9-1993

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Marschall, Laurence, and Michael A. Seeds and Robert J. Davis. "Radial-Velocity and Light Variations of IR Cephei." The Astronomical Journal (September 1993) 106(3):1123-1132.

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Radical-velocity observations of the short-period Cepheid, IR Cephei, have been used to derive a complete radial-velocity versus phase curve for the variable, to investigate the presence of a possible binary companion, and to address the question of its membership in the Cepheus OB2 association. The observations are consistent with the absence of a close binary companion and shed doubt on its membership in the association. Photoelectric observations made with the Phoenix 10 Automated Photometric Telescope confirm the single nature of the star. We present simulations to show the effects of an equiluminous companion on the light curve of a Cepheid, concluding that the light curve of IR Cephei, whether or not it is corrected for a possible companion, exhibits the low-amplitude, sinusoidal variations characteristic of an *s*-type Cepheid.

Keywords

short-period Cepheid, IR Cephei, Phoenix 10 Automated Photometric Telescope

Disciplines

Astrophysics and Astronomy | Stars, Interstellar Medium and the Galaxy

THE ASTRONOMICAL JOURNAL VOLUME 106, NUMBER 3 SEPTEMBER 1993

RADIAL-VELOCITY AND LIGHT VARIATIONS OF IR CEPHEI[1]

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(Received 1993 February 23; revised 1993 May 24)

ABSTRACT

Radical-velocity observations of the short-period Cepheid, IR Cephei, have been used to derive a complete radial-velocity versus phase curve for the variable, to investigate the presence of a possible binary companion, and to address the question of its membership in the Cepheus OB2 association. The observations are consistent with the absence of a close binary companion and shed doubt on its membership in the association. Photoelectric observations made with the Phoenix 10 Automated Photometric Telescope confirm the single nature of the star. We present simulations to show the effects of an equiluminous companion on the light curve of a Cepheid, concluding that the light curve of IR Cephei, whether or not it is corrected for a possible companion, exhibits the low-amplitude, sinusoidal variations characteristic of an *s*-type Cepheid.

1. INTRODUCTION

The bright Cepheid variable IR Cephei (HD 208960; SAO 19765; BD+60°, 2321; mean $V=7.8$) has been singled out (Kun & Szabados 1988) as worthy of special attention for two reasons. First, it is located in the direction of the Cepheus OB2 association (Antonello & Poretti 1986). The question of its membership in the association may therefore shed some light on its age as well as providing an independent check on its luminosity and distance. Second, the extant photoelectric *UBV* data on IR Cephei may show an anomalous light curve. While the period (2.114 days) and amplitude (0.4 mag) of IR Cephei are consistent with its membership in the group of *s*-type, or small amplitude Cepheids (Petit 1987), the shape of its published light curves (Wachmann 1976; Szabados 1977) is somewhat asymmetric, while the light curves of *s* Cepheids are nearly sinusoidal. The light curve, according to Kun and Szabados, resembles that of the larger amplitude classical Cepheids but with smaller amplitude. They suggest that perhaps IR Cephei is a classical Cepheid but has a bright companion whose constant contribution to the light of the pair reduces the measured amplitude of the Cepheid's variations (Kun & Szabados 1988).

No detailed spectroscopic study of IR Cephei had been made at the time of Kun & Szabados' 1988 paper. Radial-velocity measurements of early-type stars in the Cepheus OB2 association, however, had been published in the literature (Simonson 1968). To investigate the association of IR Cephei with Cepheus OB2, as well as to check for the possibility of a bright spectroscopic companion, a radial-velocity study of the Cepheid was carried out during 1989–1990. In addition the star was added to the observing program of the Phoenix 10 Automated Photometric Telescope on Mount Hopkins with the purpose of obtaining an up-to-date light curve of the star to investigate possible period changes (Henden 1979) or changes in the shape of the light curve.

2. SPECTROSCOPIC OBSERVATIONS

Between 1989 January and 1990 January, 63 spectra of IR Cephei covering a 45 Å wide bandpass centered on 5187 Å were obtained using the echelle spectrograph of the 1.3 m Tillinghast Reflector at F. L. Whipple Observatory on Mount Hopkins (MHO). An additional eight spectra were obtained during the same period using an identical spectrograph at the Wyeth Reflector of the Oak Ridge Observatory, Harvard, MA (ORO) and one additional spectrum was obtained from the echelle at the Multiple Mirror Telescope (MMT).

The spectra were reduced using standard cross-correlation techniques at the Harvard-Smithsonian Center for Astrophysics (Latham 1992) to obtain radial velocities. Spectra of IR Cephei were cross correlated against solar templates and zero points were set against dusk and dawn spectra of the sky. The standard precision for such velocity determinations is about 0.25 km/s. A typical spec-

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[1] Some of the observations reported herein were obtained with the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

