RADIAL VELOCITIES OF SS CYGNI

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Introduction

SS Cygni was found by Joy (1956) to be a spectroscopic binary with an orbital period of about 6-1/2 hours. At minimum light it has m_v=12 and is the brightest member of the dwarf nova class of variables. The minimum light spectrum reveals faint, narrow absorption lines of a G- or K-type star along with strong, broad emission lines of hydrogen, helium, and calcium which are produced by an accretion disk surrounding a white dwarf star. Joy's radial velocities were not very accurate. Nevertheless, he was able to estimate the orbital elements, finding 115 km/s for the absorption line K-velocity and 122 km/s for the emission line K-velocity. In addition, he derived an orbital period of $0^d.276244$. Later minimum light observations by Walker and Chincarini (1968) were too few to be able to improve the orbital elements. Kiplinger (1979) refined the emission line radial velocities but was not able to remeasure the faint absorption line spectrum. This paper presents new radial velocity measurements of both the emission and absorption line spectra of SS Cygni at minimum light, and is the first thorough investigation of this star's radial velocity variations in more than 20 years. The accuracy of the radial velocity curves has been greatly improved. We also find that Joy's orbital period is in error by nearly two minutes.

Observations

The spectroscopic data consist of 34 pairs of spectra obtained with the Cassegrain Digicon Spectrograph (Tull et al. 1979) on the 2.1 m Struve reflector at McDonald Observatory during four nights in July, 1978. The spectra were obtained at a dispersion of 1.9 Å per pixel and covered a useful wavelength range from 3700 Å to 5000 Å. The data were obtained as a series of 20 minute exposures of SS Cyg bracketed by observations of argon and neon comparison lamps for wavelength calibration. Accurate wavelengths were achieved by linearly interpolating the bracketing wavelength calibrations to the time of mid-exposure of each SS Cyg spectrum. In addition, flux standard stars and a tungsten filament lamp were observed with a wide slit each night in order to determine the instrumental response function. Although each spectrum of SS Cyg was reduced to fluxes outside the atmosphere, the data were obtained using a narrow slit, and the flux determinations are therefore not very accurate.

Radial Velocities

The radial velocities of the absorption line spectrum of the late-type star were measured by cross-correlating each spectrum with a comparison spectrum of a single late-stype star. The measurements presented here were obtained by cross-correlation with the spectrum of HD199178. In order to do the cross-correlation over a wide wavelength range the spectra are first transformed onto a logarithmic wavelength scale. When this is done, a shift of one pixel corresponds to the same radial velocity increment at all wavelengths. The relative radial velocity is then simply proportional to the relative shift between the SS Cyg spectrum and the HD199178 spectrum which gives the maximum in the cross-correlation function. The cross-correlations were computed using only the emission-free spectral regions between Hβ and Hγ and between Hγ and Hδ.

The emission line radial velocities were measured by fitting a gaussian function to the wings of the emission lines. By fitting just the wings, the distorting effects of the hot spot are greatly reduced. However, in order to obtain consistent radial velocities for all of the emission lines the underlying late-type absorption spectrum had to be removed. In fact, we found that the underlying absorption spectrum was the primary source of systematic error in the emission line velocities. The spectrum of HD199550 was found to match closely the relative line strengths of the late-type star in SS Cyg. Therefore, for each SS Cyg spectrum, the spectrum of HD199550 was shifted to match the velocity-shifted spectrum of the late-type star and the appropriate fraction subtracted to minimize the residual absorption lines. The emission-line radial velocities presented here are the average of the measurements on Hβ, Hγ and Hδ.

Figure 1 shows the spectrum of SS Cyg between 3700 Å and 5000 Å. The spectrum has been transformed onto a logarithmic wavelength scale just as is used in the cross-correlation procedure. The upper curve shows the co-addition of all 68 spectra of SS Cyg. However, before co-adding, each spectrum was shifted to remove the radial velocity of the late-type star. Therefore, the absorption line spectrum is represented in the greatest possible detail, with no velocity smearing. The lower curve shows the result of subtracting the spectrum of HD199550. No smoothing has been applied to either spectrum. The effect on the continuum regions is dramatic. In addition, the emission lines become much more symmetrical and smooth. The improvement in Hγ is particularly apparent where the severe distortion by the G-band of the late-type star has been removed. Between 4000 Å and 5000 Å the late-type star contributes about 45% of the total light.

