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THE ORBIT AND COLORS OF THE CEPHEID S MUSCAE

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ABSTRACT

A new orbit has been computed for the binary Cepheid S Mus combining new data from Mount John Observatory with previous data (Table 3). Continued observations are highly desirable to improve the period and the amplitude of the orbit. In addition, corrections to the colors and reddening due to the light from the companion are derived. The spectral type determined from IUE low-dispersion spectra is used for these corrections. The corrections are small, even though the companion is one of the hottest (B5 V) known for a Cepheid. The photometric reddening is reduced from $0^{m}_{.}27$ to $0^{m}_{.}23$ because of the corrections.

Key words: variable stars–Cepheids–binaries–orbits–S Muscae

1. Introduction

The determination of the masses of classical Cepheids has been a problem for two decades. Observational progress has been made in the last few years through the realization that at least two binary systems containing a Cepheid become double-lined systems in the ultraviolet. Specifically, the flux for the companions of S Muscae (Böhm-Vitense 1986) and SU Cygni (Evans and Bolton 1990) makes a significant contribution to the total flux at 2600 Å. The orbital velocity of the main-sequence companion can be measured on IUE high-dispersion spectra in this wavelength region. In the case of S Mus this velocity can be combined with the orbital velocity of the Cepheid from the ground-based orbit and the mass of the companion estimated from its temperature to produce the mass of the Cepheid. In the case of SU Cyg the companion is itself a short-period binary star and the IUE velocities result in a dynamical lower limit to the mass of the Cepheid.

Recently, Böhm-Vitense *et al.* (1990) have obtained new ultraviolet and optical data for the S Mus system in order to improve the accuracy of the mass determination. They did not redetermine the orbit of the Cepheid, and so we have redetermined it in this paper using their new optical data combined with earlier data. This note discusses the orbit in Section 2. It is also possible to determine the spectral type of the companion from IUE data. In Section 3 we discuss the effect that the companion has on the colors and reddening and derive uncontaminated colors. The mass of the Cepheid resulting from the combination of the ultraviolet and optical data is discussed by both Böhm-Vitense *et al.* (1990) and Evans and Bolton (1989).

*IUE Archival Research.

2. Orbit

Lloyd Evans (1982) determined an orbital solution for S Mus. Because of the new velocity data from Mount John University Observatory (Böhm-Vitense *et al.* 1990) at high dispersion, we have reinvestigated the orbit. Table 1 lists the data sources used, together with their dispersion. In addition to these sources there are also observations by Rodgers and Bell (1967) and Grayzeck (1978). We did not use these because the times of observation were not precisely given by Rodgers and Bell, and the Grayzeck observations are at a lower dispersion and show a much larger scatter than the data which were used. In order to

TABLE 1
Velocity Sources

Source	Dispersion (Å mm^{-1})	Δ V_r km sec^{-1}	Code
Paddock (Campbell and Moore, 1928)	41	0	A
Stibbs, 1955	49	0	B
Lloyd Evans, 1968	49	0	C
Lloyd Evans, 1980	49	0	D
Lloyd Evans, 1980	29	0	E
Böhm-Vitense, Clark, Cottrell, and Wallerstein, 1989	2.4	-1.8	F

combine data from different sources, the velocity corrections listed in Table 1 are used. They are taken from Lloyd Evans (1980, 1982), except in the case of data sets A and F which are discussed below.

In selecting a weighting scheme, the Lloyd Evans and Stibbs data (B, C, D, and E) are given weight 1. The Paddock data are given low weight (0.2) but retained in the solution. In this way they are important in determining the period, because they are at an early epoch, but have little effect on the other parameters. Finally, although the observations of Böhm-Vitense, Clark, Cottrell, and Wallerstein are at a much higher dispersion than the other data, they cover only a small portion of the orbit, and that a portion with nearly constant velocity, and so they are also given weight 1.

The orbital solutions are performed as described by Evans (1988) using the same computer routine. A pulsation curve digitized at 100 phase points is used. Originally the curve of Lloyd Evans (1982) was used, but it was revised somewhat because the new data define the pulsation curve very precisely. The adopted pulsation curve is listed in Table 2. The velocities in each row in Table 2 are given for increments of 0.01 in phase from left to right. The first velocity in each row corresponds to the beginning of the pulsation phase range. The process is, of course, iterative. A pulsation curve is assumed, the velocities are corrected, and an orbital solution is made. The residuals from the orbital solution are then plotted as a function of pulsation phase. If necessary the pulsation curve is then revised. Figure 1 shows the residuals from the final orbital solution as a function of pulsation phase for the data of Lloyd Evans, Stibbs, and Böhm-Vitense

