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Kam-Ching Leung
University of Nebraska-Lincoln, kleung2@unl.edu

Donald P. Schneider
University of Nebraska-Lincoln, dps7@psu.edu

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ECLIPSING SYSTEMS IN STAR CLUSTERS. III. EARLY-TYPE CONTACT SYSTEM BH CENTAURI

KAM-CHING LEUNG
Behlen Observatory, Department of Physics and Astronomy, University of Nebraska, Lincoln; and La Plata Observatory, La Plata, Argentina*

AND

DONALD P. SCHNEIDER
Department of Physics and Astronomy, University of Nebraska, Lincoln
Received 1976 May 3

ABSTRACT

Close to 1000 photoelectric observations of BH Cen in the yellow, blue, and ultraviolet regions were analyzed. The period found was 0.791616 days. The depths of minima were about equal, and were more than 1 magnitude! A photometric solution was derived with the Wilson and Devinney model. The binary is an overcontact system with primary and secondary masses equal to 10 $M_{\odot}$. Based on its membership in IC 2944 and the size of the primary radius, BH Cen may be another example of a zero-age contact system.

Subject headings: clusters: open — stars: eclipsing binaries — stars: individual

I. INTRODUCTION

The variability of BH Cen was discovered by Oosterhoff (1928). From his photographic study he found a β Lyrae–type light curve and a period of 0.791598 days, which was later (Oosterhoff 1930) refined to 0.7915814 days from 10 times of minima. Sahade and Davila (1963) suggested that BH Cen was a member of the galactic cluster IC 2944. A photometric and spectroscopic study of the cluster was carried out by Thackeray and Wesselink (1965). Eggen (1967) included this system in his study of contact binaries. BH Cen was classified as a B5 star in the HD Catalog. Thackeray (1975) suggested a spectral type of B3 with double lines of similar strength.

The reasons we included BH Cen in our observing program were as follows: (i) It is a member of a star cluster. This has a distinct advantage in studying binary evolution. (ii) Based on the shape of the photographic light curve and period, this binary might be a good candidate for a contact system. There have been only a few early-type systems discovered. (iii) There was no previous photoelectric study of this system.

* Guest Investigator.

II. OBSERVATIONS

BH Cen was observed on six nights with the 84 cm reflector at La Plata Observatory. The yellow, blue, and ultraviolet observations were made with filters matched to the Johnson *UBV* system. The photometer used was described by Feinstein (1963). The observations used in this study consist of 322, 335, and 287 individual observations in the yellow, blue, and ultraviolet regions, respectively.

The coordinates and characteristics of the stars observed are given in Table 1. The check star was observed on each night. Extinction coefficients were determined for each night, except for two nights for which mean values were adopted. Since the comparison stars and the check star were within the cluster radius, the differential extinction corrections were extremely small. The color-dependent extinction is assumed to be small since the colors of the stars observed were very similar to each other. Even though visible nebulosity was seen around comparison star 1 (Thackeray and Wesselink 1965), no variability was detected in comparing it with comparison star 2 or the check star. These three stars were found to be constant within the limit of observational error during the period of study. The sky

TABLE 1

COORDINATES, MAGNITUDES, COLORS, AND SPECTRAL TYPES OF THE STARS OBSERVED

Star	CPD	Thackeray and Wesselink (1965) No.	R.A. (1875)	Decl. (1875)	V	$B-V$	Sp.
BH Cen..........	−62°2189	29	33^h20^m5	−62°43′7	10.58	+0.15	B3 + B3?
Check...........			33 10.4*	−62°43.5*	10.65†	+0.12†	...
Comparison 1.....	−62°2184	25	33 9.7	−62°47.1	10.65	+0.20	B5 V
Comparison 2.....	−62°2179	24	33 3.0	−62°45.1	10.76	+0.17	B8 V

* Measured from photography of Thackeray and Wesselink (1965, plate I).

† Estimated from the present study.

conditions were good, except for one evening when the observations had to be terminated because of cloudiness. Unfortunately this evening was the only coverage of the secondary minimum. The individual yellow, blue, and ultraviolet observations are listed in Tables 2, 3, and 4. The probable errors for a single observation were estimated to be ± 0.008, ± 0.007, and ± 0.010 magnitudes for yellow, blue, and ultraviolet, respectively. The magnitudes are in the sense of variable minus comparison. There was no attempt to transform the magnitudes into the *UBV* system.

III. PERIOD

A period of 0.7915814 days for BH Cen was determined by Oosterhoff (1930), employing the photographic times of minimum of the 1920s. There have been no photometric observations reported since then. Unfortunately, the La Plata observations in 1967 contain only one complete coverage of the primary minimum. Therefore the conventional method of period determination by least-squares fit of the times of minimum was not possible. Instead the period was determined by trial and error until the most consistent light curves (yellow, blue, and ultraviolet) were achieved. The light elements adopted for the 1967 observations, and their estimated errors, are:

$$\text{Min I} = 2439621.7975 + 0.791616\,E$$
$$\pm\, 0.0015 \pm 0.000002\ \text{(p.e.)}\,.$$

The new period is slightly longer than the older one. Because of the lack of observations between the 1920s and 1967 and the relatively short observing run in 1967, it is not certain that this difference is significant. The light curves according to the period listed above are shown in Figure 1.

