (4)$$

The plotted residuals overlaid by the sinusoidal term of Equation 3 is given in Figure 4. The O–C curve is a low amplitude sinusoid, covering some fourteen years and nearly 18,000 orbits. It possibly indicates the presence of a third component. The period of this sinusoid is 11.2 ± 0.5 years. Using the amplitude from the ephemeris, the binary mass of 1.1 solar masses, the mass ratio, and the inclination from our Wilson-Devinney (1971) program solution (the orbital inclination of the close binary), we determined the third body to have ~0.1 $M_\odot$, which is slightly above the maximum limit of a brown dwarf (0.075 $M_\odot$). Since the orbital inclination of the distant third component does not necessarily have the same inclination as that of the close pair, we calculate the mass for various inclinations. For inclinations 60°, 45°, 30°, and 20°, we obtain masses of 0.11, 0.15, 0.21, 0.33 $M_\odot$, respectively. Since no third light was found, we tend to think that the lower masses are near the actual value. Tran *et al.* (2013) have shown that such amplitudes (< 0.01d) are expected in spotted contact binaries and can result in quasi-periodic variations of a few hundred days. Although the amplitude variations are on this order, the period found here is much too long to be due to spots. However, a magnetic spot cycle is not out of the question to explain the variation. The times of minimum light and the linear residuals are given in Table 3.

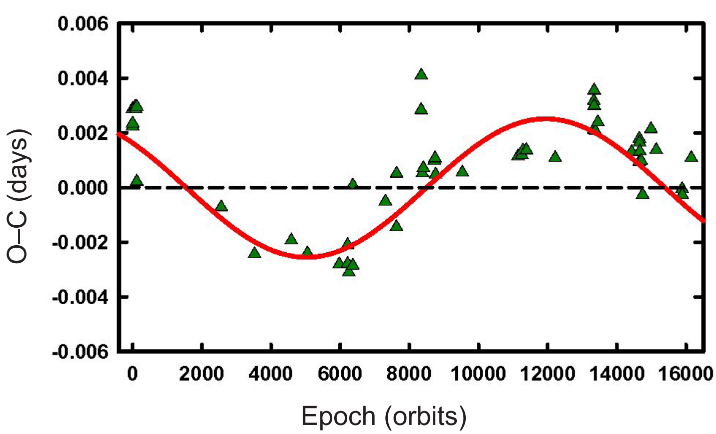

Figure 4. Sinusoidal O–C residuals from the period study.

Table 3. V1073 Her times of minimum light and linear residuals.

No.	*Epochs*	*Cycles*	*Weight*	*O–C*	*References*
1	51258.8894	–1657.0	1.0	0.0029	Blätter and Diethelm 2000
2	51277.8726	–1592.5	1.0	0.0049	Blätter and Diethelm 2000
3	51746.3660	–0.5	1.0	0.0019	BBSAG 2000
4	51746.5125	0.0	1.0	0.0012	BBSAG 2000
5	51768.4372	74.5	0.5	0.0019	BBSAG 2000
6	51773.4399	91.5	0.5	0.0018	BBSAG 2000
7	51781.3856	118.5	1.0	0.0019	BBSAG 2000
8	51781.5300	119.0	1.0	–0.0008	BBSAG 2000
9	51746.5126	0.0	0.0	0.0013	BBSAG 2000
10	52500.1649	2561.0	0.0	–0.0017	Kreiner 2004
11	52783.4093	3523.5	1.0	–0.0035	Diethelm 2003
12	53096.5255	4587.5	1.0	–0.0030	Diethelm 2004
13	53233.5132	5053.0	1.0	–0.0034	Brát *et al.* 2007
14	53504.5462	5974.0	1.0	–0.0038	Brát *et al.* 2007
15	53575.4681	6215.0	0.5	–0.0038	Malkov *et al.* 2006
16	53575.4688	6215.0	0.5	–0.0031	Malkov *et al.* 2006
17	53585.4733	6249.0	0.5	–0.0041	Brát *et al.* 2008
18	53620.3489	6367.5	1.0	–0.0009	Diethelm 2006
19	53620.4931	6368.0	1.0	–0.0039	Diethelm 2006
20	53897.4145	7309.0	1.0	–0.0015	Hübscher 2007
21	53992.3194	7631.5	1.0	–0.0025	Diethelm 2007
22	53992.4685	7632.0	1.0	–0.0005	Diethelm 2007
23	54202.4408	8345.5	1.0	0.0018	Diethelm 2007
24	54202.5892	8346.0	1.0	0.0031	Diethelm 2007
25	54211.8555	8377.5	1.0	–0.0005	Nelson 2008
26	54220.5370	8407.0	1.0	–0.0003	Hübscher 2007
27	54314.4131	8726.0	1.0	0.0000	Brát *et al.* 2007
28	54319.4160	8743.0	1.0	0.0001	Hübscher *et al.* 2009
29	54324.4182	8760.0	1.0	–0.0005	Hübscher *et al.* 2009
30	54551.8980	9533.0	1.0	–0.0005	Nelson 2009
31	55026.4278	11145.5	0.5	0.0001	Brát *et al.* 2011
32	55058.3574	11254.0	0.5	0.0002	Brát *et al.* 2011
33	55067.4803	11285.0	1.0	0.0003	Diethelm 2010
34	55097.3499	11386.5	1.0	0.0004	Hübscher and Monninger 2011
35	55342.4863	12219.5	0.5	0.0001	Brát *et al.* 2011
36	55670.4642	13334.0	1.0	0.0011	Hübscher *et al.* 2012
37	55670.6124	13334.5	1.0	0.0022	Hübscher *et al.* 2012
38	55673.4079	13344.0	1.0	0.0020	Hübscher *et al.* 2012
39	55673.5556	13344.5	1.0	0.0025	Hübscher *et al.* 2012
40	55683.4126	13378.0	0.5	0.0011	Hoňková *et al.* 2013

