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An overtone Cepheid variable in an LMC eclipsing binary

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Abstract. Eclipsing binary systems potentially allow the direct and precise determination of the important properties of their component stars. An eclipsing binary containing a Cepheid variable which is also a double-lined spectroscopic binary would allow, for the first time, the direct measurement of the absolute luminosity and mass of the Cepheid. The MACHO Project LMC database contains five systems whose light curves show variations due to both eclipses and pulsation but only one has been clearly identified as an intermediate-mass, Population I object. This object, MACHO 81.8997.87 (= OGLE LMC_SC16 119952) is a 2.035-d overtone Cepheid in an 800.4-d binary system with an M-type companion. Here we present the results of the analysis of the light curve of this system, the implications for its evolutionary history and discuss the prospects for future observations.

1. Introduction

Very few eclipsing binary star systems are known that contain a radially pulsating star as one of their components. This is unfortunate since such systems have considerable astrophysical potential. If an eclipsing binary system is also a double-lined spectroscopic binary, then the mass, radius, temperature and other properties of the components can be directly determined. A Cepheid variable in a double-lined spectroscopic binary could significantly reduce the current 10-15% uncertainty in the Cepheid period-luminosity relation as well as providing the first direct determination of the mass of a Cepheid.

There are five systems in the MACHO LMC database whose light curves show evidence for both eclipses and pulsation. Only one of them, 81.8997.87 (=OGLE LMC_SC16 119952), has been found to contain an intermediate-mass Cepheid: a 2.035-d first overtone pulsator in an 800.4-d binary system.

2. Observations

The majority of the observations of this system are from the MACHO and OGLE projects (Udalski 1999). The light curve from these two sources covers three primary eclipses of the system. Observations of a fourth primary eclipse were obtained in 2001 April with the 1.9-m telescope at Mt. Stromlo. A single set of JHK_s observations have also been obtained from the 2MASS all-sky release.

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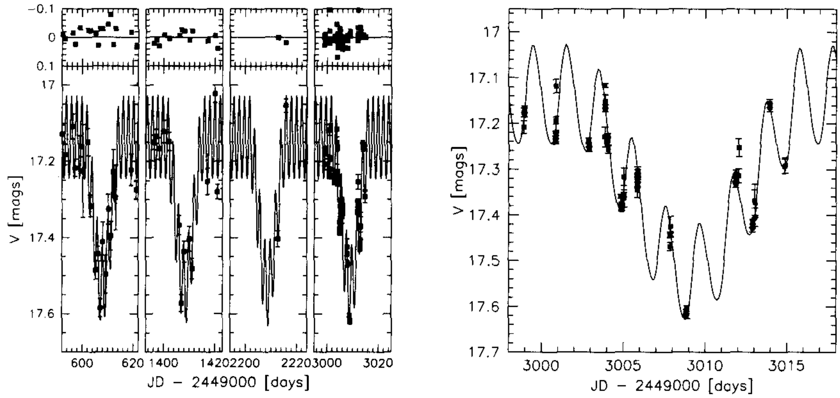

Figure 1. Observations and best fit model for four primary eclipses of 81.8997.87 (left) and the 2001 April primary eclipse (right).

The model and fitting procedure used in the analysis of the light curve have been described in detail in Alcock et al. (2002). Briefly, the model makes use of the simultaneous V and R observations of the MACHO data to define a $V-R$ colour for each star and the V magnitude is computed via a modified Barnes-Evans relation. The model also treats variations in the surface brightness and radius of the Cepheid self-consistently.

3. Results and Discussion

In Table 1 we present the derived system parameters that are most useful for the classification of the component stars. The variable star in this system can be definitively classified as an overtone Cepheid by the shape of its light curve and its location in the period-luminosity diagram. For periods close to 2 d the R_{21} Fourier parameter cleanly separates overtone Cepheids from those pulsat-

Table 1. Component radii and magnitude values from the best-fit model. The radii and radial amplitude are expressed as a fraction of the orbital separation of the two stars.