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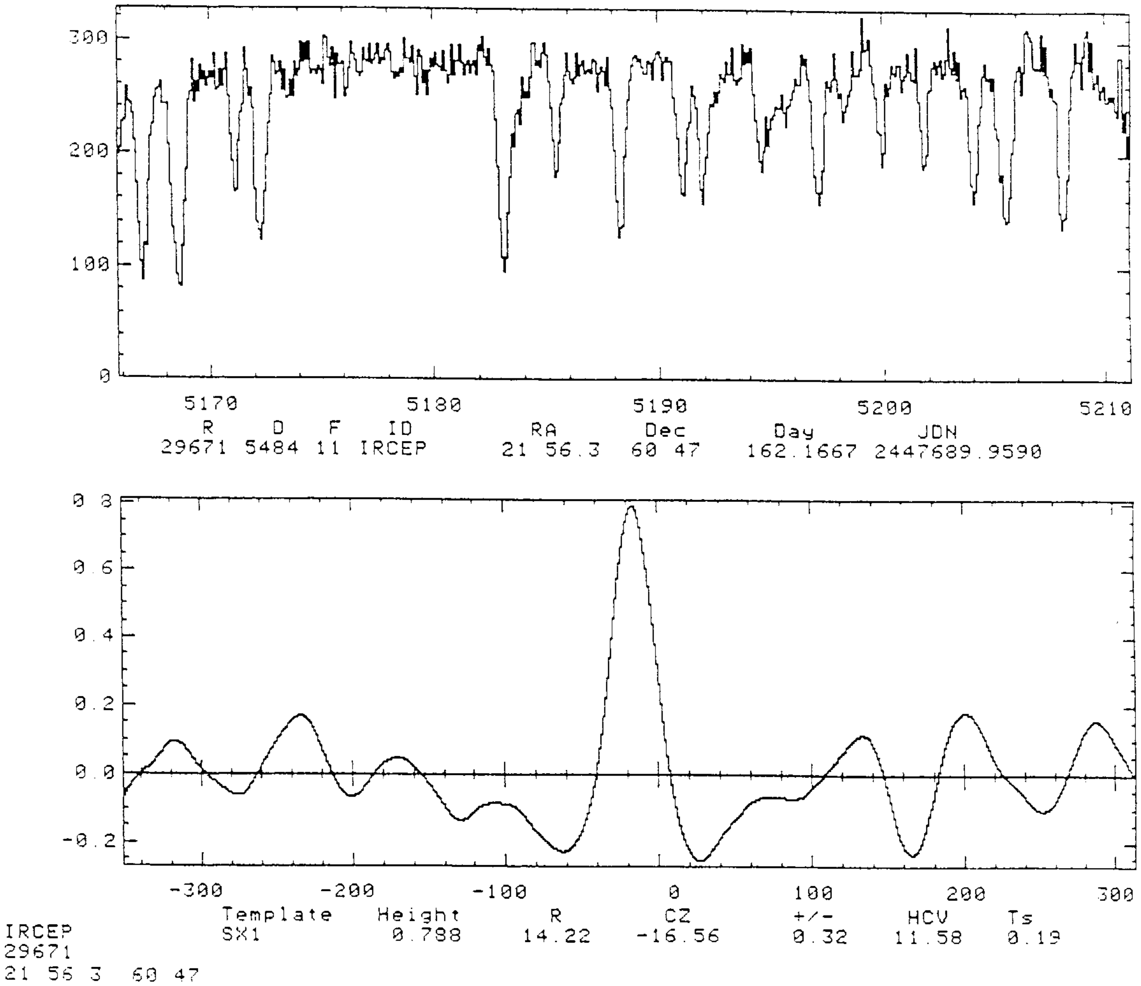

FIG. 1. Sample spectrum and cross-correlation plot of IR Cephei.

trum of IR Cephei along with the corresponding correlation plot is shown in Fig. 1. Typical spectra had at least 100 counts/pixel.

The radial-velocity data are presented in Table 1. Column 1 lists the heliocentric Julian date of midexposure and Column 2 the derived radial velocity in km/s. Column 5 lists the telescope used to obtain the spectrum. Columns 3 and 4 list the epoch and phase of the observations using Szabados' published elements (Szabados 1991) for the heliocentric time of maximum brightness in *V*:

$$\text{Max}_{\text{hel}} = \text{JD } 2441696.581 + 2.114088 \text{ d}.$$

Using the derived phase, a plot of radial velocity versus phase can be made. This has been done in Fig. 2. The scatter of the data around a mean curve is consistent with the expected precision of the radial-velocity determinations. Measurements, it will be noted, cover more than 180 cycles of the star. A Scargle periodogram analysis of the radial-velocity data yields a period consistent with that of both Szabados (1977, 1991) and Wachmann (1976). This results is in agreement, within the precision of our measurements, with that of Szabados (1991), who found no substantial change in the period over at least 15 yr. A communication from Szabados (Szabados 1993), indicates that there has recently been a slight change in the pulsation period, which may have occurred after the observations he published in 1991, and that our data are also consistent with a period of 2.114170 days, in agreement with the most recent published photometry (Berdnikov 1992) and radial-velocity data (Gorynya *et al.* 1992). For the purposes of this study, however, the resulting radial-velocity plots show no significant difference in scatter whichever period we use.

3. PHOTOMETRIC OBSERVATIONS

Between 1989 May and 1991 July, 139 separate photometric observations in *V* (somewhat fewer in *B* and *U*) were obtained using the Phoenix 10 Automated Photometric telescope (Boyd & Genet 1984). The pulse-counting photometer uses a 60 arcsec diameter diaphragm and 10 s integration times. Observations were corrected for extinction and transformed to the Johnson *UBV* system. Each magnitude difference shown in Table 2 is the mean of three integrations of the variable minus the mean of four integrations of the comparison star HD 209102 (SAO 33939).

TABLE 1. Radial-velocity observations of IR Cephei.