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Table 3. V1073 Her times of minimum light and linear residuals, cont.

No.	*Epochs*	*Cycles*	*Weight*	*O–C*	*References*
41	55705.4840	13453.0	1.0	0.0014	Hübscher *et al.* 2012
42	55992.9961	14430.0	1.0	0.0003	Nelson 2013
43	56056.8549	14647.0	1.0	–0.0001	Present observations
44	56058.7686	14653.5	1.0	0.0008	Present observations
45	56058.9149	14654.0	1.0	–0.0001	Present observations
46	56059.9455	14657.5	1.0	0.0006	Present observations
47	56062.4466	14666.0	1.0	0.0003	Hübscher and Lehmann 2013
48	56074.5118	14707.0	1.0	0.0000	Hübscher and Lehmann 2013
49	56085.8404	14745.5	1.0	–0.0013	Diethelm 2012
50	56157.5004	14989.0	1.0	0.0011	Hübscher and Lehmann 2013
51	56201.3476	15138.0	1.0	0.0004	Hübscher and Lehmann 2013
52	56422.3517	15889.0	0.5	–0.0011	Hoňková *et al.* 2013
53	56422.4986	15889.5	0.5	–0.0013	Hoňková *et al.* 2013
54	56500.4846	16154.5	0.5	0.0001	Hoňková *et al.* 2013

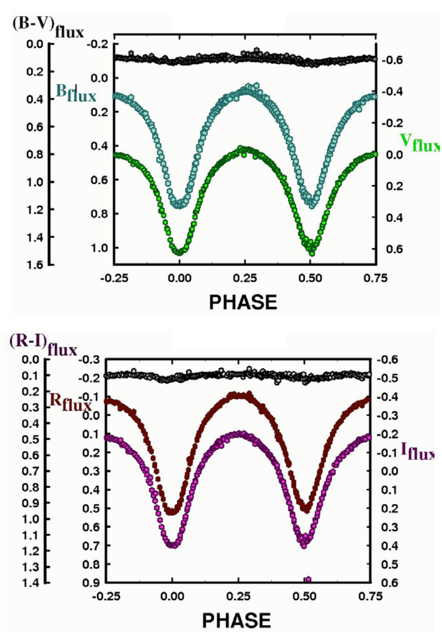

Figure 5. (a, top panel) B,V delta magnitude and color magnitudes vs. phase plots in the sense of V–C. (b, bottom panel) R,I delta magnitude and color magnitudes vs. phase plots in the sense of V–C.

4. Light curves and temperature determination

The light curves were phased using Equation (3). These are given as Figures 5a and 5b. A table of light curve characteristics are given in Table 4. The curves are of high precision with a standard errors of 3–5 mmag. The amplitude of the light curves are 0.6–0.7 magnitude from I to B. The O'Connell effect, which is classically an indication of spot activity, is about 0.03 in all filters, with MAX I (the maximum following MIN I) being the most luminous. Thus, spot activity is expected. The minima are the nearly the same, within 0.02–0.03 magnitude, indicating a high degree of thermal contact. Since the minima are so close it is difficult to say if the binary is W-type or A-type, and season-to-season variations will probably go either way.

2MASS photometry (Skrutskie 2006; TYCHO Hog *et al.* 2000) gives the temperature of the binary as ~5150 ± 300. We used this value for the primary component in our light curve solution.