Discussion

Figure 2 shows the measured radial velocities. The solid curves represent the circular orbit solutions given in Table 1. The absorption line radial velocities have a mean residual about the fitted curve of less than 7 km/s, corresponding to about 1/20 pixel in the original

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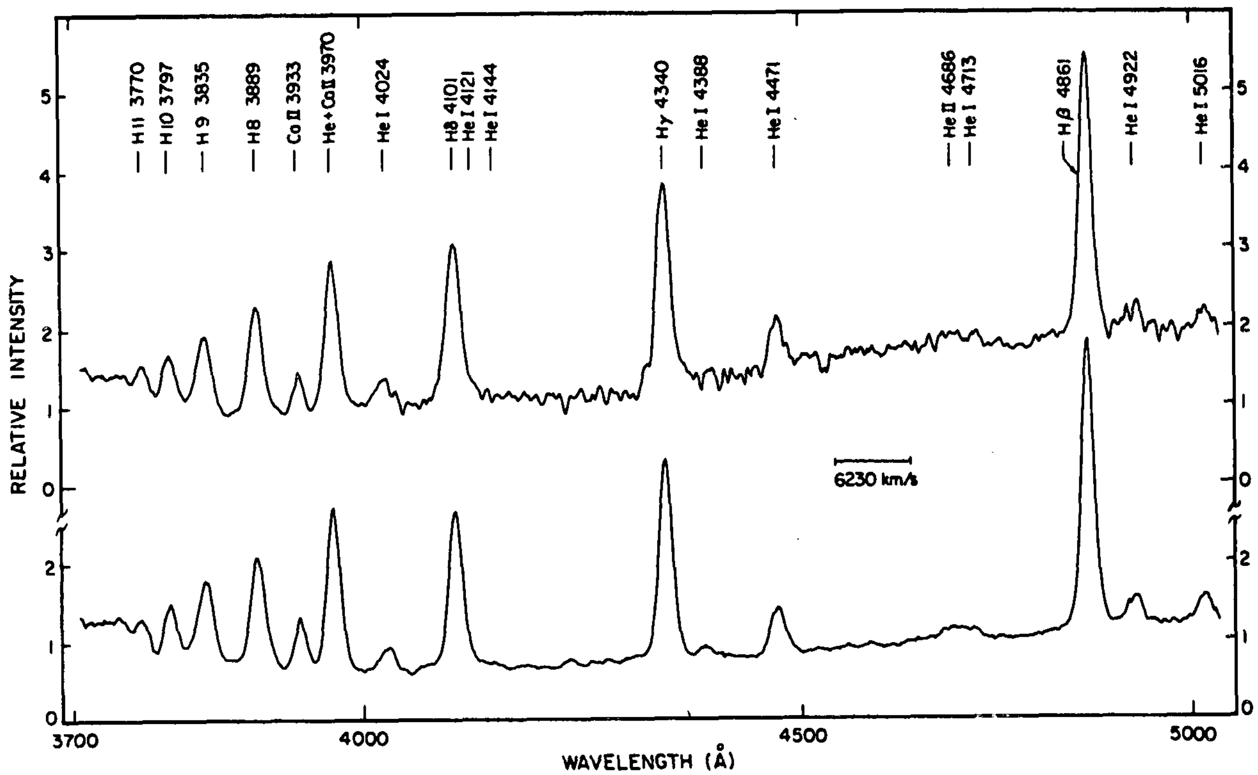

Fig. 1 - Removal of late-type component from the SS Cyg spectrum. Upper: The spectrum of SS Cyg formed by co-adding 64 separate spectra. Lower: The spectrum of SS Cyg after subtraction of the spectrum of the late-type star HD199550.

spectra. The emission line radial velocities have a slightly higher mean residual of about 10 km/s. Much of the remaining residual seems to arise from systematic distortions caused by the hot spot on the edge of the accretion disk. In addition, the hot spot produces an apparent 9° phase shift between the emission line and absorption line velocity curves.

Because of the high accuracy of the absorption-line radial velocities it was immediately obvious that Joy's orbital period did not fit our data. Our best fitting period, 0ᵈ2749 is nearly two minutes shorter than Joy's value of 0ᵈ276244. This very large difference indicates that Joy's value is probably an alias of the true period; re-investigation of the correct period is currently under way. We also find that out K-velocities differ significantly from Joy's values. Our lower emission line K-velocity (93 km/s) is supported by Kiplinger (1979) and probably results from a large reduction in distortions produced by the hot spot as well as improved measurement accuracy. Our larger value for the absorption-line K-velocity (152 km/s) is also supported by Kiplinger, although he chose to disregard his results. Joy's lower value probably is the result of poorer accuracy and long photographic exposures.