HJD (2400000+)	RADIAL VELOCITY (km/sec)	EPOCH	PHASE	TELESCOPE
47545.5671	4.28	2766	0.671	MHO
47546.5550	-13.19	2767	0.138	MHO
47552.5810	-16.72	2769	0.989	MHO
47555.5789	-2.82	2771	0.407	MHO
47556.5689	-7.26	2771	0.875	MHO
47580.5901	-9.61	2783	0.238	MHO
47688.9638	1.16	2834	0.500	MHO
47689.9573	-16.55	2834	0.970	MHO
47690.9799	-0.62	2835	0.454	MHO
47691.9714	-11.98	2835	0.923	MHO
47692.9731	-3.40	2836	0.397	MHO
47693.9792	-6.19	2836	0.873	MHO
47697.8987	2.82	2838	0.727	MMT
47698.9317	-10.74	2839	0.215	MHO
47699.9690	4.01	2839	0.706	MHO
47700.9302	-13.07	2840	0.160	MHO
47701.8950	3.17	2840	0.617	MHO
47702.9603	-14.37	2841	0.121	MHO
47812.6063	-15.34	2892	0.985	MHO
47812.7978	-16.60	2893	0.076	MHO
47815.5900	-2.36	2894	0.397	MHO
47816.5855	-5.78	2894	0.867	MHO
47816.7495	-11.67	2894	0.945	MHO
47817.5634	-5.30	2895	0.330	MHO
47817.7913	-1.06	2895	0.438	MHO
47818.5649	-1.90	2895	0.804	MHO
47819.5585	-8.24	2896	0.274	MHO
47822.5812	4.14	2897	0.704	MHO
47822.7616	1.57	2897	0.789	MHO
47837.5616	0.11	2904	0.789	MHO
47838.5502	-9.75	2905	0.257	MHO
47839.5500	3.40	2905	0.730	MHO
47839.7323	-1.44	2905	0.816	MHO
47840.5689	-9.97	2906	0.212	MHO
47840.7172	-7.68	2906	0.282	MHO
47841.5493	3.65	2906	0.676	MHO
47841.7488	1.26	2906	0.770	MHO
47842.5452	-14.51	2907	0.147	MHO
47842.7431	-9.52	2907	0.240	MHO
47843.5488	4.12	2907	0.622	MHO
47843.6415	3.17	2907	0.665	ORO
47843.7487	4.38	2907	0.716	MHO
47844.5581	-16.52	2908	0.099	MHO
47844.6320	-14.31	2908	0.134	ORO
47844.7248	-12.51	2908	0.178	MHO
47845.5521	2.60	2908	0.569	MHO
47845.7671	4.36	2908	0.671	MHO
47846.5547	-16.55	2909	0.043	MHO
47846.7461	-14.04	2909	0.134	MHO
47847.6420	1.82	2909	0.558	MHO
47847.6695	1.60	2909	0.571	ORO
47847.7965	3.27	2909	0.631	MHO
47848.6485	-16.52	2910	0.034	MHO
47848.6732	-16.64	2910	0.045	ORO
47849.5560	-0.85	2910	0.463	MHO
47849.6414	0.76	2910	0.503	ORO
47850.5468	-13.09	2910	0.932	MHO
47850.7563	-16.43	2911	0.031	MHO
47854.6126	-3.20	2912	0.855	ORO
47865.5638	-17.24	2918	0.035	ORO
47871.5395	-6.29	2920	0.862	MHO
47873.5552	-0.41	2921	0.815	MHO
47878.5389	-12.31	2924	0.172	MHO
47879.5824	4.02	2924	0.666	MHO
47880.5446	-14.12	2925	0.121	MHO
47901.5645	-15.37	2935	0.064	MHO
47902.5501	1.92	2935	0.530	MHO
47905.5612	-15.02	2936	0.954	MHO
47906.5562	-2.71	2937	0.425	MHO
47908.5604	-3.75	2938	0.373	MHO
47909.5758	-3.50	2938	0.853	MHO

All observations whose internal errors exceed 0.02 mag are automatically rejected during data reduction, and further nights likely to be of poor quality were removed following the procedure described by Seeds (1992).

The data were first analyzed using a Scargle period analysis program, and a period was derived in good agreement with Wachmann's published period (1976), Szabados' more recent photometric study (1991), and the new radial-velocity data noted above. The light curves plotted from the data, phased with Szabados' period, are shown in Fig. 3. Because of a lack of published *UBV* photometry for the comparison and check stars, the data were left in differential form.

4. ANALYSIS OF RADIAL-VELOCITY MEASUREMENTS

The radial-velocity curve of IR Cephei (Fig. 2) shows very little scatter around the mean curve we would expect for a single pulsating star. By fitting simulated radial-velocity curves to the data we found an rms scatter of about 0.5 km/s. Binning the data by season had no noticeable effect on the curve. Within the limits set by this scatter, we find no evidence that IR Cephei is an unresolved spectroscopic binary. This is consistent with the recent results of Evans (1992), who surveyed Cepheids brighter than 8th magnitude using the *International Ultraviolet Explorer*. Evans found no sign of a hot companion in the ultraviolet spectrum of IR Cep, and included it in her list of probable single stars. It is also consistent with the survey of past results on Cepheid binarity by Szabados (1992), who does not include IR Cephei in a compilation of known binary Cepheids.

We cannot, of course rule out the possibility of a more distant companion to IR Cep, but the stability of our measurements over a year's time sets limits on the separation of a companion of similar mass (assumed to be about 3 solar masses) to about 10 AU, and a period of about 20 yr.

There is, however, an optical companion to IR Cephei reported in the literature. IR Cephei is designated as IDS 21548+6032 in the *Index Catalog of Visual Double Stars* (Jeffers *et al.* 1963) and in the *Hipparchos Input Catalog* (as HIC 108426), presumably on the basis of reports by Muller (1958). Further measures of the separation of the pair indicate a noticeable orbital motion (Couteau 1971; Worley 1990). The companion, designated Mlr 17, appears to be roughly equal in brightness, separated from IR Cephei by 0.15 arcsec (Gaustad 1991). If IR Cephei is, in fact, located at the distance of the Cepheus OB2 association (for which $m-M=10$, Garrison & Kormendy 1976), this angular separation corresponds to a physical distance