Table 4. Light curve characteristics.

Filter	*Phase* *Max. I*	*Max. II*	
	0.25	0.75	
B	0.106 ± 0.002	0.077 ± 0.013	
V	0.007 ± 0.005	–0.027 ± 0.003	
R	0.006 ± 0.005	–0.106 ± 0.003	
I	–0.178 ± 0.006	–0.198 ± 0.003	
	Min. II	*Min. I*	
	0.5	0.0	
B	0.749 ± 0.007	0.721 ± 0.017	
V	0.622 ± 0.005	0.586 ± 0.019	
R	0.519 ± 0.003	0.503 ± 0.007	
I	0.398 ± 0.002	0.373 ± 0.016	
	Min. II–Max. II	*Max. I–Max. II*	*Min. II–Min. I*
B	0.672 ± 0.020	0.029 ± 0.015	0.028 ± 0.024
V	0.649 ± 0.008	0.033 ± 0.008	0.035 ± 0.024
R	0.625 ± 0.005	0.029 ± 0.008	0.016 ± 0.010
I	0.596 ± 0.005	0.020 ± 0.009	0.025 ± 0.018

5. Synthetic light curve solution

The B V R and I curves were pre-modeled with BINARY MAKER 3.0 (Bradstreet and Steelman 2004) fits in all filter bands. The parameters were then averaged

Table 5. V1073 Her light curve solution.

Parameters	*Values*
λ_B, λ_V, λ_R, λ_I (nm)	440, 550, 640, 790
$x_{bol1,2}$, $y_{bol1,2}$	0.647 0.647, 0.176 0.176
$x_{1I,2I}$, $y_{1I,2I}$	0.637 0.637, 0.208 0.208
$x_{1R,2R}$, $y_{1R,2R}$	0.724 0.724, 0.200 0.200
$x_{1V,2V}$, $y_{1V,2V}$	0.790 0.790, 0.159 0.159
$x_{1B,2B}$, $y_{1B,2B}$	0.851 0.851, 0.044 0.044
g_1, g_2	0.32, 0.32
A_1, A_2	0.5
Inclination (°)	82.3 ± 0.1
T_1, T_2 (K)	5150, 5176 ± 1
Ω_1, Ω_2	2.640 ± 0.001
$q(m_2/m_1)$	0.404 ± 0.004
$L_1/(L_1+L_2)_I$	0.663 ± 0.001
$L_1/(L_1+L_2)_R$	0.660 ± 0.001
$L_1/(L_1+L_2)_V$	0.658 ± 0.001
$L_1/(L_1+L_2)_B$	0.652 ± 0.001
JD_o (days)	56056.8558 ± 0.00004
Period (days)	0.294264 ± 0.000007
r_1, r_2 (pole)	0.440 ± 0.001, 0.292 ± 0.001
r_1, r_2 (side)	0.472 ± 0.002, 0.306 ± 0.002
r_1, r_2 (back)	0.502 ± 0.002, 0.345 ± 0.004
SPOT Parameters	
Spot I on STAR 1	Cool Spot
Colatitude (°)	93 ± 2
Longitude (°)	244 ± 1
Spot radius (°)	21.8 ± 0.3
Spot T-factor	0.861 ± 0.005

and input into a four-color simultaneous light curve calculation using the Wilson-Devinney Program (W-D, Wilson and Devinney 1971; Wilson 1990, 1994; Van Hamme and Wilson 1998). There is no third light in the solutions. Only small negative and negligible values resulted when it was included in the adjustable parameters, indicating that no third body of appreciable brightness contributes to the overall light of the system. The solution was computed in Mode 3, the contact mode. Convective parameters g = 0.32 A = 0.5 were used. Since the eclipses did not appear to be total (later we found out the eclipses did have a brief time of totality, ~3 minutes in the secondary), a q-search was performed over a mass ratio, q, range of 0.3 to 2.0. The initial and best residual occurred at q = 0.4. The q search mass ratios and residuals are shown in Figure 6.

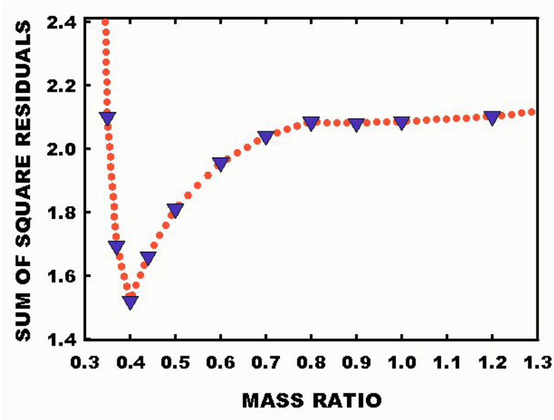

Figure 6. Chart of solution residuals of mass ratios extending from 0.35 to 1.2 minimizes near 0.4.