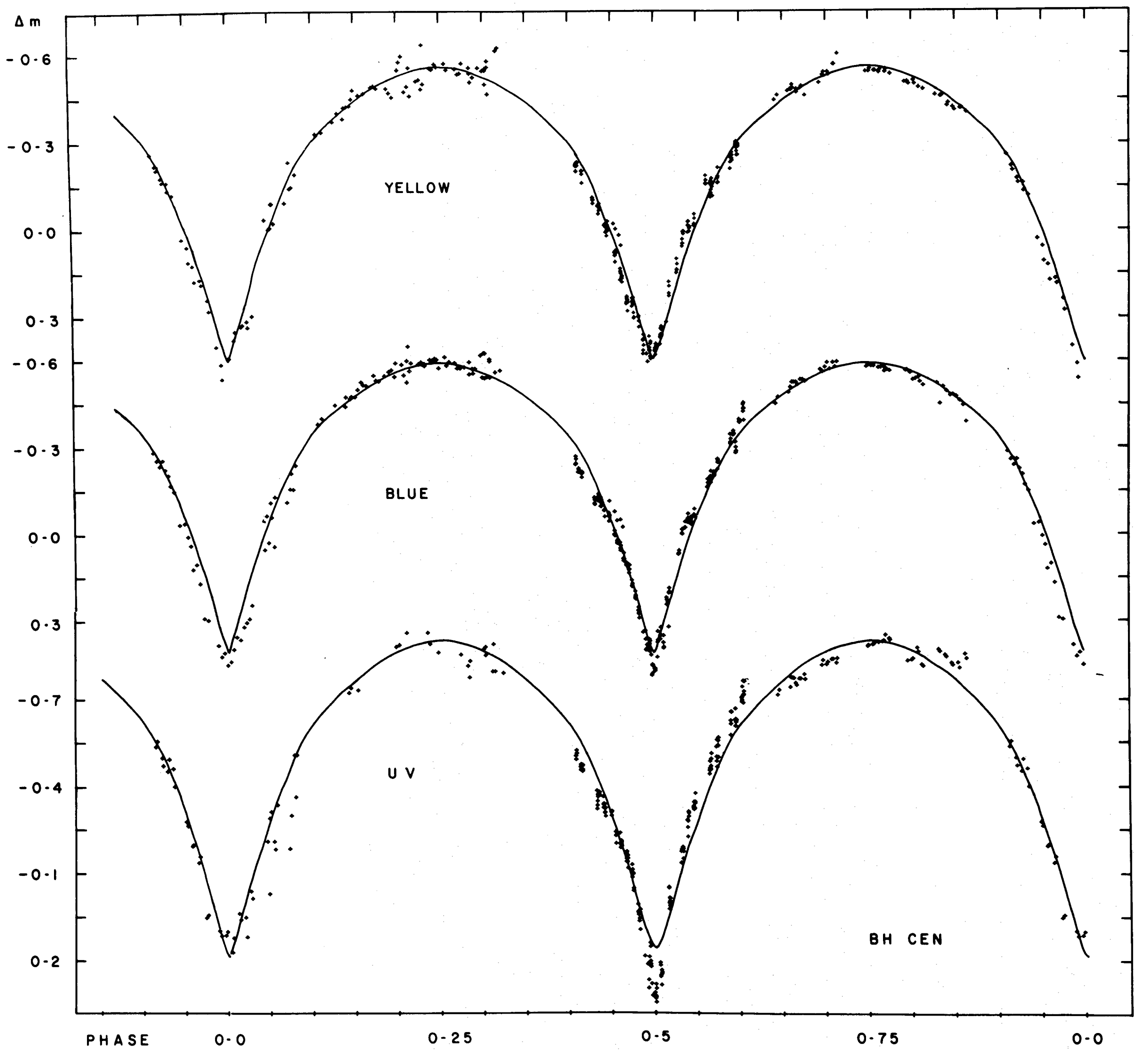

FIG. 1.—Light curves of BH Cen. The points are the individual observations, the yellow, blue, and ultraviolet magnitudes given in Tables 2, 3, and 4. The magnitudes are in the sense of BH Cen minus the comparison star. The solid lines are the theoretical light curves based on the parameters in Table 6.