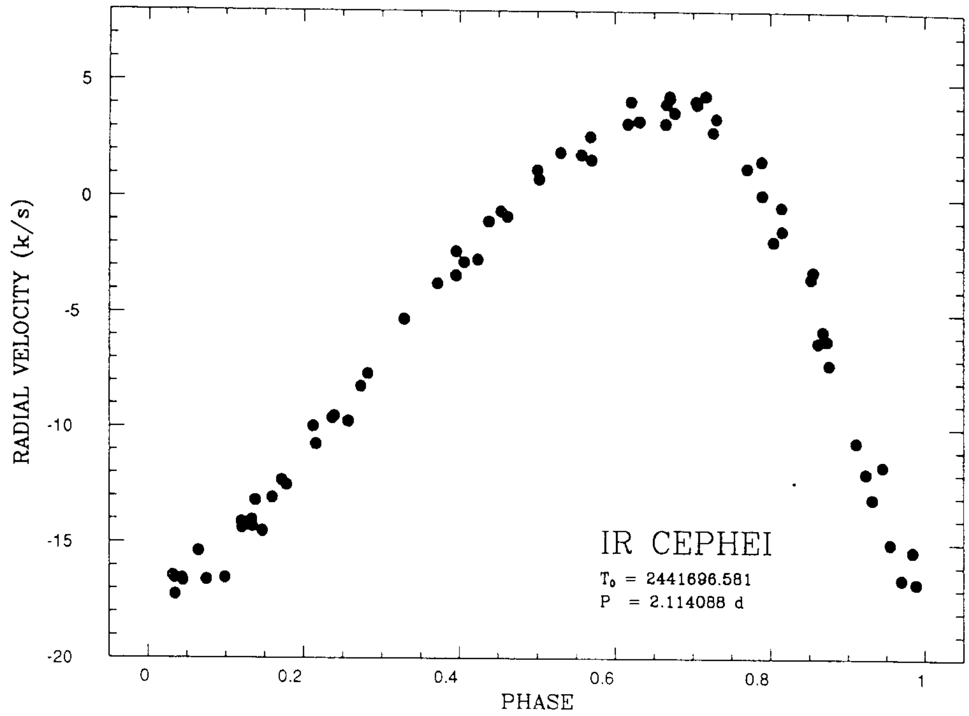

FIG. 2. Radial-velocity curve of IR Cephei.

of about 150 AU. Orbital motion for a circular orbit of this size (assuming a few solar masses per component) would have a semiamplitude of less than 0.5 km/s and a period of roughly 10^3 yr, and so would surely be undetectable in our radial-velocity measurements.

A companion equal in luminosity, however, might be expected to make itself known in the correlation plots (Fig. 1) as a second stationary peak at the gamma velocity of the binary system. Consequently, one might expect to see a variation in the half-width of the correlation peak as the radial velocity of the Cepheid member of the pair varies. The effect might be marginal, since the width of the peak is about the same magnitude as the radial-velocity excursion of the Cepheid, but in any case we see no such variation in any of the spectra. It is, of course, possible that the spectrum of the companion is weak or broadlined, in which case its contribution to the correlation peak would not be noticeable. It is also possible that it is, in fact, much less luminous than the Cepheid. In a previous study (Marschall & Mathieu 1988), we investigated the effects of relative luminosity and spectral type on the correlation plots of binary stars by using synthetic spectra. A companion of similar spectral type should be noticeable if its brightness were greater than about 0.2 that of the Cepheid. Rotation and differing spectral type can raise this limit.

If the companion is, in fact, a main-sequence star physically associated with the variable, the membership of IR Cephei in the Cepheus OB2 association becomes a bit troublesome. At a distance modulus, $m-M$, of 10, the companion would have an approximate absolute magnitude $M_v = -1.5$. Even if the extent of the association were a few hundred parsecs along the line of sight (Kun & Szabados 1988), this value would not change by more than a magnitude. Yet, based on *IUE* spectra, Evans sets an upper limit of A3 to the spectral type of the companion. An equiluminous main-sequence companion to IR Cephei, in other words, should have been detectable in Evans' study.

There are several ways to reconcile these observations. (1) The reported companion may not be a physical companion, but rather a late-type foreground star. Its reported orbital motion may either be in error or attributable to proper motion. (2) The companion may be a nonvariable late-type giant, so similar spectrally to IR Cephei that it escaped detection by *IUE*, and perhaps low enough in luminosity to escape detection on our spectra. (3) The relative brightness estimates in the literature, which are sketchy at best, may be in error, and the companion star may be fainter than reported or even nonexistent.

The last option, that the companion does not exist, deserves most serious consideration. The only observations of the binary nature of IR Cephei are those of Muller. Heinz (1983), reported seeing it as "round," i.e., apparently single, and McAlister's speckle interferometer observed IR Cephei on five occasions between 1983 and 1987 (McAlister 1993) without seeing any evidence for a companion wider than 0.035 arcsec or within 2 mag of the primary. It is possible that these nondetections are due to orbital motion, but further investigation by speckle interferometric techniques could resolve the question of whether the reported motion is secular, periodic, or spurious. High resolution optical spectroscopy may also be able to distinguish individual features in the composite spectra.

We have determined the heliocentric center-of-mass (gamma) velocity of IR Cephei by an iterative procedure that requires that the area above the gamma velocity on the radial-velocity curve equal the area below it. The value we

TABLE 2. Photometric observations of IR Cephei.