TABLE 2
Pulsation Velocity Curve

Pulsation Phase Range	V_r (km s^{-1}) ϕ_1	ϕ_2	ϕ_3	ϕ_4	ϕ_5
).01 - 0.05	-11.5	-11.6	-11.6	-11.7	-11.7
).06 - 0.10	-11.1	-10.5	-9.9	-9.1	-8.6
).11 - 0.15	-7.9	-7.3	-7.0	-6.7	-6.3
).16 - 0.20	-6.4	-6.5	-6.7	-6.9	-7.0
).21 - 0.25	-7.2	-7.4	-7.6	-7.8	-8.1
).26 - 0.30	-8.4	-8.6	-8.8	-9.0	-9.1
).31 - 0.35	-9.0	-8.8	-8.6	-8.2	-7.6
).36 - 0.40	-7.0	-6.4	-5.6	-4.8	-4.2
).41 - 0.45	-3.1	-2.1	-1.1	-0.1	0.9
).46 - 0.50	1.7	2.6	3.2	4.0	4.8
0.51 - 0.55	5.6	6.3	7.1	7.8	8.5
0.56 - 0.60	9.1	10.0	10.8	11.7	12.4
0.61 - 0.65	13.2	13.9	14.6	15.4	16.0
0.66 - 0.70	16.8	17.6	18.2	18.9	19.4
0.71 - 0.75	19.5	19.5	19.4	19.1	18.4
0.76 - 0.80	17.4	15.4	12.9	10.6	8.6
0.81 - 0.85	6.6	5.0	3.4	1.9	0.4
0.86 - 0.90	-1.1	-2.6	-4.2	-5.9	-7.4
0.91 - 0.95	-8.0	-8.5	-9.0	-9.5	-9.8
0.96 - 0.00	-10.3	-10.6	-11.0	-11.3	-11.5

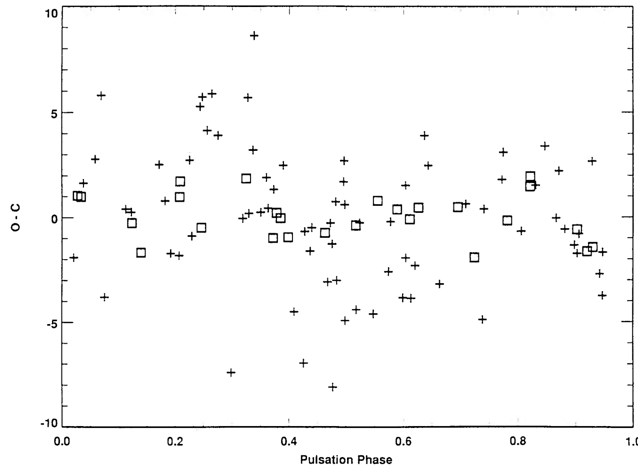

FIG. 1–Residual velocities as a function of pulsation phase. The residuals from the orbital solution are in the sense observed minus computed $(O-C)$. Total velocities have been corrected for the pulsation velocity. All velocities are in km sec^{-1}. Data from Stibbs and Lloyd Evans are pluses; data from Böhm-Vitense, Clark, Cottrell, and Wallerstein are shown as squares.

et al. The scatter in Figure 1 for the new data demonstrates that the pulsation curve in Table 2 is accurate to within a km sec^{-1}.

The pulsation period from Lloyd Evans (1980) is used:

$$JD_{max} = 9.660070\,E + 2440299.42 \ ,$$

where E is the epoch. A new pulsation period has recently been derived by Szabados (1989):

$$JD_{max} = 9.659875\,E + 2440299.163 \ .$$

Orbital solutions using this pulsation period, and the pulsation curve in Table 2 shifted by an appropriate amount, were investigated. The orbital parameters did not change by more than the formal errors when the new pulsation period was used. Since the high-quality data in the $(O-C)$ curve Szabados presents are fit equally well by the older period, we adopt $9^{d}.660070$ as the pulsation period.