TABLE 2

YELLOW OBSERVATIONS

HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm
2439620.60092	0.375	21.76561	0.121	80.53181	-0.458	85.49283	0.128	85.53791	0.222
0.60162	0.373	0.76723	0.175	0.54338	-0.477	0.49301	0.138	0.53809	0.188
0.60439	0.422	0.77209	0.169	0.54593	-0.495	0.49318	0.137	0.54480	0.142
0.60532	0.449	0.77348	0.186	0.54848	-0.463	0.49335	0.144	0.54497	0.094
0.60833	0.439	0.77927	0.239	0.55449	-0.513	0.49399	0.157	0.54515	0.131
0.62268	0.312	0.78042	0.278	0.55692	-0.518	0.49416	0.161	0.54532	0.133
21.51422	-0.449	0.78748	0.401	0.55901	-0.486	0.49434	0.163	0.54550	0.112
0.51700	-0.465	0.79200	0.463	0.56074	-0.503	0.49451	0.175	0.55007	0.051
0.52649	-0.479	0.79304	0.513	0.56931	-0.554	0.49469	0.153	0.55024	0.026
0.52903	-0.485	0.79802	0.444	0.57162	-0.571	0.49827	0.250	0.55041	0.042
0.52967	-0.484	0.79929	0.440	0.57348	-0.561	0.49845	0.244	0.55059	0.041
0.53054	-0.500	0.80357	0.377	0.58054	-0.573	0.49862	0.225	0.55076	0.001
0.53112	-0.490	0.80484	0.348	0.58262	-0.551	0.49879	0.232	0.55134	0.008
0.53471	-0.485	0.81040	0.330	0.59060	-0.554	0.49908	0.225	0.55151	-0.001
0.53482	-0.475	0.81179	0.325	0.59292	-0.536	0.49926	0.237	0.55522	0.003
0.53829	-0.489	0.81584	0.312	0.60380	-0.539	0.49943	0.275	0.55539	-0.021
0.53922	-0.496	0.81665	0.333	0.60704	-0.526	0.49960	0.237	0.55557	-0.034
0.54234	-0.464	0.82093	0.293	0.61584	-0.548	0.49978	0.245	0.55574	-0.035
0.55542	-0.507	0.83690	-0.006	0.61815	-0.502	0.50342	0.259	0.55643	0.0
0.55866	-0.534	0.83818	-0.011	0.62047	-0.469	0.50360	0.230	0.55661	0.0
0.55959	-0.543	0.84165	-0.026	85.45146	-0.225	0.50377	0.241	0.55678	-0.011
0.56318	-0.544	0.85207	-0.097	0.45169	-0.230	0.50394	0.244	0.55695	-0.017
0.56422	-0.535	0.85693	-0.146	0.45192	-0.207	0.50452	0.250	0.56106	-0.020
0.56839	-0.570	0.85832	-0.151	0.45215	-0.235	0.50470	0.249	0.56124	-0.026
0.56908	-0.570	0.86179	-0.195	0.45238	-0.233	0.50487	0.229	0.56141	-0.060
0.57209	-0.605	76.45435	-0.039	0.45256	-0.235	0.50504	0.281	0.56158	-0.045
0.59825	-0.545	0.46048	-0.094	0.45273	-0.226	0.50522	0.300	0.57165	-0.165
0.60102	-0.546	0.46164	-0.094	0.45290	-0.238	0.50539	0.296	0.57183	-0.192
0.60207	-0.555	0.47727	-0.236	0.45701	-0.208	0.50950	0.296	0.57200	-0.176
0.60589	-0.548	0.52796	-0.385	0.45719	-0.209	0.50967	0.292	0.57217	-0.165
0.60693	-0.548	0.53595	-0.453	0.45736	-0.197	0.50985	0.331	0.57235	-0.163
0.61040	-0.542	0.53733	-0.483	0.45753	-0.167	0.51002	0.310	0.57622	-0.167
0.61144	-0.551	0.57883	-0.551	0.46697	-0.117	0.51378	0.423	0.57640	-0.118
0.61596	-0.544	0.58039	-0.578	0.46714	-0.109	0.51396	0.411	0.57657	-0.174
0.61665	-0.553	0.58247	-0.598	0.46731	-0.116	0.51413	0.356	0.57675	-0.133
0.62070	-0.537	0.58942	-0.559	0.46754	-0.097	0.51430	0.393	0.57692	-0.162
0.63401	-0.509	0.60174	-0.637	0.46772	-0.109	0.51928	0.362	0.57709	-0.143
0.63667	-0.511	0.60938	-0.556	0.47217	-0.087	0.51945	0.401	0.57727	-0.160
0.63783	-0.503	0.61095	-0.553	0.47235	-0.090	0.51963	0.410	0.57744	-0.182
0.64223	-0.515	0.63699	-0.539	0.47252	-0.088	0.51980	0.413	0.57808	-0.153
0.64304	-0.503	0.63872	-0.574	0.47269	-0.061	0.52026	0.432	0.57825	-0.164
0.64709	-0.491	0.64532	-0.559	0.47322	-0.073	0.52044	0.387	0.57842	-0.122
0.65126	-0.485	0.65365	-0.559	0.47339	-0.086	0.52061	0.380	0.58288	-0.167
0.66237	-0.466	0.66025	-0.556	0.47356	-0.096	0.52079	0.432	0.58305	-0.219
0.66700	-0.461	0.66210	-0.582	0.47374	-0.082	0.52437	0.410	0.58323	-0.183
0.66804	-0.463	77.43798	-0.509	0.47796	-0.022	0.52455	0.413	0.58340	-0.189
0.67348	-0.429	0.45164	-0.550	0.47883	-0.022	0.52472	0.403	0.58357	-0.169
0.67440	-0.439	0.45360	-0.561	0.47900	-0.026	0.52489	0.403	0.59463	-0.215
0.67857	-0.424	0.46159	-0.617	0.47918	0.002	0.52518	0.426	0.59480	-0.237
0.68019	-0.415	0.46333	-0.627	0.47935	-0.016	0.52536	0.388	0.59497	-0.253
0.68528	-0.421	80.46040	-0.333	0.48039	0.016	0.52553	0.388	0.59596	-0.271
0.68609	-0.423	0.46630	-0.339	0.48057	0.0	0.52570	0.396	0.59613	-0.250
0.69096	-0.407	0.47672	-0.375	0.48074	-0.022	0.52929	0.389	0.59631	-0.243
0.72765	-0.261	0.48088	-0.405	0.48091	-0.013	0.52947	0.363	0.59648	-0.261
0.73193	-0.222	0.48690	-0.424	0.48109	-0.006	0.52964	0.356	0.59966	-0.297
0.73332	-0.208	0.48956	-0.427	0.48751	0.073	0.52981	0.367	0.59984	-0.304
0.73737	-0.180	0.49223	-0.430	0.48768	0.071	0.52999	0.335	0.60001	-0.308
0.73852	-0.166	0.50067	-0.466	0.48803	0.083	0.53039	0.356	0.60018	-0.302
0.74292	-0.165	0.50554	-0.472	0.48820	0.105	0.53057	0.328	0.60036	-0.287
0.74339	-0.137	0.51236	-0.493	0.48844	0.067	0.53074	0.339	0.60053	-0.275
0.74790	-0.122	0.51491	-0.497	0.48861	0.066	0.53091	0.356	0.60070	-0.261
0.75589	0.029	0.51734	-0.489	0.48878	0.074	0.53109	0.335	0.60134	-0.263
0.76075	0.056	0.52672	-0.488	0.48896	0.069	0.53757	0.173	0.60151	-0.301
0.76190	0.108	0.52903	-0.473	0.49266	0.167	0.53774	0.213	0.60169	-0.296