	Cepheid	Companion
Radius (minimum)	0.035 ± 0.003	0.051 ± 0.007
Radial Amplitude	0.00097 ± 0.0002	
$\langle V \rangle$	17.2 ± 0.2	19.8 ± 0.6
$\langle R \rangle$	16.6 ± 0.2	18.5 ± 0.6
$\langle I \rangle$	16.0 ± 0.2	17.2 ± 0.6
$\langle V-R \rangle$	0.61 ± 0.01	1.3 ± 0.1

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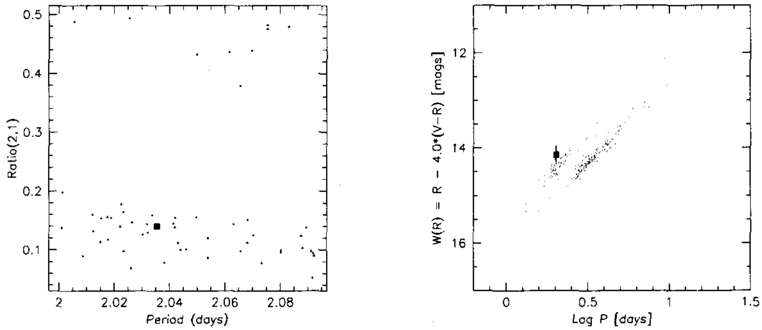

Figure 2. Classification of the Cepheid as overtone pulsator. The left panel shows the values of R_{21} for LMC Cepheids. There is a clear separation between regions occupied by fundamental (upper part of the plot) and first overtone (lower part of the plot) Cepheids. The right panel shows the de-reddened P-L diagram for LMC Cepheids. The more luminous band at a given period contains the overtone Cepheids. The variable component of 81.8997.87 is indicated by the large black square in both plots.

ing in the fundamental mode. After the light curve has had the companion's contribution removed, it is found to have $R_{21} = 0.139$, consistent with overtone pulsation. The Cepheid's location in the de-reddened period-luminosity diagram (shown in Fig. 2) is also consistent with an overtone Cepheid. The amplitude of the radial displacement of the Cepheid's photosphere over the course of one pulsational cycle is 2.8% of the star's minimum radius. This is consistent with estimates of radial amplitudes of galactic overtone Cepheids.

The identity of the secondary in this system is less obvious. Its faint and cool appearance can be only partially explained by extinction (as estimated from the Cepheid's location in the colour magnitude diagram of Fig. 3). Even after correcting for extinction, the companion, whose colour and radius most resemble a early-type M giant, still appears fainter and redder than is consistent with the appropriate evolutionary isochrones.

At optical wavelengths the Cepheid completely dominates the flux from the system. IR observations should supply more useful information about the nature of the companion. Fig. 3 shows the overall colours for the system from the single set of JHK_s observations at our disposal. The companion's colours have been derived by assigning colours to the Cepheid based on the P-L relations of Groenewegen (2000). This places the companion, with considerable uncertainty, near the region of the plot occupied by M-type stars.

4. Conclusions

The results of the analysis of the light curve appear inconsistent with the expectation that this system consists of two stars which have been well-detached throughout their lifetimes. Two possible resolutions to this difficulty are that