Because the new velocity data cover only a fraction of the orbit at maximum velocity, the orbital solution depends largely on the previous data. From early solutions it was clear that there is a velocity offset between the Mount John data and the Lloyd Evans data. Note that because of the orbital phase range (Fig. 2) of the Mount John data, a velocity shift between them and the previous data is very well defined and cannot be due to uncertainty in the orbital period. For this reason an orbital solution was made giving the new data very low weight (weight 0.01). The mean residual of the new data from this solution (-1.8 ± 0.2 km sec^{-1}, listed in Table 1) was added to the new data for the final solution, to put all data on a consistent velocity scale. Although this ensures that the velocities are internally consistent (on the Lloyd Evans

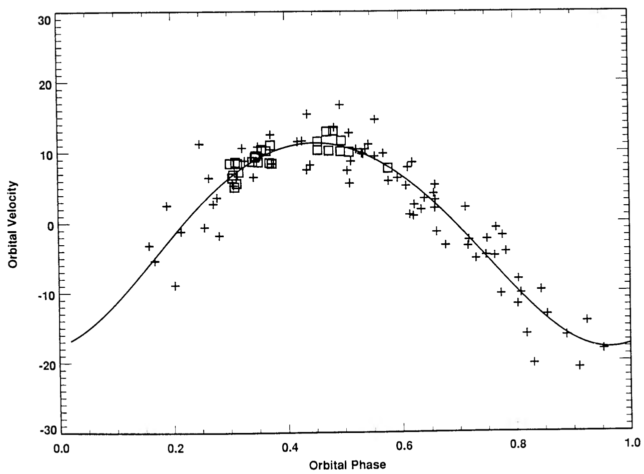

FIG. 2a–The orbit of S Mus. Data are shown in the same symbols as in Figure 1. The solid line is the computed orbit from the solution (Table 3). Total velocities have been corrected for the pulsation velocity (Table 2).

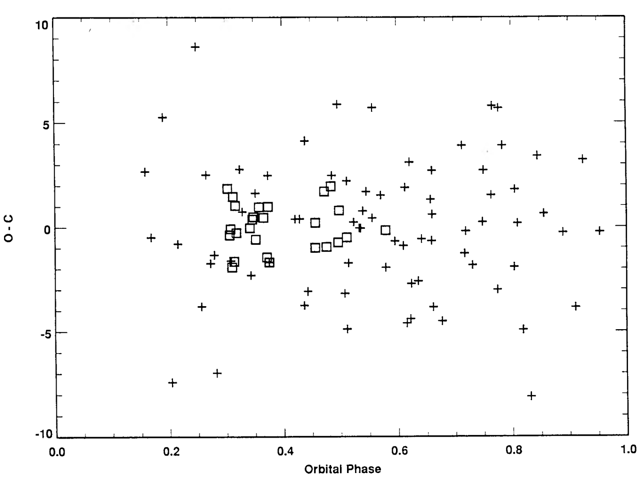

FIG. 2b–Orbital velocity residuals ($O-C$). Symbols are the same as in Figure 1.

system) they may not be exactly on the IAU system. We cannot resolve this question from the existing data. Measurements cited by Böhm-Vitense, Clark, Cottrell, and Wallerstein show that $+0.8$ km sec^{-1} should be added to their velocities to put them on the IAU system. (This correction has not been added to the data as used here.)

Lloyd Evans added a correction of "about $+4$ km sec^{-1}" to the Paddock velocities. This correction was originally added to the present solutions. Experimentation showed that the orbital period is quite sensitive to the velocity correction of the early Paddock data, even when it is given low weight. Specifically, if the correction is changed from 0 km sec^{-1} to $+4$ km sec^{-1}, the period changes from $505^{\mathrm{d}}.44 \pm 0^{\mathrm{d}}.35$ to $505^{\mathrm{d}}.76 \pm 0^{\mathrm{d}}.38$. This indicates that the actual uncertainty in the period is larger than the formal errors from the solution, since it depends on the velocity correction to the Paddock data. Because the mean residual for the Paddock data is $+3.2$ km sec^{-1} if the velocity correction $+4$ km sec^{-1} is used, but is reduced to 0.8 km sec^{-1} if no correction is used, the period resulting from the 0 km sec^{-1} correction was adopted. The difference between this period ($505^{\mathrm{d}}.44$) and the period found by Lloyd Evans ($506^{\mathrm{d}}.4$) results in a phase difference over the 7000 days which have elapsed between the previous orbital data and the present IUE data of 0.027 P. This is half the phase difference hypothesized by Böhm-Vitense (1986) to produce reasonable results in the previous analysis of IUE data.

The orbital parameters are listed in Table 3 together with those of Lloyd Evans. The orbital parameters are within the errors of the parameters found by Lloyd Evans, except for the period. Table 3 also lists the orbital parameters for a circular orbit, since the eccentricity of the adopted solution is very small. The most important difference between the circular solution and the full solution is that the velocity amplitude is 0.9 km sec^{-1} smaller in the circular solution.

Table 4 lists the date, pulsation phase and pulsation velocity, orbital phase and orbital velocity, and residuals from the orbit for all data. The source refers to the code from Table 1. All velocities in the tables as well as the graphs are in km sec^{-1}. The velocity corrections listed in Table 1 have been added to the data.