TABLE 3
BLUE OBSERVATIONS

HEL. J.D.	Δm	HEL. J.D.	Δm	HEL. J.D.	Δm	HEL. J.D.	Δm	HEL. J.D.	Δm
2439620.60046	0.338	21.76457	0.122	80.54199	-0.546	85.48954	0.032	85.54579	0.070
0.60208	0.333	0.76804	0.104	0.54477	-0.521	0.48971	0.020	0.54596	0.069
0.60393	0.382	0.77116	0.171	0.54720	-0.560	0.49197	0.029	0.54613	0.069
0.60567	0.396	0.77498	0.292	0.55565	-0.584	0.49214	0.049	0.54631	0.066
0.60775	0.416	0.77880	0.298	0.55797	-0.591	0.49231	0.057	0.54648	0.057
0.62338	0.234	0.78818	0.385	0.56005	-0.582	0.49249	0.040	0.54920	-0.002
0.62384	0.320	0.79130	0.424	0.56121	-0.578	0.49486	0.085	0.54937	-0.016
21.51491	-0.448	0.79408	0.410	0.56838	-0.597	0.49503	0.093	0.54955	0.001
0.51734	-0.470	0.79721	0.452	0.57047	-0.598	0.49521	0.065	0.54972	-0.016
0.52695	-0.486	0.80010	0.438	0.57232	-0.600	0.49538	0.086	0.54989	-0.016
0.52846	-0.504	0.80276	0.396	0.57440	-0.570	0.49758	0.104	0.55169	-0.021
0.53019	-0.521	0.80589	0.353	0.57984	-0.609	0.49775	0.109	0.55204	-0.042
0.53002	-0.521	0.80936	0.363	0.58181	-0.579	0.49793	0.105	0.55221	-0.022
0.53175	-0.521	0.81248	0.319	0.58401	-0.592	0.49810	0.100	0.55441	-0.040
0.53366	-0.521	0.81515	0.304	0.58922	-0.588	0.50001	0.135	0.55458	-0.054
0.53528	-0.513	0.81769	0.291	0.59165	-0.569	0.50018	0.123	0.55475	-0.049
0.53766	-0.530	0.82012	0.244	0.59385	-0.575	0.50036	0.122	0.55493	-0.070
0.53974	-0.530	0.83227	0.052	0.60264	-0.548	0.50053	0.107	0.55730	-0.057
0.54200	-0.524	0.83609	0.027	0.60554	-0.567	0.50261	0.160	0.55747	-0.050
0.55612	-0.565	0.83887	-0.060	0.60831	-0.568	0.50279	0.179	0.55765	-0.034
0.55820	-0.557	0.84130	0.041	0.61468	-0.538	0.50296	0.182	0.55782	-0.042
0.56040	-0.573	0.85311	-0.112	0.61699	-0.535	0.50313	0.172	0.55800	-0.056
0.56248	-0.589	0.85612	-0.157	0.61908	-0.539	0.50568	0.198	0.56031	-0.064
0.56491	-0.566	0.85901	-0.155	0.62162	-0.537	0.50585	0.219	0.56048	-0.067
0.56769	-0.589	0.86121	-0.238	85.45053	-0.239	0.50603	0.212	0.56066	-0.062
0.56977	-0.574	76.45574	-0.065	0.45076	-0.267	0.50620	0.224	0.56083	-0.086
0.57151	-0.591	0.45933	-0.110	0.45092	-0.242	0.50863	0.264	0.57264	-0.161
0.59859	-0.574	0.46326	-0.130	0.45122	-0.258	0.50881	0.253	0.57281	-0.163
0.60068	-0.582	0.47865	-0.211	0.45308	-0.213	0.50898	0.276	0.57298	-0.189
0.60288	-0.576	0.52952	-0.439	0.45325	-0.212	0.50915	0.271	0.57316	-0.176
0.60519	-0.576	0.53386	-0.466	0.45342	-0.226	0.50933	0.290	0.57553	-0.188
0.60971	-0.570	0.53838	-0.472	0.45360	-0.220	0.51529	0.363	0.57570	-0.199
0.61190	-0.571	0.57622	-0.588	0.45614	-0.208	0.51546	0.400	0.57588	-0.176
0.61457	-0.572	0.58178	-0.583	0.45632	-0.214	0.51563	0.399	0.57605	-0.216
0.61515	-0.557	0.58664	-0.596	0.45649	-0.195	0.51581	0.396	0.57860	-0.198
0.61734	-0.564	0.58786	-0.646	0.45666	-0.214	0.51835	0.393	0.57877	-0.214
0.62001	-0.559	0.59063	-0.588	0.45684	-0.209	0.51853	0.363	0.57894	-0.206
0.63471	-0.560	0.60296	-0.584	0.46789	-0.126	0.51870	0.378	0.57912	-0.202
0.63609	-0.562	0.60799	-0.599	0.46818	-0.106	0.51888	0.404	0.58201	-0.222
0.63876	-0.552	0.61257	-0.604	0.46841	-0.118	0.51905	0.369	0.58219	-0.257
0.64130	-0.528	0.63618	-0.569	0.46859	-0.102	0.52102	0.486	0.58236	-0.245
0.64373	-0.532	0.64011	-0.573	0.46888	-0.120	0.52119	0.481	0.58253	-0.253
0.64640	-0.536	0.64463	-0.591	0.47148	-0.115	0.52136	0.449	0.59393	-0.342
0.64778	-0.521	0.65504	-0.614	0.47165	-0.129	0.52154	0.453	0.59411	-0.310
0.65068	-0.509	0.65909	-0.621	0.47183	-0.139	0.52350	0.463	0.59428	-0.315
0.66329	-0.517	0.66338	-0.593	0.47200	-0.121	0.52368	0.471	0.59445	-0.326
0.66607	-0.446	77.43972	-0.551	0.47391	-0.096	0.52385	0.462	0.59665	-0.339
0.66908	-0.504	0.44944	-0.622	0.47408	-0.110	0.52403	0.466	0.59683	-0.353
0.67232	-0.489	0.45499	-0.601	0.47426	-0.118	0.52594	0.424	0.59700	-0.345
0.67556	-0.474	0.46020	-0.555	0.47443	-0.109	0.52611	0.373	0.59717	-0.343
0.67788	-0.477	0.46472	-0.561	0.47460	-0.096	0.52628	0.336	0.59862	-0.315
0.68112	-0.470	80.46179	-0.379	0.47715	-0.081	0.52646	0.365	0.59879	-0.316
0.68436	-0.456	0.46526	-0.398	0.47732	-0.082	0.52860	0.352	0.59897	-0.278
0.68737	-0.440	0.47776	-0.444	0.47750	-0.083	0.52877	0.362	0.59914	-0.298
0.69026	-0.384	0.48783	-0.472	0.47767	-0.060	0.52894	0.347	0.59932	-0.284
0.72811	-0.283	0.49304	-0.473	0.48138	-0.073	0.52912	0.322	0.59949	-0.285
0.73123	-0.254	0.49894	-0.497	0.48155	-0.044	0.53143	0.374	0.60204	-0.393
0.73390	-0.235	0.50206	-0.523	0.48172	-0.063	0.53161	0.393	0.60221	-0.384
0.73667	-0.255	0.50403	-0.513	0.48190	-0.060	0.53178	0.350	0.60238	-0.383
0.73922	-0.223	0.50681	-0.510	0.48207	-0.065	0.53195	0.389	0.60256	-0.382
0.74200	-0.203	0.51375	-0.545	0.48664	0.001	0.53450	0.220	0.60273	-0.387
0.74408	-0.168	0.51607	-0.528	0.48682	-0.012	0.53467	0.244	0.60568	-0.444
0.74721	-0.148	0.51861	-0.526	0.48699	0.002	0.53485	0.227	0.60585	-0.419
0.75241	-0.032	0.52394	-0.544	0.48716	0.005	0.53682	0.204	0.60603	-0.428
0.75693	-0.037	0.52787	-0.558	0.48734	0.006	0.53699	0.201	0.60620	-0.449
0.76005	0.009	0.53054	-0.564	0.48919	0.024	0.53716	0.187	0.60638	-0.431
0.76260	0.040	0.53331	-0.541	0.48936	0.031	0.53734	0.200	0.60655	-0.389