HJD(2400000+)	PHASE	Uv-Uc	Bv-Bc	Vv-Vc
47665.9784	0.6277			0.139
47668.9635	0.0397	0.453		-0.195
47670.9616	0.9848		0.006	-0.223
47672.9545	0.9275	0.555	0.044	-0.208
47673.9544	0.4005		0.429	0.072
47680.9303	0.7002		0.478	0.106
47683.9373	0.1226	0.612	0.088	-0.170
47686.9632	0.5539		0.548	0.148
47687.9555	0.0232		-0.009	-0.234
47688.9276	0.4830		0.506	0.105
47689.9384	0.9612		0.025	-0.212
47690.9511	0.4402		0.459	0.070
47691.9413	0.9086	0.600	0.087	-0.149
47692.8971	0.3607		0.385	0.020
47693.9081	0.8389		0.232	-0.076
47694.9277	0.3212		0.337	-0.011
47695.9274	0.7941	0.824	0.317	0.001
47699.9295	0.6871		0.497	0.119
47701.9350	0.6358			0.133
47780.8248	0.9520		0.017	
47786.8124	0.7842	0.943	0.352	0.022
47788.7939	0.7215	1.097	0.442	0.074
47789.8042	0.1994	0.774	0.151	-0.152
47793.7891	0.0843	0.645	0.045	-0.195
47796.8158	0.5160	1.150	0.510	0.128
47800.8100	0.4053	1.050	0.435	0.056
47807.7572	0.6915	1.172	0.494	0.120
47816.7565	0.9483	0.612	0.019	-0.212
47824.7456	0.7273	1.096	0.436	0.093
47826.7406	0.6710	1.158	0.511	0.122
47827.7357	0.1417		0.108	-0.150
47832.6964	0.4882		0.511	0.109
47838.6772	0.3172	1.011	0.342	0.001
47842.6534	0.1980	0.707	0.183	-0.121
47843.6515	0.6701		0.508	0.133
47844.6507	0.1428	0.646	0.110	-0.151
47845.6552	0.6179		0.531	0.149
47846.6554	0.0910		0.041	-0.198
47847.6865	0.5787		0.559	0.133
47850.6739	0.9918	0.442	-0.001	-0.221
47864.6287	0.5927		0.537	0.148
47878.6071	0.2047		0.195	-0.098
47880.5935	0.1443	0.538	0.110	-0.152
47881.5874	0.6144		0.541	0.137
47882.5876	0.0876	0.539	0.049	-0.194
47883.5813	0.5576	1.143	0.539	0.140
47884.5876	0.0336	0.532	0.006	-0.216
47885.5809	0.5034		0.505	0.113
47886.5750	0.9737	0.497	0.020	-0.207
47893.5626	0.2789		0.303	-0.037
47896.5635	0.6984		0.500	0.113
47897.5645	0.1719		0.152	-0.117
47899.5654	0.1184		0.082	-0.165
47900.5654	0.5914			0.156
47901.5657	0.0645		0.023	-0.228
48027.9796	0.8605			-0.078
48032.9726	0.2223		0.234	-0.086

TABLE 2. (continued)

HJD(2400000+)	PHASE	Uv-Uc	Bv-Bc	Vv-Vc
48036.9616	0.1091		0.078	-0.196
48041.9513	0.4693		0.476	0.086
48043.9408	0.4104	1.052	0.426	0.075
48044.9422	0.8841	0.637	0.141	-0.122
48053.9469	0.1435	0.627	0.102	-0.147
48054.9526	0.6192	1.058	0.542	0.142
48055.9541	0.0929	0.524		-0.230
48056.9149	0.5474		0.556	0.173
48057.9383	0.0315		0.013	-0.226
48058.9378	0.5042		0.503	0.093
48059.9519	0.9839	0.532	0.007	-0.215
48062.9566	0.4052	0.988	0.424	0.059
48067.9614	0.7726		0.401	0.066
48068.9091	0.2208	0.740	0.213	-0.087
48143.8732	0.6801		0.508	0.114
48168.8030	0.4724	1.109	0.474	0.112
48169.8105	0.9489	0.500	0.038	-0.208
48173.7835	0.8282	0.780	0.274	-0.027
48174.7858	0.3023	0.880	0.307	-0.034
48176.7835	0.2473	0.786	0.246	-0.070
48177.7754	0.7165	0.994	0.465	0.104
48178.7807	0.192	0.672	0.163	-0.132
48179.7739	0.6618	1.067	0.531	0.144
48180.7728	0.1343	0.584	0.094	-0.160
48182.7643	0.0763	0.505	0.031	-0.212
48183.7653	0.5498	1.070	0.517	0.123
48185.7602	0.4934		0.488	0.096
48186.7573	0.9651	0.484	0.024	-0.207
48188.7509	0.9081	0.604	0.107	-0.151
48192.7472	0.7984	0.881	0.344	0.000
48193.7150	0.2562	0.767	0.240	-0.075
48194.7250	0.7339	1.010	0.445	0.096
48199.7145	0.0940	0.530	0.054	-0.189
48201.7134	0.0396	0.508	-0.010	-0.223
48204.7073	0.4557		0.538	0.113
48206.6987	0.3977	0.990	0.413	0.053
48207.6986	0.8707	0.695	0.197	-0.102
48208.6979	0.3433	0.896	0.363	0.016
48210.6874	0.2844	0.823	0.279	-0.043
48211.6848	0.7562		0.435	0.081
48214.6709	0.1687		0.121	-0.192
48218.6651	0.0580	0.463	0.025	-0.235
48219.6717	0.5341	1.089	0.535	0.141
48227.6402	0.3034		0.315	-0.017
48228.6410	0.7768	0.907	0.377	0.041
48229.6358	0.2473	0.697	0.225	-0.075
48230.6336	0.7193	1.014	0.478	0.101
48232.6318	0.6645	1.110	0.523	0.136
48233.6266	0.1350	0.569	0.073	-0.173
48234.6247	0.6072	1.133	0.530	0.134
48235.6438	0.0892	0.555	0.060	-0.193
48236.6133	0.5478	1.118	0.516	0.134
48243.5978	0.8516		0.246	-0.046
48244.6119	0.3313	0.887	0.333	-0.005
48245.5998	0.7986	0.871	0.355	0.026
48250.5873	0.1578		0.114	-0.151
48257.5765	0.4638	1.119	0.470	0.096

TABLE 2. (continued)