Figure 2 shows the orbit and the residuals. The most important point which Figure 2 demonstrates is that the amplitude of the orbit is not well determined. Minimum velocity ($\phi_{\rm orb} = 0.9$) is only covered by a few data points which show a large velocity scatter. At slightly later phases there is a gap in coverage of $\Delta\phi = 0.2$. Because of the importance of this binary system, new, high-precision data are badly needed to improve the orbit. The uncertainty in the orbital amplitude contributes to the uncertainty of the mass ratio from the IUE data.

3. The Colors of S Mus

Because S Mus has a companion which is one of the hottest and brightest known for a Cepheid, the combined system will have somewhat different colors from the Cepheid alone. If we know the temperature of the companion and the magnitude difference between the two stars, we can calculate the colors of the Cepheid alone. This is what is needed to compute the luminosity from a period-luminosity-color (PLC) relation, and also a photometrically determined reddening.

Table 5 lists the IUE images used to determine the properties of the companion. The main-sequence spectral standards were taken from the IUE Spectral Atlas (Wu *et al.* 1983). Reductions were done with the version of the Goddard RDAF software implemented at the University of Toronto, as described by Evans (1989). Since the large-aperture, long-wavelength (2000 Å to 2300 Å) spectra are overexposed for a portion of the spectrum, the large-

TABLE 3
Orbital Parameters of S Mus

Orbital Parameters	Adopted	Circular	T. Lloyd Evans
γ	-2.31 ± 0.50 km sec^{-1}	-1.91 ± 0.37 km sec^{-1}	-2.5 ± 0.5 km sec^{-1}
K	14.69 ± 0.80 km sec^{-1}	13.82 ± 0.53 km sec^{-1}	14.4 ± 0.9 km sec^{-1}
e	0.08 ± 0.04		0.05 ± 0.05
ω	3.41 ± 0.49		3.12 ± 1.1
T_o	2440496 ± 42 JD	2440220 ± 3 JD	2440476 ± 91 JD
P	505.44 ± 0.35 days	505.41 ± 0.31 days	506.4 ± 2 days
a sini	101.8 ± 5.6 10^6 km	96.0 ± 3.7 10^6 km	
	0.68 ± 0.04 AU	0.64 ± 0.02 AU	
f(m)	0.165 ± 0.027 $M_\odot$	0.138 ± 0.016 $M_\odot$	0.157 $M_\odot$

aperture spectrum of LWR 11966 has been used to scale the small-aperture spectrum (which has an arbitrarily reduced flux throughput). The ratio of the large to small aperture spectrum from 2000 Å to 2300 Å was used. This ratio is somewhat larger in the wavelength region 3200 Å to 3300 Å. However, the 2000 Å–2300 Å region should suffer less from the combined uncertainties due to spectra being very close to saturation (large aperture) and very weak (small aperture).

Figure 3 shows the comparison between S Mus and the main-sequence star which appears to be the best match, B5 V. The reddening used is the final value, $E(B-V) =$ $0\overset{m}{.}23$. Since the derived spectral type of the companion may change as the reddening is varied, the process must be iterated. A preliminary determination of the spectral type is made, changes to the colors and, hence, the reddening are calculated, and then the spectral type of the companion is reinvestigated. In fact, no change was found necessary after the first solution.

A B5 V main-sequence star matches the spectrum of S Mus well from Lyman-α to 2500 Å. At longer wavelengths than this the Cepheid makes a contribution. At the pulsation phase of the observation (ϕ = $0\overset{d}{.}43$) a G0 I*b* star, β Aquarii, is very close in $(B-V)_0$ to the corrected

