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CEPHEID BINARIES WITH LARGE MASS RATIOS (M_1/M_2)

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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 (M_1/M_2) larger than 3.0. IUE observations of 3 Cepheid systems (Polaris, FF Aql, and S Sge) are used to derive, or set limits on, the temperatures and masses of the companions. Light from the companions of FF Aql and S Sge from 1700 to 2000 Å is consistent with an A5 to A7 main sequence companion for both Cepheids, with a mass of 1.8 $M_\odot$. 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 Polaris, the mass of the companion must be less than 1.8 $M_\odot$.

Keywords: 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 fairly flat distribution of secondary masses (Ref. 2). For longer periods, the distribution is dramatically different, and the frequency rises steeply as the mass of the companion decreases. O stars, on the other hand, seem to be severe deficient in binaries with mass ratios larger than $M_1/M_2 = 3$ (Ref. 5). There are observational limitations of 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 pairs. 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 (M_1/M_2), 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 sharp lined stars, orbits of very small semi amplitude can derived. This means that gravitationally bound long period systems can be studied, as well as *systems with small mass ratios and low inclinations*. IUE 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). Rediscussion of the systems Polaris, FF Aql, and S Sge is in preparation (Evans, Ref. 4, Welch and Evans, Ref. 11, and Slovak, Welch, and Evans, Ref. 10 respectively). For all three stars, IUE long and short wavelength *spectra have been ratioed with nonvariable supergiants bracketing* them in temperature to look for flux from the companion at the shortest wavelengths. At the phases of observation, the temperature and $(B-V)_o$ of all three stars happen to be very similar, and are best matched by 15 Dra (F7Ib).

As an example, Figure 1 shows the comparison between the long and short wavelength spectra of FF Aql and 15 Dra. The 15 Dra spectrum in the long wavelength region (Figure 1 b) has been scaled to match the FF Aql spectrum. The *same* scaling has been applied to the short wavelength spectrum of 15 Dra (Figure 1 a). The excess light from the FF Aql companion is apparent from 1600 to 2000 Å. A spectrum of S Sge also shows light from the companion in this wavelength region.

When 15 Dra is subtracted from the spectra of both FF Aql and S Sge, the resulting spectrum of the companion is a good match to an A5V or A7V standard star from the IUE Spectral Atlas. Figure 2 shows the comparison between the subtracted spectrum, S Sge - 15 Dra, and the spectrum of an A5V star (80 UMa). The match is good; both A3V and A9V standard stars match the subtracted spectra of both the companions poorly. Using the mass compilation of Popper (Ref. 7), this corresponds to masses of 1.8 ± 0.2 $M_\odot$. This information has been added to Table 1.

For Polaris, no light from the companion was found in a comparison with the spectra of nonvariable standard stars. Using 1.8 $M_\odot$ as an upper limit for the companion to Polaris is a generous upper limit, since FF Aql and S Sge demonstrate that such a companion would be found.

[1] IUE Guest Observer

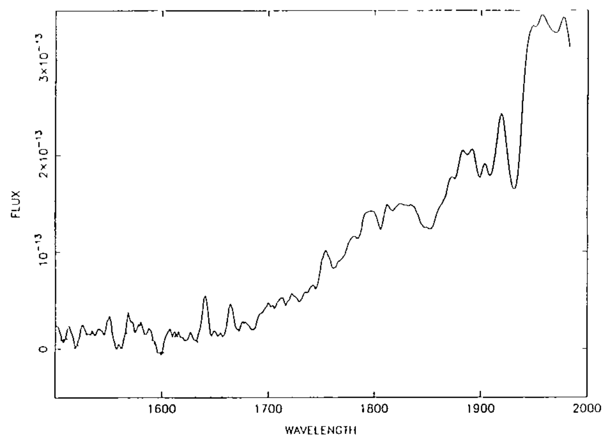

Figure 1a. The spectra of FF Aql (solid) and 45 Dra (dots), F7Ib. All fluxes are in units of ergs cm^{-2} sec^{-1} $\AA^{-1}$, wavelengths are in Å The same scaling has been used as in Figure 1b