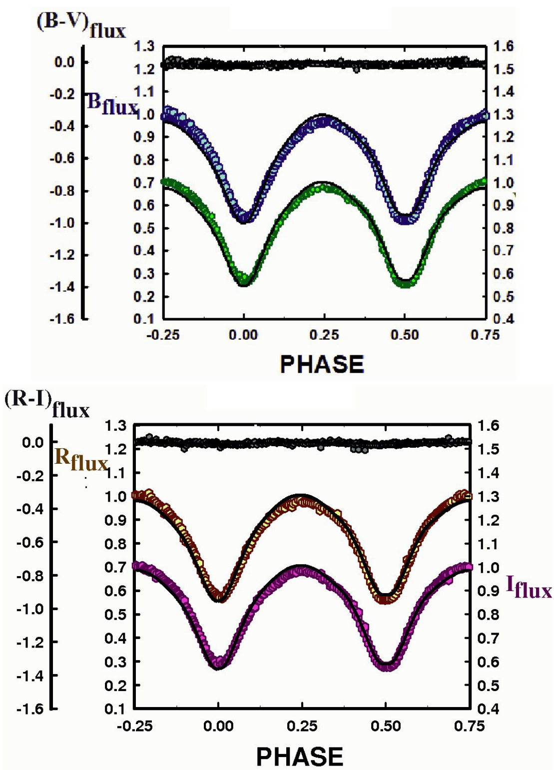

Figure 7. (a, top panel) B,V synthetic light curve solutions overlaying the normalized flux curves. (b, bottom panel) R,I synthetic light curve solutions overlaying the normalized flux curves.

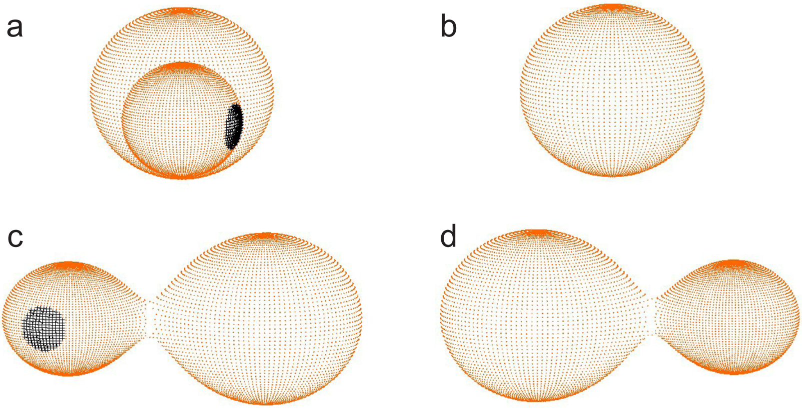

Figure 8. Roche Lobe surfaces from our BVRI solution: (a) phase 0.00 (the primary eclipse); (b) phase 0.25; (c) phase 0.50; (d) phase 0.75.

The mass ratio as well as the other free parameters were allowed to adjust in W-D for the final runs. The synthetic light curve solution is given in Table 5. The normalized curves overlain by our light curve solutions are shown as Figures 7a and 7b. A geometrical representation of the system in Figures 8a–8d is given at quadratures so that the reader may visualize the placement of the spot and the relative size of the stars as compared to the orbit.

6. Conclusion

V1073 Herculis is a very short period (P = 0.294281673(4) day) W UMa totally eclipsing binary. The fourteen-year orbital study (16,000 orbits) reveals a very low amplitude, ~0.0025 day sinusoidal variation with a period of 11.25 years, which may indicate the orbital period of a near-Brown Dwarf third component. This would be one of the first detections of such a body through an O–C study. 2MASS photometry gives a temperature for the primary component of ~5200 K while the Wilson-Devinney Program preliminary solution gives a mass ratio of 0.4, nearly identical component temperatures, and a cool magnetic spot with a T-factor of 0.86 with a spot radius of 22 degrees. The system is magnetically active. The Roche Lobe fill-out is 0.18. The inclination is 82 degrees not quite totally eclipsing. The binary is only slightly of W-type (the less massive component of the binary is slightly hotter). This system is apparently just on the verge of leaving its shallow contact stage and is of intermediate age. Radial velocity curves are needed to confirm or refute our solution and to obtain absolute (not relative) system parameters.

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