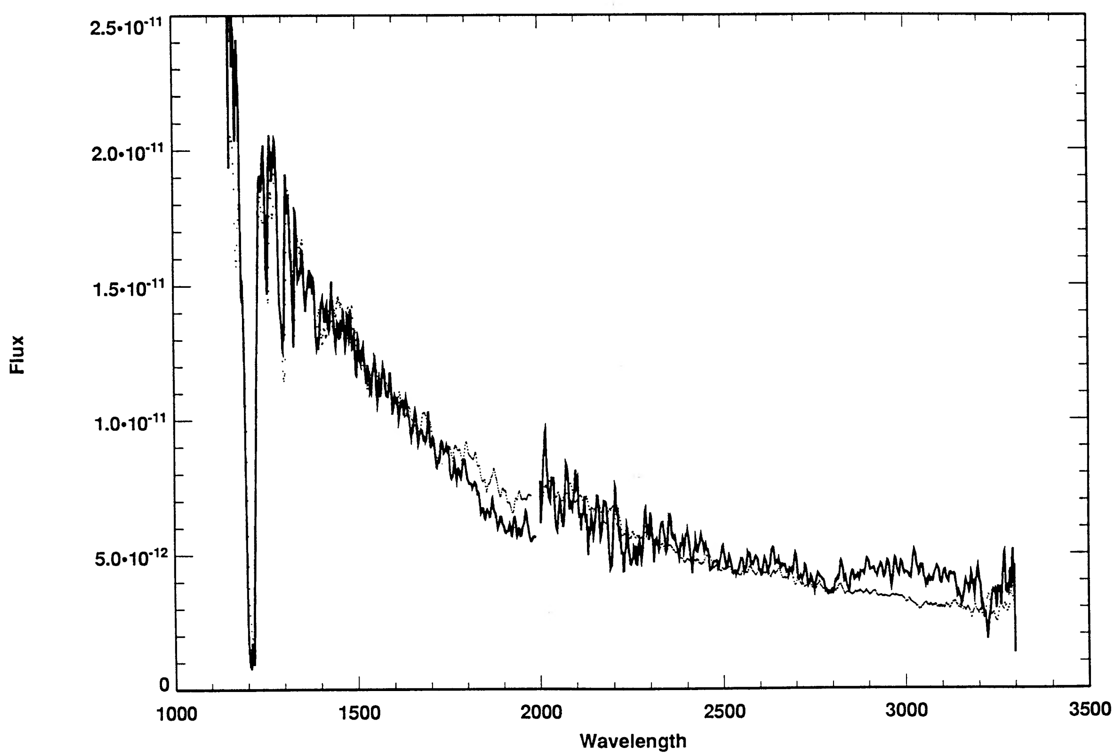

FIG. 3–The IUE spectrum of S Mus compared with a B5 V star. S Mus is the solid line; the B5 V star is shown by dots. The wavelength is in Å; the flux is in ergs sec^{-1} cm^{-2} Å^{-1}. A five-point smooth has been used on the data.

