CEPHALID BINARIES WITH LARGE MASS RATIOS (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 1:10. HST observations of 5 Cepheid systems (Porbats, FT Aql, and S Sge) are used to derive, or set limits on, the temperatures and masses of the companions. Light from the companions of FT Aql and S Sge from 1500 to 2800 Å is consistent with an M₅ to M₇ main sequence companion for both Cepheids, with a mass of 1.8 M. This mass for the companion of S Sge is smaller than required by the orbital mass function and an evolutionary mass of the Cepheid, suggesting that the companion may itself be a binary. For Porbats, the mass of the companion must be less than 1.8 M.

Key words: Cepheids, binaries, star formation

1 INTRODUCTION

The separations and mass ratios observed in multiple systems are basic data about star formation. The emerging picture for B-stars is that stars with periods shorter than 10 years have a high density distribution of secondary masses (Ref 2). For longer periods, the distribution is dramatically different, and the frequency of close stars as the mass of the companion decreases. O stars on the other hand seem to be very deficient in binaries with mass ratios larger than M₁/M₂ = 3 (Ref 7). There are observational limitations to these studies. Only O systems with a semi-amplitude larger than 15 km sec⁻¹ were detected because of atmospheric motions. Inferences about long period B systems are drawn from common proper parts. Most of the mass ratios are from inferences 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 young hot stars, almost all our information can be derived. The means 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.

2 OBSERVATIONS

The spectroscopic binaries discussed here are well known (Refs 1, 6, and 9). Reduction of the system Porbats, FT Aql, and S Sge was in preparation (Kneer, Ref 14, Welch and Evans, Ref 14, and Skark Welch, and Evans, Ref 10 respectively). For all three systems, HST long and short wavelength spectra have been obtained with nonvariable targets bracketing the image in temperature to look for flux from the companion at the shortest wavelength. At the phase of observation, the temperature and (BV)₅ of all three stars happens to be very similar and are best matched by 15 Dna (F5IV).

As an example, Figure 1 shows the comparison between the long and short wavelength spectra of FT Aql and 15 Dna. The 15 Dna spectrum in the long wavelength region (Figure 1 b) has been scaled to match the FT Aql spectrum. The same scaling has been applied to the short wavelength spectrum of 15 Dna (Figure 1 a). The excess light from the FT Aql companion is apparent from 1000 to 2000 Å. A spectrum of S Sge also shows light from the companion in this wavelength region.

When 15 Dna is subtracted from the spectra of both FT Aql and S Sge, the resulting spectrum of the companion is a good match to an A0V or A2V standard star from the IUE Spectral Atlas. Figure 2 shows the comparison between the subtracted spectrum, S Sge - 15 Dna, and the spectrum of an A2V star (88.1 M). The match is good both for A0V and A2V standard stars match the subtracted spectra of both the companions poorly. Using the mass compilation of Poppier (Ref 7), this corresponds to masses of 1.8 ± 0.2 M. This information has been added to Table 1.

For Porbats, no light from the companion was found in a comparison with the spectra of nonvariable standard stars. Using 18 M, as an upper limit for the companion to Porbats is a generous upper limit since FT Aql and S Sge demonstrate that such a companion would be found.

Figure 1a. The spectra of FF Aql (solid) and 45 Dra (dots). 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 2800 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 2800 Å, as 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-convective), and the visible
companions are assumed to be main sequence stars. The data
for the companions is summarized in Table 1. Cepheid evolu-
tionary 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%.
Pulsation masses are 0.8 (Caldbed) to 0.6 (Schmidt) of the
evolutionary masses.

For S Sco, 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 this 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 Polaris, an early F main-
sequence star is the most probable candidate. It would not be
detected in H & L spectra, but is consistent with the mass
function and a Cepheid mass. There are two likely possibilities for
an invisible companion: an evolved red star and a white dwarf.
An evolved red star is too massive to be consistent with the
mass function and inclination. Estimates (Ref. 1) show that
the hottest white dwarfs in the Pleiades and the Hyades (pro-
totypes for a Cepheid companion) would be detected in H & L
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 frequencies and separations
of multiple systems containing massive stars—particularly for
widely spaced systems.

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