CEPHALID BINARY WITH LARGE MASS RATIO (M1/M2)

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ABSTRACT

Because of the temperature difference between Cepheids and their hot main sequence companions, the properties of both stars can be determined, even for mass ratios (M1/M2) larger than 10. HST observations of 3 Cepheid systems (Peebles, HW Vir, and S Sge) are used to derive, or set limits on, the temperatures and masses of the companions. Light from the companions of HW Vir and S Sge from 1700 to 2900 Å is consistent with an 

**N89 - 10727**

2 OBSERVATIONS

The spectroscopic binaries discussed here are well known (Refs. 4, 6, and 9). Redeemer of the southern polaris, 61 Vir, and S Sge are in preparation (Refs. 6, 14, and 5, Refs. 6, 14). For all three stars, HST and short wavelength spectra have been taken with monochromatic instrumentation, blanketing them in temperature to look for light from the companion at the shortest wavelengths. At the phase of observation, the temperature and (B-V), of all three stars happen to be very similar and are best matched by 15 Dna (171b).

As an example Figure 1 shows the comparison between the long and short wavelength spectra of HW Vir and 15 Dna. The 15 Dna spectrum in the long wavelength region (Figure 1-b) has been scaled to match the HW Vir spectrum. The same scaling has been applied to the short wavelength spectrum of 15 Dna (Figure 3). The excess light from the HW Vir companion is apparent from 1600 to 2900 Å. A spectrum of S Sge also shows light from the companion in this wavelength region.

When 15 Dna is subtracted from the spectrum of both HW Vir and S Sge, the resulting spectrum of the companion is a good match to an A4V or A5V standard star from the HST Spectral Atlas. Figure 2 shows the comparison between the subtracted spectrum, S Sge, 15 Dna, and the spectrum of an A5V star (89 UMa). The match is good; both A5V and A4V standard stars match the subtracted spectrum of both the companions poorly. Using the mass compilation of Popper (Ref. 7), this corresponds to masses of 1.8 ± 0.2 M☉. This information has been added to Table 1.

For Polaris, no light from the companion was found in a comparison with the spectra of measurable standard stars. Using 1.8 M☉ as an upper limit for the companion to Polaris is a generous upper limit, since FF Vir and S Sge demonstrate that such a companion would be found. 

**Keywords:** Cepheids, binaries, star formation

**INTRODUCTION**

The separations and mass ratios observed in multiple systems are best data to test theories about star formation. The emerging picture for B stars is that stars with periods shorter than 10 years have a line that distribution of secondary masses (Ref. 2). For longer periods, the distribution is dramatically different, and the frequency of systems with the mass of the companion decreases (Ref. 3). Light from the other star is not seen, but is a more distant companion. Most of the mass ratios are from distances from the distributions of single-line spectroscopic binaries. In addition, corrections must be made for incompleteness. Any further information about systems with primaries of comparable mass, particularly with large mass ratios (M1/M2), is useful.

The value of studying Cepheid binary systems to improve our knowledge of mass ratios and separations is clear from Table 1. Because Cepheids are short-lived stars, almost all of the amplification can be derived. The results that gravitationally bound long-period systems can be studied, as well as systems with small mass ratios and low luminosities. HST adds important data to these studies in that companions in large mass ratio systems can be detected because of the temperature difference between the secondary and the primary.
The spectra of FF Aql (solid) and 45 Dra (dots), Figure 1a. All fluxes are in units of ergs cm$^{-2}$ sec$^{-1}$ Å$^{-1}$, wavelengths are in Å. The same scaling has been used as in Figure 1b.

Figure 1b. The spectra of FF Aql (solid) and 45 Dra (dots). The 45 Dra spectrum has been scaled to match the FF Aql flux near 2500 Å.

Figure 2. The spectrum of the S Sge companion (solid) compared with the spectrum of an AV5 standard star. A spectrum of 45 Dra was scaled to match the S Sge composite spectrum near 2500 Å, as is shown in Figure 1 for FF Aql. With this scaling, the short wavelength spectrum of 45 Dra was subtracted from the S Sge spectrum to produce the spectrum of the companion in this Figure.
3 DISCUSSION

A simple picture of the evolution of the system has been assumed (no mass loss, or semi-rotation), and the visible companions are assumed to be main sequence stars. The data for the companions are summarized in Table 1. Cepheid evolutionary masses are listed (computed as in Evans and Welch, this conference) from luminosities derived from Caldwell's (Ref. 4) period-luminosity relation. A shorter distance scale (Schmidt, Ref. 8) decreases the mass ratios by less than 10%. The pulsation masses are 0.8 (Caldwell) to 0.6 (Schmidt) of the evolutionary masses.

For S Sex, the mass function (Ref. 6) implies that the mass of a single companion (sin i = 90°) must be at least 2.7 M☉ in order to be compatible with an evolutionary mass in Table 1. The companion mass in Table 1 is significantly smaller. The simplest way to remove the disagreement is a companion which is itself a binary. Among the computed Cepheid masses, only a pulsation mass with a short distance scale is compatible with a companion less than 2 M☉.

For the invisible companion to Polars, an early F main sequence star is the most probable candidate. It would not be detected, in H.α spectra, but is consistent with the mass function and a Cepheid mass. There are two other possibilities for an invisible companion: an evolved red star and a white dwarf. An evolved red star too massive to be consistent with the mass function and inclination. Estimates (Ref. 7) show that the hottest white dwarfs in the Hyades and the Pleiades (prototypes for a Cepheid companion) would be detected in H.α spectra, but that cooler dwarf white dwarfs would not.

When this work is completed on all Cepheid binaries, the individual mass ratios will be available to the limits of Table 1, which will complement the O and B star results. This will provide direct measurements of the frequency and separations of multiple systems containing massive stars—particularly for widely spaced systems.

Acknowledgements. It is a pleasure to thank the H.α observers and R. D. P. for assistance in obtaining and reducing these spectra. Financial assistance was provided by a NASA grant NAG 5-28749 and an NSF grant to Dr. J. B. Pery.

REFERENCES


Table 1: Cepheid Binaries

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<th>Binary Period (days)</th>
<th>Polars</th>
<th>FT Aql</th>
<th>S Sex</th>
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<tr>
<td>10810</td>
<td>105</td>
<td>145</td>
<td>682</td>
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<tr>
<td>4.9</td>
<td>3.5</td>
<td>14.6</td>
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<tr>
<td>4.9</td>
<td>4.47</td>
<td>8.38</td>
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<tr>
<td>5.6</td>
<td>5.7</td>
<td>7.0</td>
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<td>Companion Spectral Type</td>
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<td>A5V A7V</td>
<td>A5V A7V</td>
</tr>
<tr>
<td>Companion Mass (M☉)</td>
<td>≤ 10</td>
<td>1.8</td>
<td>1.8</td>
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<td>Mass Ratio (M1/M2)</td>
<td>2.41</td>
<td>3.2</td>
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