TABLE 4
ULTRA-VIOLET OBSERVATIONS

HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm	HEL.J.D.	Δm
2439621.51561	-0.713	21.76387	-0.197	85.45539	-0.469	85.50244	-0.048	85.55325	-0.280
0.51700	-0.729	0.76908	-0.135	0.45562	-0.450	0.50643	0.007	0.55360	-0.313
0.52741	-0.739	0.77047	-0.156	0.45580	-0.456	0.50661	0.033	0.55377	-0.296
0.52811	-0.772	0.77626	0.054	0.45597	-0.472	0.50678	0.036	0.55383	-0.296
0.52950	-0.771	0.77811	0.045	0.46905	-0.384	0.50695	0.043	0.55412	-0.308
0.53071	-0.770	0.78876	0.099	0.46922	-0.321	0.50759	0.066	0.55817	-0.327
0.53227	-0.753	0.79061	0.116	0.46940	-0.334	0.50776	0.056	0.55834	-0.331
0.53332	-0.746	0.79501	0.114	0.46957	-0.348	0.50794	0.036	0.55846	-0.325
0.53575	-0.768	0.79651	0.101	0.46974	-0.371	0.50829	0.094	0.55863	-0.346
0.53714	-0.768	0.80079	0.172	0.46992	-0.363	0.50846	0.025	0.55881	-0.320
0.54043	-0.783	0.80195	0.123	0.47079	-0.380	0.51610	0.266	0.55956	-0.324
0.54130	-0.766	0.80693	0.039	0.47096	-0.374	0.51627	0.212	0.55973	-0.341
0.55658	-0.815	0.80866	0.060	0.47113	-0.379	0.51644	0.207	0.55991	-0.375
0.55762	-0.831	0.81318	0.052	0.47131	-0.368	0.51662	0.187	0.56008	-0.346
0.56109	-0.817	0.81457	0.119	0.47478	-0.364	0.51749	0.139	0.57333	-0.441
0.56214	-0.825	0.81815	-0.038	0.47495	-0.337	0.51766	0.152	0.57350	-0.453
0.56584	-0.835	0.81943	-0.013	0.47513	-0.326	0.51783	0.202	0.57368	-0.485
0.56711	-0.836	0.83332	-0.209	0.47530	-0.338	0.51801	0.212	0.57385	-0.461
0.57012	-0.822	0.83540	-0.029	0.47547	-0.339	0.51818	0.221	0.57403	-0.459
0.57082	-0.838	0.83957	-0.209	0.47565	-0.337	0.52177	0.310	0.57449	-0.456
0.59894	-0.880	0.84061	-0.182	0.47617	-0.308	0.52194	0.321	0.57466	-0.468
0.60346	-0.885	0.85403	-0.184	0.47634	-0.323	0.52212	0.325	0.57484	-0.493
0.59987	-0.883	0.85542	-0.298	0.47651	-0.309	0.52229	0.379	0.57501	-0.512
0.60473	-0.888	0.85971	-0.362	0.47669	-0.325	0.52252	0.329	0.57958	-0.534
0.60901	-0.893	0.86075	-0.506	0.47686	-0.296	0.52269	0.323	0.57975	-0.500
0.61248	-0.895	76.45678	-0.288	0.48230	-0.310	0.52287	0.281	0.57993	-0.485
0.61387	-0.899	0.45817	-0.311	0.48247	-0.298	0.52304	0.343	0.58010	-0.558
0.61526	-0.918	0.46419	-0.334	0.48265	-0.313	0.52322	0.295	0.58028	-0.465
0.61873	-0.906	0.47993	-0.506	0.48282	-0.314	0.52669	0.207	0.58097	-0.539
0.61943	-0.901	0.53074	-0.719	0.48595	-0.242	0.52686	0.216	0.58114	-0.555
0.63552	-0.830	0.53265	-0.735	0.48612	-0.229	0.52704	0.255	0.58132	-0.538
0.63945	-0.833	0.53942	-0.728	0.48629	-0.202	0.52721	0.250	0.58149	-0.566
0.64061	-0.837	0.57472	-0.876	0.48647	-0.231	0.52785	0.232	0.58166	-0.498
0.64443	-0.874	0.57779	-0.882	0.49011	-0.238	0.52802	0.284	0.59295	-0.574
0.64547	-0.860	0.58473	-0.924	0.49029	-0.202	0.52819	0.246	0.59312	-0.624
0.64859	-0.816	0.60400	-0.925	0.49046	-0.187	0.52837	0.240	0.59330	-0.612
0.64998	-0.811	0.60626	-0.886	0.49063	-0.199	0.53502	-0.053	0.59347	-0.655
0.66399	-0.869	0.61384	-0.857	0.49081	-0.200	0.53519	-0.050	0.59364	-0.653
0.66526	-0.861	0.63490	-0.850	0.49116	-0.199	0.53537	0.002	0.59735	-0.665
0.66977	-0.850	0.64150	-0.811	0.49133	-0.211	0.53554	0.023	0.59752	-0.629
0.67116	-0.843	0.64335	-0.828	0.49150	-0.206	0.53572	-0.016	0.59769	-0.605
0.67602	-0.822	0.65585	-0.868	0.49168	-0.193	0.53589	-0.004	0.59787	-0.626
0.67718	-0.815	0.65782	-0.876	0.49561	-0.168	0.53606	0.012	0.59804	-0.618
0.68193	-0.823	0.66511	-0.886	0.49579	-0.164	0.53629	-0.014	0.59822	-0.625
0.68332	-0.805	77.43451	-0.771	0.49596	-0.140	0.53647	0.010	0.59839	-0.626
0.68818	-0.853	0.44955	-0.848	0.49607	-0.150	0.54665	-0.176	0.60308	-0.702
0.68957	-0.837	0.45603	-0.792	0.49624	-0.174	0.54683	-0.136	0.60325	-0.705
0.72880	-0.535	0.45835	-0.793	0.49683	-0.139	0.54700	-0.137	0.60342	-0.688
0.73019	-0.554	0.46599	-0.787	0.49700	-0.161	0.54717	-0.183	0.60360	-0.694
0.73471	-0.497	85.44960	-0.503	0.49717	-0.151	0.54816	-0.191	0.60377	-0.740
0.73575	-0.470	0.44984	-0.491	0.49735	-0.117	0.54833	-0.191	0.60458	-0.760
0.73991	-0.450	0.45007	-0.522	0.50082	-0.102	0.54850	-0.151	0.60475	-0.684
0.74130	-0.492	0.45030	-0.512	0.50099	-0.129	0.54868	-0.185	0.60493	-0.711
0.74501	-0.459	0.45401	-0.465	0.50117	-0.085	0.54885	-0.175	0.60510	-0.714
0.74640	-0.398	0.45418	-0.454	0.50134	-0.112	0.55256	-0.284	0.60528	-0.724
0.75762	-0.276	0.45435	-0.474	0.50192	-0.099	0.55273	-0.284	0.60545	-0.758
0.75901	-0.262	0.45452	-0.457	0.50209	-0.097	0.55290	-0.258	0.0	0.0
0.76306	-0.192	0.45470	-0.468	0.50227	-0.039	0.55308	-0.226	0.0	0.0