HJD(2400000+)	PHASE	Uv-Uc	Bv-Bc	Vv-Vc
48258.5693	0.9334		0.078	-0.174
48397.9750	0.8747		0.226	-0.073
48400.9754	0.2939			-0.029
48402.9523	0.2290	0.708	0.181	-0.114
48404.9474	0.1727		0.132	-0.128
48405.9505	0.6472	1.149	0.543	0.154
48406.958	0.1238	0.573	0.077	-0.183
48410.9371	0.0060	0.482	0.004	-0.222
48411.9281	0.4747	1.027	0.471	0.092
48412.9287	0.9480	0.526	0.038	-0.203
48413.9297	0.4215	1.004	0.443	0.063
48414.9260	0.8928	0.613	0.158	-0.128
48415.9607	0.3822	0.947	0.404	0.049
48422.9299	0.6788	1.062	0.509	0.128
48424.9038	0.6125	1.097	0.565	0.159
48425.8977	0.0826	0.527	0.052	-0.201
48427.8974	0.0285	0.447	-0.004	-0.230
48428.9265	0.5153	1.058	0.510	0.116
48429.9204	0.9854	0.500	0.037	-0.198
48430.9058	0.4515		0.442	0.069
48432.8807	0.3857		0.427	0.060
48433.8832	0.8599	0.749	0.243	-0.057
48434.8677	0.3256		0.314	-0.012
48435.8963	0.8121	0.759	0.334	0.018
48436.9612	0.3158	0.864	0.313	-0.029
48437.9049	0.7622	0.948	0.429	0.086

derive is -5.6 ± 0.4 km/s. Samus (1990, quoted in Szabados 1991) has recently obtained a radial-velocity series of almost a dozen measurements on IR Cep, finding a center-of-mass value of -4.9 km/s. The difference in these two values is not significant, however, since Samus quotes errors for an individual measurement of about 0.5 km/s, and since the radial velocities he obtains phase exactly with the measurements we report here (Szabados 1991).

The value of the center-of-mass velocity differs by more than 10 km/s from the published mean velocity of the bright stars in Cepheus OB2 (Simonson 1968), -16.0 km/s, which is approximately the velocity expected from a simple galactic rotation model in which the association lies at a distance modulus of $(m-M)=10$.

A case can still be made for the membership of IR Cephei in Cepheus OB2. Kun & Szabados (1988) argue that, using reasonable Cepheid period–luminosity relations and plausible values for reddening, the line-of-sight distance to IR Cephei may be between 630 and 850 parsecs, a figure which overlaps estimates of the extent of the association. Szabados (1991) further notes that there are stars in Cepheus OB2, notably HD 206267 (about 4.3 degrees from IR Cep, but located in the core of the association), which have published velocities significantly different from that of the association. While this may be the case, we note that HD 206267 is itself a known spectroscopic binary with a high radial-velocity semiamplitude (Monet 1979) and its published gamma velocity may itself be in need of revision.

Alternately, it is conceivable that IR Cephei was born in the core of Cepheus OB2 and was ejected from it in a stellar collision. At a distance modulus $(m-M)=10$, its separation from HD 206267 corresponds to about 1.5×10^7 AU. If we assume that the tangential velocity of IR Cephei with respect to the association is the same as its radial velocity with respect to the association mean, it could have covered 1.5×10^7 AU in approximately 7×10^6 yr in good agreement with the age of the association, which is less than 10^7 yr (Simonson 1968; Marschall *et al.* 1990). The corresponding proper motions would be of the order of $0\farcs002$/yr. Although the values of the proper motion of IR Cephei tabulated in the *Smithsonian Astrophysical Observatory Catalog* are of this magnitude, there is a large tabulated uncertainty, and, in any case, the motion is in the wrong direction to account for the present separation ($\mu_\alpha=-0\farcs0017/\mathrm{yr}\pm0\farcs0017$; $\mu_\delta=-0\farcs0.008\pm0\farcs0014$), since IR Cep lies to the north and east of HD 206267.

The weight of the evidence, therefore, makes it seem unlikely that IR Cephei is a member of Cepheus OB2. In