TABLE 4
Velocities

HJD -2,400,000	ϕ (pul)	V_r (pul) km sec^{-1}	ϕ (orb)	V_r (orb) km sec^{-1}	O–C km sec^{-1}	Source
18392.78	0.248	-8.0	0.270	3.0	-1.3	A
18395.74	0.555	8.8	0.276	5.2	0.5	A
18403.75	0.384	-5.3	0.292	8.3	2.4	A
18416.71	0.726	19.4	0.318	8.6	1.1	A
18426.65	0.754	17.9	0.337	9.1	0.6	A
18463.57	0.576	10.5	0.410	12.5	1.5	A
34088.56	0.058	-11.2	0.324	10.6	2.8	B
34113.52	0.642	15.5	0.373	12.5	2.5	B
34137.38	0.112	-7.8	0.421	11.5	0.4	B
34145.44	0.947	-9.7	0.437	7.5	-3.8	B
34181.34	0.663	17.0	0.508	7.4	-3.2	B
34183.34	0.870	-2.6	0.512	12.7	2.2	B
34206.31	0.248	-8.0	0.557	14.6	5.7	B
39287.33	0.230	-7.6	0.610	5.2	-0.9	C
39290.40	0.547	8.3	0.616	1.1	-4.6	C
39294.21	0.942	-9.6	0.623	2.5	-2.7	C
39300.31	0.573	10.3	0.635	1.8	-2.6	C
39303.28	0.881	-4.3	0.641	3.4	-0.6	C
39312.21	0.805	7.6	0.659	2.0	-0.6	C
39564.56	0.928	-8.9	0.158	-3.2	2.7	C
39569.50	0.440	-0.2	0.168	-5.4	-0.5	C
39587.46	0.299	-9.1	0.203	-8.9	-7.4	C
39593.32	0.905	-7.7	0.215	-1.2	-0.8	C
39614.28	0.075	-10.2	0.256	-0.6	-3.8	C
39622.27	0.902	-7.5	0.272	2.7	-1.7	C
39627.33	0.426	-1.5	0.282	-1.8	-7.0	C
39658.18	0.620	13.9	0.343	6.5	-2.3	C
39662.22	0.038	-11.7	0.351	10.8	1.6	C
39870.54	0.603	12.6	0.763	-4.8	1.5	D
39898.51	0.498	4.7	0.819	-16.1	-4.9	D
39911.53	0.846	1.0	0.844	-9.8	3.4	D
39966.37	0.523	6.5	0.953	-18.3	-0.2	D
40254.50	0.350	-7.6	0.523	10.4	0.2	D
40259.48	0.866	-1.9	0.533	9.8	0.0	D
40262.54	0.182	-6.7	0.539	10.4	0.8	D
40278.46	0.830	3.4	0.571	9.8	1.5	D
40304.42	0.518	6.1	0.622	0.9	-4.4	D
40322.34	0.373	-6.2	0.657	4.1	1.3	D
40323.53	0.496	4.5	0.660	5.3	2.7	D
40323.54	0.497	4.6	0.660	3.2	0.6	D
40324.52	0.598	12.3	0.662	-1.4	-3.8	D
40332.35	0.409	-3.2	0.677	-3.3	-4.5	D
40350.38	0.275	-8.7	0.713	2.1	3.9	D
40352.31	0.475	2.9	0.717	-3.4	-1.2	D
40353.29	0.577	10.5	0.719	-2.5	-0.2	D
40359.38	0.207	-7.1	0.731	-5.2	-1.8	D
40368.22	0.122	-7.2	0.748	-4.7	0.3	D
40369.22	0.226	-7.5	0.750	-2.4	2.7	D
40377.37	0.069	-10.5	0.766	-0.8	5.8	D
40381.37	0.483	3.5	0.774	-10.3	-3.0	D
40396.22	0.021	-11.6	0.804	-11.8	-1.9	D
40399.20	0.329	-8.6	0.809	-10.2	0.2	D
40410.29	0.477	3.0	0.831	-20.3	-8.1	D
40422.18	0.708	19.5	0.855	-13.3	0.7	D
40439.22	0.472	2.7	0.889	-16.3	-0.3	D
40450.24	0.613	13.4	0.910	-20.9	-3.9	D
40457.23	0.336	-8.3	0.924	-14.3	3.2	D
40621.47	0.338	-8.3	0.249	11.2	8.6	D
40629.52	0.172	-6.5	0.265	6.4	2.5	D
40636.53	0.897	-7.0	0.279	3.6	-1.3	D
40651.40	0.437	-0.4	0.308	5.3	-1.6	D
40661.49	0.481	3.3	0.328	8.8	0.8	D
40685.31	0.947	-9.7	0.375	8.4	-1.7	D
40712.29	0.740	19.1	0.429	11.6	0.4	D
40717.28	0.256	-8.3	0.439	15.4	4.1	D
40719.32	0.468	2.4	0.443	8.2	-3.1	D
40746.34	0.265	-8.5	0.496	16.7	5.9	D
40755.30	0.192	-6.9	0.514	8.7	-1.7	D
40766.18	0.318	-8.8	0.535	9.7	0.0	D

TABLE 4 (Continued)

HJD -2,400,000	ϕ (pul)	V_r (pul) km sec^{-1}	ϕ (orb)	V_r (orb) km sec^{-1}	O–C km sec^{-1}	Source
40776.27	0.363	-6.8	0.555	9.4	0.4	D
40788.25	0.603	12.7	0.579	5.9	-1.9	D
40796.21	0.427	-1.4	0.595	6.3	-0.7	D
40805.22	0.360	-7.0	0.613	7.8	1.9	D
40809.22	0.774	14.4	0.621	8.5	3.1	D
39877.54	0.327	-8.7	0.777	-1.9	5.7	E
39880.52	0.636	15.1	0.783	-4.2	3.9	E
39891.49	0.772	15.0	0.805	-8.2	1.8	E
40235.56	0.389	-4.9	0.486	13.5	2.5	E
40248.59	0.738	19.2	0.511	5.6	-4.9	E
40265.56	0.495	4.4	0.545	11.1	1.7	E
40591.58	0.244	-7.9	0.190	2.5	5.3	E
47225.955	0.027	-11.6	0.316	8.4	1.0	F
47254.995	0.034	-11.6	0.373	11.0	1.0	F
47226.881	0.123	-7.2	0.318	7.2	-0.3	F
47256.019	0.140	-6.7	0.375	8.4	-1.7	F
47247.019	0.208	-7.2	0.358	10.4	1.0	F
47304.989	0.209	-7.2	0.472	12.9	1.7	F
47324.671	0.246	-8.0	0.511	10.0	-0.5	F
47219.164	0.324	-8.7	0.303	8.4	1.9	F
47296.900	0.372	-6.3	0.456	10.3	-1.0	F
47296.959	0.378	-5.8	0.456	11.5	0.2	F
47239.067	0.385	-5.2	0.342	8.7	0.0	F
47306.816	0.398	-4.3	0.476	10.2	-0.9	F
47317.100	0.463	1.9	0.496	10.1	-0.7	F
47221.019	0.516	6.1	0.306	6.4	-0.4	F
47317.985	0.554	8.8	0.498	11.6	0.8	F
47241.032	0.588	11.5	0.346	9.3	0.4	F
47221.924	0.610	13.2	0.308	6.8	-0.1	F
47251.050	0.625	14.3	0.366	10.2	0.5	F
47242.059	0.694	19.1	0.348	9.5	0.5	F
47223.018	0.723	19.5	0.310	5.1	-1.9	F
47358.815	0.781	12.7	0.579	7.7	-0.1	F
47223.958	0.821	4.9	0.312	8.6	1.5	F
47310.901	0.821	4.9	0.484	13.0	2.0	F
47244.064	0.902	-7.5	0.352	8.6	-0.6	F
47224.913	0.920	-8.5	0.314	5.6	-1.6	F
47253.990	0.930	-9.0	0.371	8.5	-1.4	F