TABLE 5

ECLIPSING SYSTEMS HAVING EQUAL MINIMA WITH DEPTH LARGER THAN 0.8 MAGNITUDES

Name	Sp.	m_V	Primary Minimum	Secondary Minimum	Period (days)	Notes
V343 Ori.......	...	10.0	1.0	1.0	0.57579	1
AY Pup........	...	11.5	0.9	0.9	0.46895986	
RZ Pyx........	B7V	9.0	0.9	0.9	0.65627	
BH Cen........	B3 + B3?	10.0	1.0	1.0	0.791616	
V508 Oph......	...	10.0	1.0	1.0	0.34479163	2
SW Lac........	G3p + G3p	9.2	1.0	0.9	0.32072277	
CR Cas........	G5	11.0	1.3	0.9	2.840166	

NOTES.—(1) According to Koch *et al.* (1963), ranges to be checked. (2) According to Koch *et al.* (1963) photographic depth gives 0.48 mag, ranges to be checked.

The observations show that the maxima are equal in all three wavelength regions. The minima are also equal except for the ultraviolet. One should note that there is considerable scatter in the ultraviolet light curve. One of the most unusual features of the light curves is that the depths are over 1 mag! A search for eclipsing systems having equal minima with depths larger than 0.8 mag was måde. We were able to find only six other systems besides BH Cen in the catalog of Koch, Sobieski, and Wood (1963). The systems are listed in Table 5. The ranges for two of these (V343 Ori and V508 Oph) were questionable according to the catalog. Thus this leaves only one system, BH Cen, with this unusual depth of 1 mag in a catalog of 1266 systems! This large depth of minima suggests that the components must be nearly equal in radius and highly distorted, and that the inclination must be very near 90°. Judging from the spectral type, the shape of the light curves, and the period, BH Cen may be similar to the zero-age contact system V701 Sco (Leung and Wilson 1976).

IV. PHOTOMETRIC SOLUTION

In this study we adopted the model of Wilson and Devinney (1971). The subscripts 1 and 2 refer to the components eclipsed at the primary and secondary minimum, respectively. In deriving the photometric solution the following parameters were adopted: the polar effective temperature of component 1 is equal to 17,800 K (adopted from spectral type of B3 of Thackeray 1975 and the temperature calibration of Morton and Adams 1968); the gravity darkening coefficients, $g_1 = g_2 = 1$; and the bolometric albedos, $A_1 = A_2 = 1$. The luminosities were calculated in the program from the Planck function. All three light curves were used simultaneously in deriving the parameters.