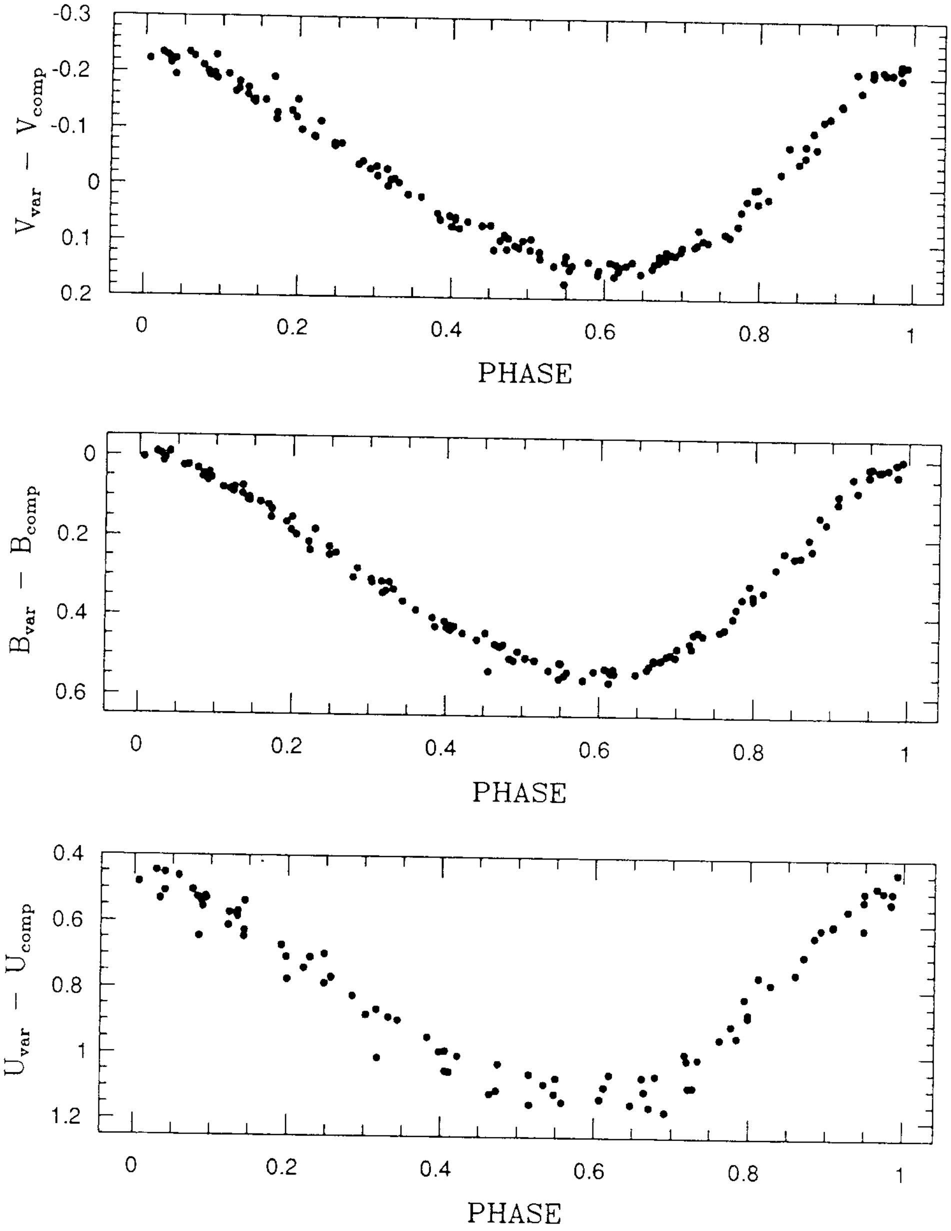

FIG. 3. Observed light curves of IR Cepehi in *V*, *B*, and *U* are phased with the ephemeris of Szabados (1991). The symmetry of the light curve and its amplitude suggest that IR Cephei is an *s*-type Cepheid.

addition to the velocity discrepancy we have discussed above, the 10^7 yr figure for the age of the Cepheus OB2 association is an order of magnitude younger than the expected age for a Cepheid of this period (Kun & Szabados, 1988). If, in fact, IR Cephei lies within the limits of the Cepheus OB2 association, its relationship seems more accidental than physical.

5. ANALYSIS OF PHOTOMETRIC MEASUREMENTS

The photometry from the Phoenix 10 telescope phased with the period from Szabados (1991) produces a light curve whose appearance is typical of an *s*-type Cepheid, i.e., characterized by a low amplitude, less than 0.5 mag, and a nearly sinusoidal shape (Petit 1987). To verify the symmetry of the light curve, the data were subjected to Fourier decomposition using two to eight terms. A two-term Fourier decomposition fit the light curve well, and further decomposition up to eight terms did not significantly improve the fit. Typical Cepheids require four terms, but Antonello & Poretti (1986) point out that two terms are typically sufficient for *s*-type Cepheids.

Additional measures of the symmetry of the light curve can be drawn from the amplitude ratios of the second to the first terms, R21, and the phase ratios $\phi 21$. Terms derived from this data set are consistent with terms published by Antonello *et al.* (1990) and are similar to terms for known *s*-type Cepheids.

Yet another measure of symmetry is *D*, the fraction of the period between minimum and maximum. In a perfectly symmetric curve, *D* is 0.5, and typical Cepheids have an