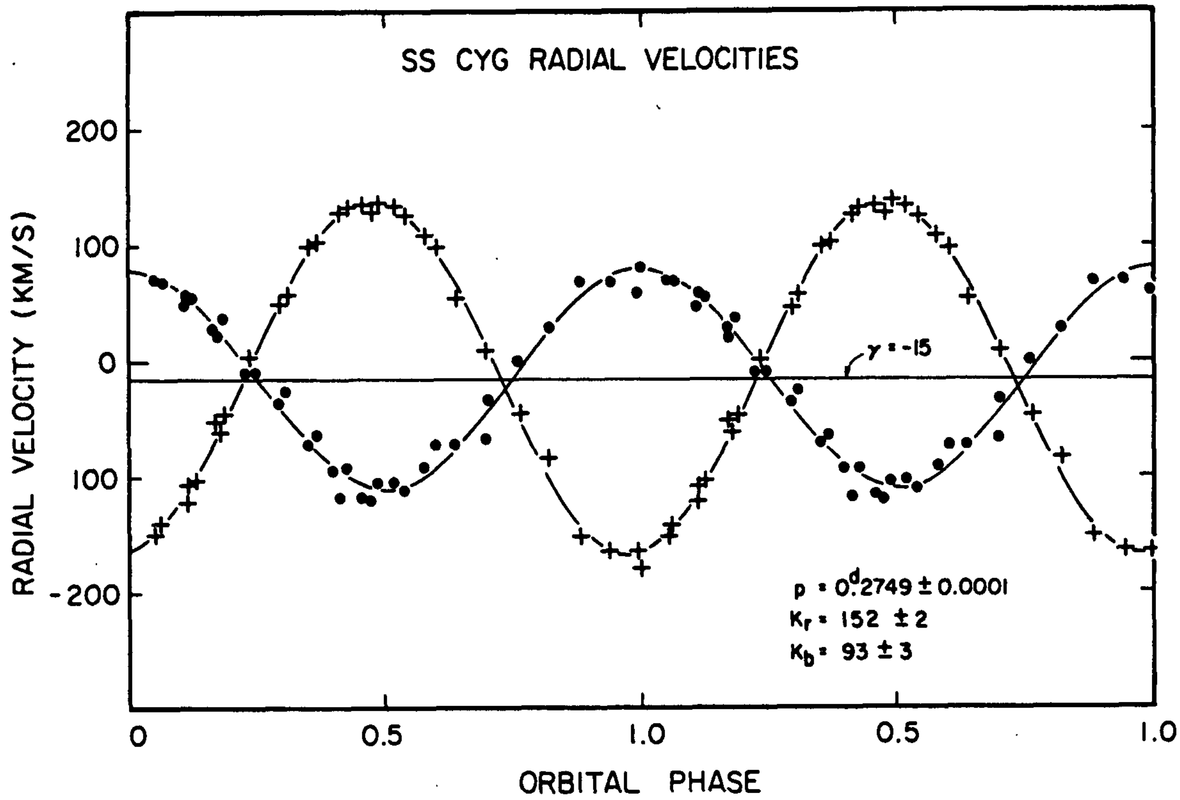

Fig. 2 - Radial velocity curves of SS Cyg. Emission-line velocities are represented by circles, absorption-line velocities by pluses. The curves correspond to the circular orbit fits given in Table 1.

Because SS Cyg is not an eclipsing system, the masses of the components cannot be determined without making assumptions about the inclination of the orbit, or about the evolutionary state of the system. However, the velocity data do give a reliable mass ratio $m_b/m_r = 1.63 \pm 0.05$.

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TABLE 1

SS Cyg Circular Orbit Solution

$P=0^{d}.2749$, $e=0$, $\gamma=-15\pm4$		
Element	Emission (white dwarf)	Absorption (late-type star)
K (km s^{-1})	93±3	152±2
T_o^* ($JD_\odot$ 2443000.+	699.9474 ±.0013	700.0779 ±.0005
a sin(i) (10^5 km)	3.52±0.10	5.76±0.06
m $\sin^3$(i) ($M_\odot$)	0.26±0.03	0.16±0.02

*T_o = time of maximum positive velocity

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