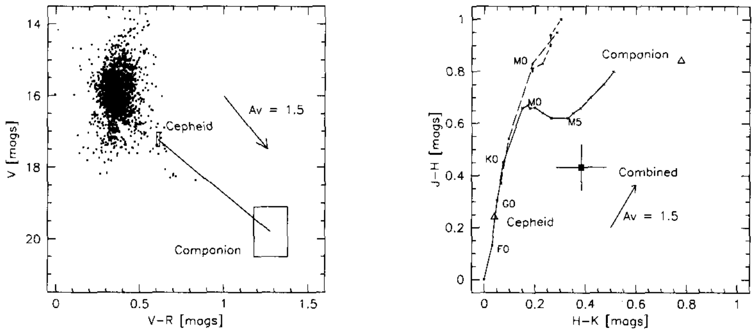

Figure 3. The nature of the secondary star. The left panel shows the CMD for LMC Cepheids and the boxes indicate the error bounds on the properties of the two components. The right panel shows the near-IR colour-colour diagram with fiducial sequences for main sequence, giant and supergiant stars (Allen 1973). The large square indicates the location of 81.8997.87 and the open triangles indicate the locations of the components, assuming one is a 2.035-d overtone Cepheid.

this is a triple system and our observations are of insufficient quality to detect all three components, or that mass transfer has occurred at some point in the system's history.

Additional observations of this system are required to realize its potential. Observations of the eclipses themselves are most useful for constraining the characteristics of the component stars. As the present light curve only contains observations of four eclipses, this is a limiting factor in the accuracy of the results. The cool temperature of the secondary suggests near-infrared observations will be vital to further successful analysis. The two components appear to have similar J magnitudes with the secondary dominating the flux at longer wavelengths. This suggests that spectroscopic observations made at these wavelengths offer the best chance of obtaining simultaneous spectra of both components.

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References

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Groenewegen, M.A.T. 2000, A&A, 363, 901

Udalski, A., et al. 1999, Acta Astron., 49, 223

Discussion

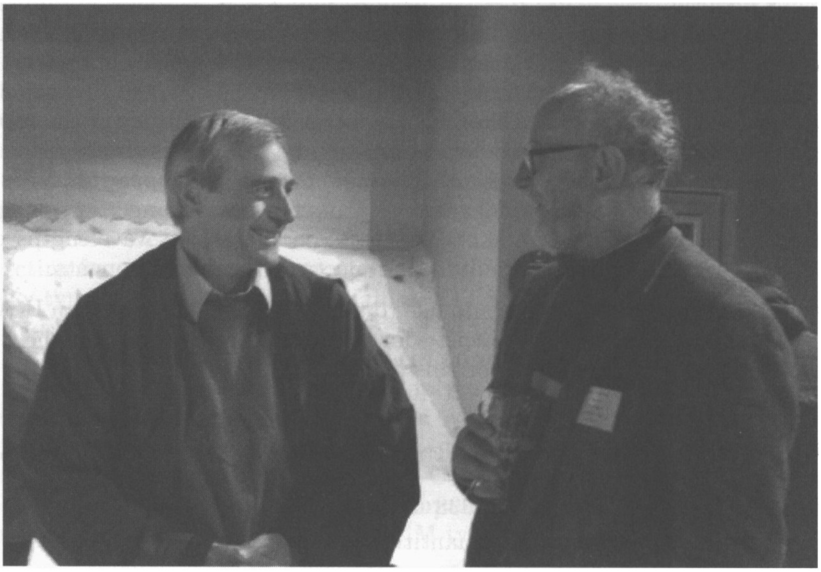
Chamblis: It seems that the comparison in this system is something like the larger component of ζ Aurigae. An extended atmosphere eclipse is then to be expected. How well do you hope to obtain planets?

Lepischak: Currently, this is limited by poor definition of the secondary eclipse which is virtually hidden by the Cepheid variations at optical wavelengths.

Evans: Comment: Ed Guinan's Roch lobe overflow scenario is very reasonable for an M supergiant in an orbit of 800 d. Overflow occurs for less massive Cepheids in the red giant phase at a year.

Lepischak: This system is in a region where interstellar extinction is known to be both large and variable on small spatial scales. The closest Cepheid to this one in the database shows evidence for roughly the same amount of extinction.

Guinan: Comment: It may be possible to explain the inferred unusual properties of the cool component of this binary by extreme mass via Roche lobe overflow of a formerly more massive star. For this to happen the evolved star would have to reach a large radius (i.e., become a supergiant) to overflow its Roche lobe.



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