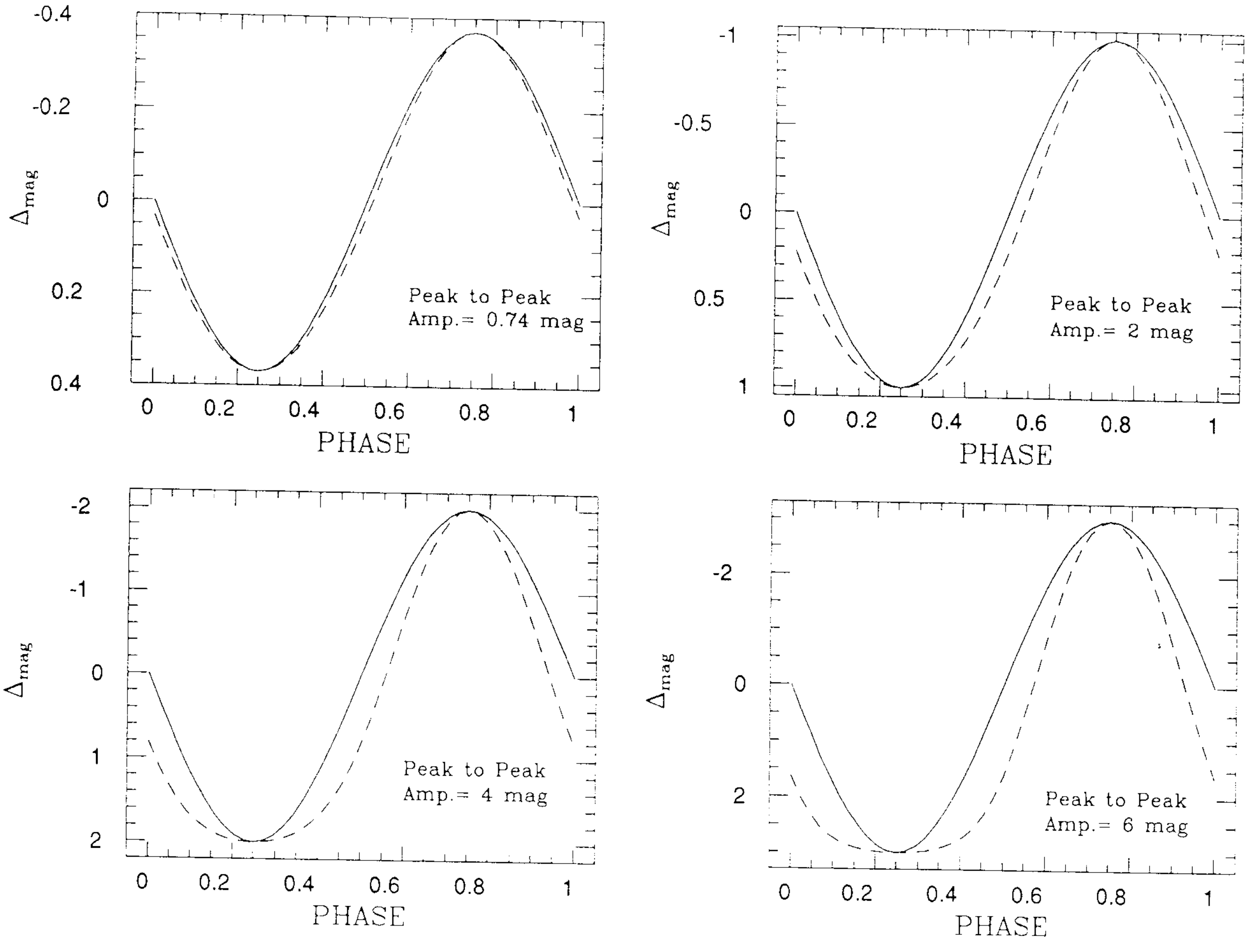

FIG. 4. Models of a sinusoidal variable star alone (solid line) and with an equiluminous companion (dashed line) were computed for a range of amplitudes. In each case the model with a companion is scaled to the same amplitude as the variable alone to reveal changes in the shape of the light curve. Note that amplitude variations of 4 to 6 mag are unrealistic for Cepheids. Changes in the shape of the light curve of IR Cephei due to an equiluminous companion are less than the scatter in the observations (upper left).

average *D* of about 0.3. *D* for IR Cephei is 0.43, again similar to values of *D* for known *s*-type variables.

As mentioned in Sec. 1, Antonello & Poretti (1986) proposed that the low amplitude of IR Cephei may be caused by the presence of an unseen companion. The optical companion we noted in Sec. 4, Mlr 17, has been reported as equal in brightness and only 0.15 arcsec distant. This companion would be included in any photometric aperture and would have lowered the observed amplitude of variation. If IR Cephei has a companion whose *V* magnitude equals the mean magnitude of the variable, then the true amplitude of the variable star is 0.74 mag, twice the observed amplitude of 0.37 mag. This amplitude is high among *s*-type Cepheids, but is not the highest known.

While contamination of our photometric data by light from an unresolved companion would lower the amplitude of observed variations, one might also worry that such contamination might reduce the intrinsic asymmetry of variations and make the light curve appear more sinusoidal. It actually does the opposite, as we found by modeling the effects of a companion on photometric observations. We computed light curves in which the light from a star varying sinusoidally with a given peak-to-peak amplitude was contaminated by the light of an equiluminous companion. We then compared these curves with the light curve expected from the variable star alone. To reveal the effect of contamination on the shape of the light curve, the light curves which included companions were scaled to the same amplitude as those which did not (Fig. 4). In general, the companion affects the light curve most when the variable is at minimum and least when the variable is at maximum, broadening the width of the light curve at minimum and narrowing the width at maximum. The size of this distortion is a function of the amplitude of the variable star and is most pronounced for stars with large amplitude variations. However, the distortions only become pronounced for amplitude variations which are much larger than those actually observed for Cepheids. Note that these distortions have no effect on *D*, the fraction of the period between light minimum and light maximum.

In the case of IR Cephei, the intrinsic peak-to-peak amplitude of the variable star is 0.74 mag when the contamination of an equiluminous companion has been accounted for. This amplitude is sufficiently low that the distortion added by the presence of the companion is less than the scatter in the photometric data (about 0.01 mag when nights of poor quality have been removed as noted in Sec. 3). We may conclude that the observed symmetry in the light curve of IR Cephei is characteristic of the variable star and is not modified by the presence of a companion.

6. CONCLUSIONS

Our spectroscopic and photometric observations are in good agreement with previously published results, and the improved time coverage and precision of our measurements enable us to draw the following conclusions.

(1) Radial-velocity measurements show that IR Cephei has no close unresolved binary companion comparable to it in brightness. While we cannot rule out long period variability in the radial-velocity curve, we have noted no variations in the center-of-mass velocity of the star at a level of about 0.5 km/s over an interval of about one year. The presence of a reported optical companion of IR Cephei, Mlr 17, is doubtful but deserves further study, especially by speckle interferometry or other high resolution imaging techniques.

(2) IR Cephei is not a member of the Cepheus OB2 association. Its heliocentric center-of-mass velocity, −5.6 km/s, differs significantly from the mean velocity of the association, −16.0 km/s. (Simonson 1968). A binary companion close enough to produce the observed deviation from the association mean can be ruled out by the stability of the measured velocities.

(3) APT photometry of IR Cephei reveals the characteristic light curve of an *s* Cepheid. If these data are affected by the light of a close optical companion, any distortion in the shape of the intrinsic light curve of the Cepheid would be less than the scatter in the data, due to the low amplitude of Cepheid brightness variations. In fact, the effect of a companion would be to make the observed light curve of a Cepheid variable less sinusoidal than the intrinsic light curve of the Cepheid itself, and thus any correction for contamination actually strengthens the case that IR Cephei is an *s* Cepheid.

This research was supported in part by grants from Gettysburg College and by NSF Grant No. AST 8503236. We thank Laszlo Szabados, Charles Worley, Hal McAlister, Wulff Heinz, and John Gaustad for sharing advice and information, and Dana Backman for his comments on the manuscript. We acknowledge the assistance of Jim Peters, Robert Stefanik, Robert Mathieu, and the late Ed Horine in obtaining spectra, Susan Tokarz in reducing data, and David Latham for continued encouragement. We also acknowledge the support of Fairborn Observatory, Lou Boyd, and Russ Genet. This research has made use of the SIMBAD Database operated at CDS, Strasbourg, France.

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