To begin, we used trial and error with the Wilson and Devinney (1971) light curve program. After many trials we derived a set of parameters which marginally represented the observed light curves. With these serving as starting parameters we immediately proceeded with the computation using the differential correction program. We assumed the system was detached, employing the mode 2 option of the computing code (Leung and Wilson 1977). The following adjustable parameters were used: inclination, i; temperature of component 2, T_2; surface potentials, Ω_1, Ω_2; mass ratio, m_2/m_1; and luminosities of component 1, L_1 (yellow), L_1 (blue), and L_1 (UV). After a few runs the solution converged to a contact configuration. At this point the computation was continued with mode 1 (contact configuration). Unfortunately, after many runs the differential corrections to the adjustable parameters failed to converge to small values. In other words, the sum of the residuals remained high. This problem did not occur for the other five systems previously analyzed by this method. Subsequently, a conversation with Dr. Wilson revealed that he too was confronted with a similar problem in analyzing the system TX Cnc (Wilson and Biermann 1976). It was suspected that this problem may be due to (1) the high correlations among parameters and (2) neglect of second and perhaps higher derivative terms in dealing with the partial derivatives. We adopted the following procedure used by Wilson and Biermann. The adjustable parameters were separated into two groups; group I—the mass ratio, luminosities L_1 (for yellow, blue, and UV), and limb darkening X_1 (for yellow, blue, and UV); and group II—the inclination and the surface potential. The procedure used was to alternate group I and group II as adjustable parameter sets. After several runs, the corrections to the adjustable parameters were reduced to values similar to those of the probable errors.

The photometric solution of BH Cen is listed in Table 6. The eclipses are complete and the primary minimum is at transit. The system is in contact, with the degree of overcontact equal to 21% (see Fig. 2). [The degree of overcontact is defined as $(\Omega_{\rm inner} - \Omega)/(\Omega_{\rm inner} - \Omega_{\rm outer})$.] The mass ratio is almost unity within twice the probable error. The two components have essentially the same temperature. The limb-darkening coefficients derived are 0.64, 0.50, and 0.89 for yellow, blue, and ultraviolet, respectively. These values are considerably higher than the values extracted from the grid of model atmospheres of Carbon and Gingerich (1969) of 0.23, 0.29, and 0.27 respectively. The reason for the difference between these values may be the fact that the limb-darkening effect for this temperature and gravity is not a linear cosine function (see Table III of Carbon and Gingerich [1969, p. 455]).

The theoretical light curves according to the parameters in Table 6 are graphed among the individual

TABLE 6

PHOTOMETRIC PARAMETERS OF BH CENTAURI

A. WAVELENGTH-DEPENDENT PARAMETERS

Parameter	Yellow (λ5500)	Blue (λ4350)	UV (λ3500)
$L1/(L1 + L2)$	0.5073 ± 0.0033	0.5074 ± 0.0026	0.5074 ± 0.0050
$X_1 = X_2$	0.635 ± 0.067	0.500 ± 0.053	0.892 ± 0.071

B. NON-WAVELENGTH-DEPENDENT PARAMETERS

i	90.00° ± 1.89°	r_1 (back)	0.4327 ± 0.0019
$\Omega_1 = \Omega_2$	3.5899 ± 0.0078	r_2 (pole)	0.3675 ± 0.0010
Percent over contact	20.6	r_2 (side)	0.3879 ± 0.0013
$g_1 = g_2$	1.0*	r_2 (back)	0.4273 ± 0.0019
$A_1 = A_2$	1.0*	Ω (inner contact)	3.699
T_1	17,900 K† ± 600 K‡	Ω (outer contact)	3.170
T_2	17,840 K ± 600 K‡	$X_{\lambda 5500}$	0.23§
m_2/m_1	0.969 ± 0.015	$X_{\lambda 4350}$	0.29§
r_1 (pole)	0.3727 ± 0.0010	$X_{\lambda 3500}$	0.27§
r_1 (side)	0.3937 ± 0.0013		

NOTE.—Primary eclipse is annular.

* Assumed value. † Adopted value from color index and spectral type.

‡ Assumed error in estimating the temperature from spectral type and color index.

§ Linear limb darkening coefficients derived from the grid model atmospheres of Carbon and Gingerich 1969 for $T = 17{,}900$ K and $\log g = 4.0$.

observations in Figure 1. The theoretical light curves fit the maxima better than the minima. Generally, however, the agreement between the theoretical light curves and the observations is satisfactory. We believe that a better coverage of the light curves and a more accurate determination of the period will improve the solution of BH Cen.

V. MASSES AND ABSOLUTE DIMENSIONS

BH Cen is a member of the young galactic cluster IC 2944. Thackeray and Wesselink (1968) studied this cluster both photometrically and spectroscopically, and derived a distance modulus ($V_0 - M_v$) of 11.5 ± 0.2 magnitudes. They found that the reddening is not uniform. There were appreciable differences among B stars, and especially among O stars. Fortunately the ratio of color excesses, $E_{(U-B)}/E_{(B-V)}$, was found to be 0.76, which was not very different from the standard value of 0.72. This suggested that the ratio of the total to selected absorption, R, may be equal to 3 (the normal value). Since the observed color and spectral type are known for BH Cen, we calculated its absolute luminosity from the knowledge of the distance modulus. With the results from the photometric solution (i.e., fractional radii, temperatures, and mass ratio), absolute luminosities, and the period of the binary, we calculated the absolute dimensions and individual masses of the components according to the equations given by Leung and Schneider (1975). The absolute dimensions and other quantities of BH Cen are listed in Table 7. The probable errors for the masses determined are large, mainly because of the error of 0.2 mag in the absolute magnitude determination (i.e., the error in the distance modulus). On the other hand, the determination of the radii is more accurate since they are dependent on a lower exponent of the luminosity (see the equation in Leung and Schneider 1975). The masses and the radii of the components are equal within the

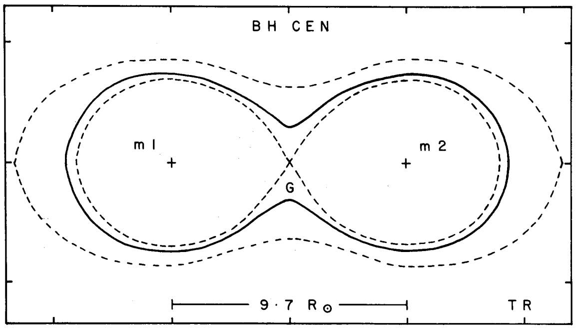

FIG. 2.—The contact configuration of BH Cen at phase 0.25. The broken envelopes represent the inner and outer contact surfaces. The center of each component is designated with a plus sign and the center of mass is located at the inner Lagrangian point (G).