TABLE 5
IUE Spectra

Star	Spectrum	Spectral Type	E(B-V) (mag)	Pulsation Phase	Program
S Mus	SWP 15485		0.23	0.43	Eichendorf
	LWR 11966			0.43	Eichendorf
ρ Aur	SWP 15537	B5V	0.01		RPSTD
	LWR 9868				RPSTD
HD 65904	SWP 15557	B4V	0.04		RPSTD
	LWR 12042				RPSTD
β Aqr	LWP 6031	G0Ib	0.03		Evans

colors of the Cepheid. If the spectrum of β Aqr is scaled and subtracted from the S Mus spectrum, the difference spectrum matches the B5 V spectrum from 1200 Å to 3200 Å. A B4 V companion has excess flux from 2300 Å to 3200 Å as compared with the S Mus (Cepheid-corrected) spectrum. However, to provide a feeling for the uncertainty in the corrections to the colors resulting from an uncertainty in the spectral type of the companion, a parallel set of calculations has been carried out for B5 V and B4 V companions.

B5 V is the spectral type of the companion found by Böhm-Vitense *et al.* (1990) from a similar comparison of the flux distribution of IUE spectra, and also from line strengths on low-dispersion spectra. We confirm (below) the smaller reddening they favor. Uncertainty in the temperature of the companion comes from two factors. First is any uncertainty to the overall reddening calibration we use (see below). Because in this temperature range the flux rises monotonically toward shorter wavelengths, spectral information comes from the slope of the distribution which is sensitive to the reddening. Second, it is desirable to have well-exposed long- and short-wavelength *large aperture* spectra to avoid scaling the spectra.

The effect of the companion on the observed colors of S Mus is worked out in the same way as for AW Persei (Evans 1989). The spectral types of both stars and the magnitude difference between them are known. Appropriate supergiant and main-sequence colors are taken or interpolated from Johnson (1966). One complication is that one of our aims is to correct the reddening found by Dean, Warren, and Cousins (1978) for the effect of the companion. They derive reddenings from *BVI* photometry in the Kron-Cousins system. For this reason the Johnson colors were transformed to Kron-Cousins colors using the transformations from Bessell (1979).

The visual magnitude of the B5 V star in Figure 3, which was matched to S Mus B in the ultraviolet, combined with the scale factor necessary results in a $V_0 = 8^{\rm m}.89$ for S Mus B. (For the B4 V star, $V_0 = 9^{\rm m}.26$.) The measured V_0 of S Mus (A + B) is $5^{\rm m}.44$, using the revised value of $E(B-V) = 0^{\rm m}.23$ and $A_v/E(B-V) = 3.1$. From standard manipulations between magnitude and intensity, these values result in a V_0 of S Mus A (the Cepheid alone) of $5^{\rm m}.49$, or a correction to the observed magnitude of $0^{\rm m}.05$.

With the magnitude difference S Mus(A) − S Mus(B) known, the main-sequence and supergiant colors are used to work out the correction to B and I, also due to the contribution of the companion. The corrections to V, $(B-V)$, and $(V-I)_{\rm KC}$ are listed in Table 6 for both a B5 V and B4 V companion. Even though S Mus B is one of the brightest and hottest Cepheid companions known, the corrections in Table 6 are small. The corrections for the B4 V companion are actually smaller than those due the B5 V companion. This is because we start by equating the flux of S Mus B from 1200 Å to 2000 Å with the flux of the companion. The larger ultraviolet−visual flux ratio for the B4 V companion results in a fainter V(B4 V) magnitude.