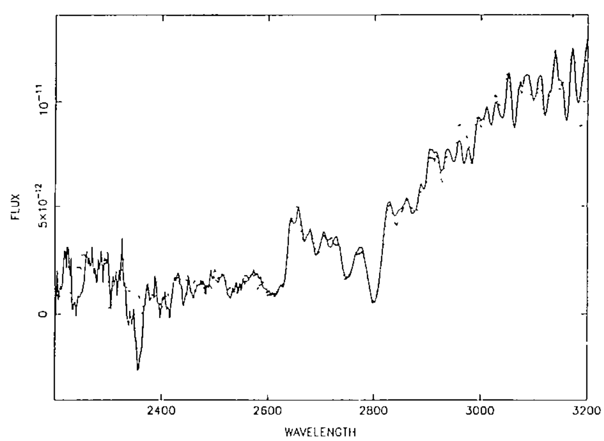

Figure 1b The spectra of FF Aql (solid) and 45 Dra (dots). The 45 Dra spectrum has been scaled to match the FF Aql flux near 2800 Å

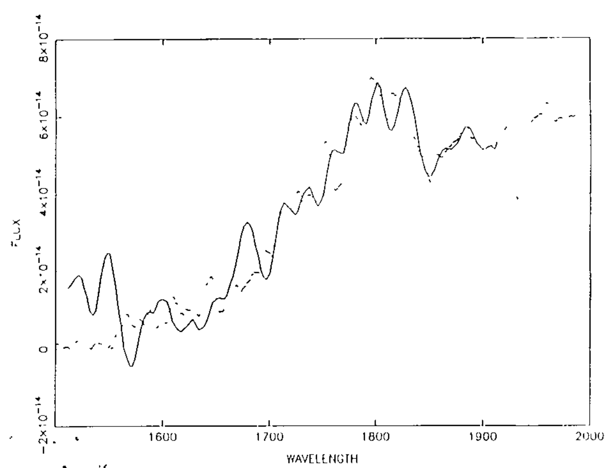

Figure 2. The spectrum of the S Sge companion (solid) compared with the spectrum of an AV5 standard star A spectrum of 45 Dra was scaled to match the S Sge composite spectrum near 2800 Å, as is shown in Figure 1 for FF Aql. With this scaling, the short wavelength spectrum of 45 Dra was subtracted from the S Sge spectrum to produce the spectrum of the companion in this Figure

Table 1 Cepheid Binaries

	Polaris	FF Aql	S Sge
Binary Period (days)	10810	1435	682
Binary Semi-Amplitude (km sec^{-1})	4.0	3.5	14.6
Pulsation Period (days)	3.97	4.47	8.38
Evolutionary Mass ($M_\odot$)	5.6	5.7	7.0
Companion Spectral Type	$\leq$ A8V	A5V A7V	A5V A7V
Companion Mass ($M_\odot$)	$\leq$ 1.8	1.8	1.8
Mass Ratio (M_1/M_2)	$\geq$3.1	3.2	3.9

3 DISCUSSION

A simple picture of the evolution of the system has been assumed (no mass loss, or semi-convection), and the visible companions are assumed to be main sequence stars. The data for the companions is summarized in Table 1. Cepheid evolutionary masses are listed (computed as in Evans and Welch, this conference) from luminosities derived from Caldwell's (Ref. 3) period-luminosity relation. A shorter distance scale (Schmidt Ref. 8) decreases the mass ratios by less than 10 %. Pulsation masses are 0.8 (Caldwell) to 0.6 (Schmidt) of the evolutionary masses.

For S Sge, the mass function (Ref. 6) implies that the mass of a single companion ($\sin i = 90^\circ$) must be at least 2.7 $M_\odot$, 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* $M_\odot$.

For the invisible companion to Polaris, an early F main sequence star is the most probable candidate. It would not be detected, in IUE 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 is too massive to be consistent with the mass function and inclination. Estimates (Ref. 1) show that *the hottest white dwarfs in the Hyades and the Pleiades* (prototypes *for a* Cepheid companion) would be detected in IUE spectra, but that cooler cluster 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.

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