TABLE 7

ABSOLUTE DIMENSIONS AND OTHER QUANTITIES OF BH CENTAURUS

A (Separation)	$9.7\ R_\odot \pm 1.7\ R_\odot$
$R_1 = 3.8\ R_\odot \pm 0.7\ R_\odot$	
$R_2 = 3.8\ R_\odot \pm 0.7\ R_\odot$	
$M_1 = 9.9\ M_\odot \pm 5.4\ M_\odot$	
$M_2 = 9.7\ M_\odot \pm 5.4\ M_\odot$	
$\log T_1 = 4.25 \pm 0.03$	
$\log T_2 = 4.25 \pm 0.03$	
$\log L_1/L_\odot = 3.12 \pm 0.22$	
$\log L_2/L_\odot = 3.12 \pm 0.22$	
$V_e \sin i = 243$ km s^{-1}	
Radius for a 10 $M_\odot$ ZAMS Star $= 3.98\ R_\odot$*	

* Mean radius for three different chemical compositions (Stothers 1972).

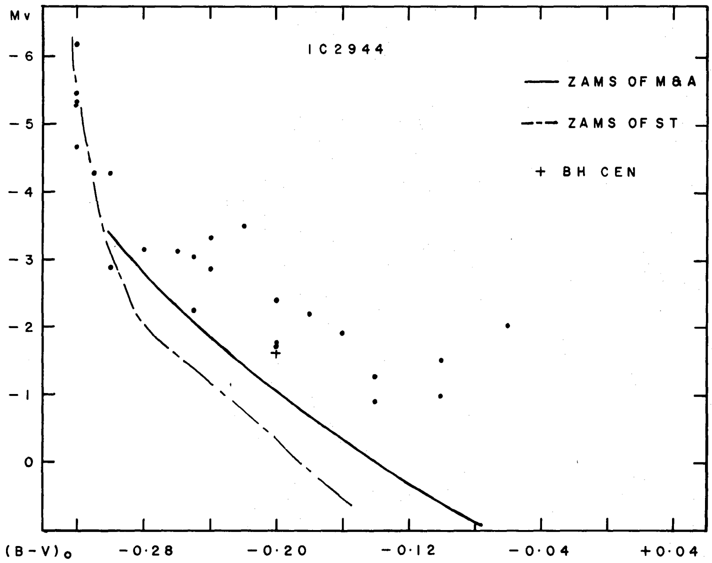

FIG. 3.—The H-R diagram of IC 2944 based on the observations of Thackeray and Wesselink (1965). The location of the components of BH Cen is denoted as a plus sign (both components occupy essentially the same location). *Solid line*, the ZAMS of Morton and Adams (1968). *Broken line*, the ZAMS of Stothers (1972).

probable errors. Since this system is known to be doubled-lined, it would be important to obtain a spectroscopic solution to check the masses and absolute dimensions.

VI. INTERPRETATION—ZERO-AGE CONTACT

In this section we wish to investigate the evolutionary state of BH Cen. Thackeray and Wesselink (1965) suggested that IC 2944 was very young, but they did not give an estimate for the age of the cluster. The problem of reddening was discussed in the previous section. Thackeray and Wesselink adopted a mean value for the reddening in their study. According to their H-R diagram (Fig. 1 in their paper), the O stars may be evolved, while the B stars are not (BH Cen is B3). In this study we employed only those cluster members for which both spectral types and $(B - V)$ colors were available; thus each star was unreddened individually. The H-R diagram of these stars, along with the ZAMS of Morton and Adams (1968) and Stothers (1972), is shown in Figure 3. The O stars are slightly bluer and brighter than in the previous study. Unfortunately, there is some discrepancy between the two theoretical ZAMS. This difference is probably due to the chemical compositions and other assumptions used in their models. According to Figure 3, the O stars may or may not be significantly evolved, depending on the ZAMS used. In either case BH Cen (shown as plus sign; both components occupy essentially the same location) has not evolved. Thus this system must be still at zero age, or, in other words, it is a zero-age contact system.

Zero-age contact must be a consequence of star fission under critical angular momentum. If the angular momentum is too large the star breaks into a detached system; if the angular momentum is too small, the star remains as a single star. Zero-age contact implies that the primary component has a zero-age radius for its mass. The primary (see Table 7) of BH Cen does have a zero-age radius. Therefore, the radius argument serves as an independent check for the evolutionary state of this binary system. As in the case of V1010 Oph (Leung and Wilson 1977), which is not a cluster member, the size of the primary radius is a reliable test for zero-age contact.

If we assume that the system is in synchronous rotation, the rotational velocity at the equator can be calculated from the radius of the component and the period of the binary. The rotational velocity for BH Cen is found to be 243 km s^{-1}. This is a fairly high velocity, and is comparable to the 260 km s^{-1} of V701 Sco (Leung and Wilson 1976). Due to the high rotational velocity, the components of BH Cen appear to be cooler and fainter in the H-R diagram (see Faulkner, Roxburgh, and Strittmatter 1968).

BH Cen and V701 Sco are the most massive zero-age contact systems discovered. We believe that there may be many more systems like these to be found. The systems listed in Table 5 are prime candidates for contact systems. RZ Pyx was found to be such a system by Devinney (1976). SW Lac is a very complicated system, and a marginal solution by Bookmeyer (1965) suggested it may be a contact system from the sum of fractional radii.

A study of these systems is of great importance in studying the common radiative envelope and the evolution of contact binaries.

We wish to express our thanks to Dr. A. D. Thackeray for the unpublished spectral type and density tracings of BH Cen. We would also like to thank Dr. R. E. Wilson for his unpublished table of the "neck radius" for contact systems and for his assistance with our

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KAM-CHING LEUNG: Behlen Observatory, Department of Physics and Astronomy, University of Nebraska, Lincoln, NE 68588

DONALD P. SCHNEIDER: Department of Astronomy, California Institute of Technology, Pasadena, CA 91125