The corrected colors can be used to calculate a photometric reddening using the relations provided by Dean *et al.* (1978). The revised value for $E(B-V)$ is $0^{\rm m}.23$ (or $0^{\rm m}.24$ for a B4 V companion). Table 7 summarizes the colors corrected for the companion (B5 V) and dereddened. The original reddening is taken from Dean, Warren, and Cousins. For convenience $\langle B\rangle - \langle V\rangle$ is included, assuming the correction for it and $(B-V)$ is the one calculated for mean light.

TABLE 6
Corrections: S Mus (A) - S Mus (A+B)

Comparison	Δ V (mag)	Δ(B−V) (mag)	Δ(V−I)$_{KC}$ (mag)
B5V	0.05	0.04	0.02
B4V	0.03	0.03	0.01

4. Discussion

Although the corrections for the colors and reddening are small, it is important to assess them since they affect determinations of the luminosity or mass. The absolute magnitude of S Mus is $-4^{\rm m}.26$ from the PLC relation of Feast and Walker (1987, eq. (3), Table 3, No. 6). This is $0^{\rm m}.18$ fainter than if the uncorrected reddening and colors are used. This corrected luminosity corresponds to an evolutionary mass of 7.3 $\mathfrak{M}_\odot$ using the mass-luminosity relation of Becker, Iben, and Tuggle (1977) for $Y = 0.28$ and $Z = 0.02$. From differences in luminosity between evolutionary tracks, we estimate that the new Maeder and Meynet (1989) calculations result in a mass several tenths of a solar mass smaller than the Becker, Iben, and Tuggle evolutionary mass. A temperature of 5970 K was determined from the color temperature calibration of Kraft, as discussed by Cox (1979). From the luminosity and temperature a pulsation mass of 4.7 $\mathfrak{M}_\odot$ was calculated from the pulsation constant as parameterized by Cox (1979).

In summary, the main purpose of this note is to provide an orbit for S Mus using all the available data. Continued observations throughout the orbital period are needed to improve both the amplitude and the period. The combination of this orbit with the ultraviolet observations and the resulting Cepheid mass will be discussed further by both Böhm-Vitense *et al.* (1990) and Evans and Bolton (1989). In addition, small corrections to the colors and reddening have been derived from the spectral type of the companion from ultraviolet observations.

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TABLE 7
Corrected Data for S Mus

	Observed (mag)	Corr. for Comp. (mag)	Corr. for Comp. & Redd. (mag)
B−V	0.78	0.82	0.59
V−I$_{KC}$	0.91	0.93	0.63
E(B−V)	0.27	0.23	
⟨B⟩−⟨V⟩	0.82	0.86	0.63

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REFERENCES

Becker, S. A., Iben, I., and Tuggle, R. S. 1977, *Ap. J.*, **218**, 633.
Bessell, M. S. 1979, *Pub. A.S.P.*, **91**, 589.
Böhm-Vitense, E. 1986, *Ap. J.*, **303**, 262.
Böhm-Vitense, E., Clark, M., Cottrell, P. L., and Wallerstein, G. 1990, *A.J.*, **99**, 353.
Campbell, W. W., and Moore, J. H. 1928, *Pub. Lick Obs.*, **16**, 180.
Cox, A. N. 1979, *Ap. J.*, **229**, 212.
Dean, J. F., Warren, P. R., and Cousins, A. W. J. 1978, *M.N.R.A.S.*, **183**, 569.
Evans, N. R. 1988, *Ap. J. Suppl.*, **66**, 343.
———. 1989, *A.J.*, **97**, 1737.
Evans, N. R., and Bolton, C. T. 1990, *Ap. J.*, in press (June).
Feast, M. W., and Walker, A. R. 1987, *Ann. Rev. Astr. Ap.*, **25**, 345.
Grayzeck, E. J. 1978, *A.J.*, **83**, 1397.
Johnson, H. L. 1966, in *Ann. Rev. Astr. Ap.*, **4**, 193.
Lloyd Evans, T. 1968, *M.N.R.A.S.*, **141**, 109.
———. 1980, *S. Afr. Astron. Obs.*, **1**, 257.
———. 1982, *M.N.R.A.S.*, **199**, 925.
Maeder, A., and Meynet, G. 1989, *Astr. Ap.*, **210**, 155.
Rodgers, A. W., and Bell, R. A. 1967, *M.N.R.A.S.*, **136**, 91.
Stibbs, D. W. N. 1955, *M.N.R.A.S.*, **115**, 363.
Szabados, L. 1989, *Mitt. Sternw. Ungaris. Akad.*, **94**, 1.
Wu, C. C., *et al.* 1983, *IUE NASA Newsletter*, **22**, 1.