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THE ORBIT OF THE CEPHEID AW PER

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ABSTRACT

An orbit for the classical Cepheid AW Per has been derived. Phase residuals from the light curve are consistent with the light-time effect from the orbit. The companion has been studied using IUE spectra. The flux distribution from 1300 to 1700 Å is unusual, probably an extreme BpSi star, comparable to a B7V or B8V star. The flux of the composite spectrum from 1200 Å through V is well matched by F7Ib and B8V standard stars with $\Delta M_v = 3^m1$. The mass function from the orbit indicates that the mass of the Cepheid must be greater that 4.7 $M_\odot$ if it is the more massive component. A B7V to B8V companion is compatible with the 1 σ lower limit (3.5 $M_\odot$) from the mass function. This implies that the Cepheid has the same mass, but the large magnitude difference rules this out. It is likely that the companion is itself a binary.

Keywords: Cepheids, binaries, masses, chemically peculiar stars

1. ORBIT

An orbit for the Cepheid AW Per has been derived (Evans, Welch, and Scarfe, Ref. 1), with a period of 13100 ± 1000 days, a semi-amplitude of 11.4 ± 0.6 km sec^{-1}, and a mass function of 1.17 ± 0.30 $M_\odot$. This orbit is compatible with a light-time effect interpretation of the phase residuals in an O–C diagram. The large physical separation between the Cepheid and its companion make AW Per an excellent candidate for a geometric distance determination with the Hubble Space Telescope.

2. COMPANION

Because of the temperature difference between the Cepheid and its hot main sequence companion, IUE spectra provide 1000 Å of uncontaminated flux in which to study the companion. Although the spectrum roughly matches the flux distribution of a B8V star from the IUE Spectral Atlas from 1170 to 2000 Å, it differs significantly in detail. Figure 1 shows the comparison between long and short wavelength spectra of AW Per and the B8V standard 18 Tau. Specifically, AW Per has excess flux at 1600 Å. We have investigated a number of possible causes for the spectral peculiarities. No known reddening law can produce the flux distribution. The closest analogy is ApSi stars, which show extra absorption at 1400 Å probably due to Si autoionization, and flux redistribution resulting in excess flux at 1600 Å. We have not found a comparison star which is as extreme an example as AW Per, but the ApSi star 56 Ari displays qualitatively similar features as compared with a normal B9V star. In searching unsuccessfully for a more exact match with AW Per B, the companion, the spectra of 23 stars were examined, including ApSi, BpSi, HgMn, He weak stars (especially those in clusters), and even β Lyr, which has excess flux at 1800 Å.

In order to investigate whether AW Per B is a main sequence star, or a more luminous evolved star with nearly the same mass as the Cepheid, we have compared the luminosity of the companion in the SWP region (1200 to 2000 Å) with that of the hot companion of SU Cyg (B7.5 HgMn). This has been done by selecting observations at phases when the Cepheids are nearly the same temperature, and dereddening them. The spectra were then scaled so that the Cepheids have the correct difference in absolute magnitude M_v according to the period-luminosity-color relation of Caldwell (Ref. 2), making small corrections for the difference from mean light at the time of observation and the contribution from the companion.

Figure 2 show this comparison between AW Per and SU Cyg. AW Per B is approximately twice as bright as SU Cyg B. For comparison, Figure 3 shows spectra of B7V (19 Eri) and B8V (18 Tau), scaled so that they have the magnitude difference at V given by the ZAMS calibration of Schmidt-Kaler (Ref. 8). The difference in the ultraviolet luminosity between AW Per B and SU Cyg B is consistent with what would be produced by two stars with main sequence luminosity and a difference of one spectral subclass. Attributing the uv luminosity difference to a small difference in spectral type is plausible, particularly considering the peculiarities in the spectrum of AW Per B.

The AW Per composite spectrum has been compared with standard star spectra from 1200 Å through V. The flux distribution is well matched by an F7Ib supergiant (45 Dra) and a B8V star with a magnitude difference ΔM_v of 3^m1

3. DISCUSSION

The mass function from the orbit is 1.17 ± 0.30 $M_\odot$. This puts a lower limit on the mass of the companion of 4.7 $M_\odot$, with a 1 σ lower limit on the mass of the companion of 3.5 $M_\odot$, assuming the Cepheid is the more massive star. Using the mass compilation of Popper (Ref. 6), the mass of B8V and B7V stars are 3.2 and 4.0 $M_\odot$ respectively. If the companion is a 4.0 $M_\odot$ single star, this implies that sin i = 90°, and the Cepheid is also a 4.0 $M_\odot$ star. However, the bolometric magnitude difference between the two stars (from the flux

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distribution) of $2^{m}5$ to $2^{m}2$ is too large to be consistent with two stars of nearly equal mass

These mass estimates for the Cepheid can be compared with evolutionary and pulsation masses computed from the following sources: B-V temperature calibration: Cox (Ref. 3), eq. 1; evolutionary masses ($Y = 0.28$, $Z = 0.02$ for all calculations) Becker, Iben and Tuggle (Ref. 1); pulsation masses: Faulkner (Ref. 5). Masses have been computed for both a long distance scale (Caldwell) and a short distance scale (Schmidt, Ref. 7) Both evolutionary masses (6.8 $M_{\odot}$ (Caldwell) and 6 4 $M_{\odot}$ (Schmidt) are much larger than 4.0 $M_{\odot}$. The same is true of the pulsation mass for the long distance scale (5.4 $M_{\odot}$). Only the pulsation mass for the short distance scale (4.0 $M_{\odot}$) is compatible with the mass implied by a single companion.

On the other hand, if the companion is itself a double star, the inclination may be lower, and the mass of the Cepheid may be larger. This is to be investigated with a high dispersion IUE spectrum by Böhm-Vitense, Evans, and Welch.

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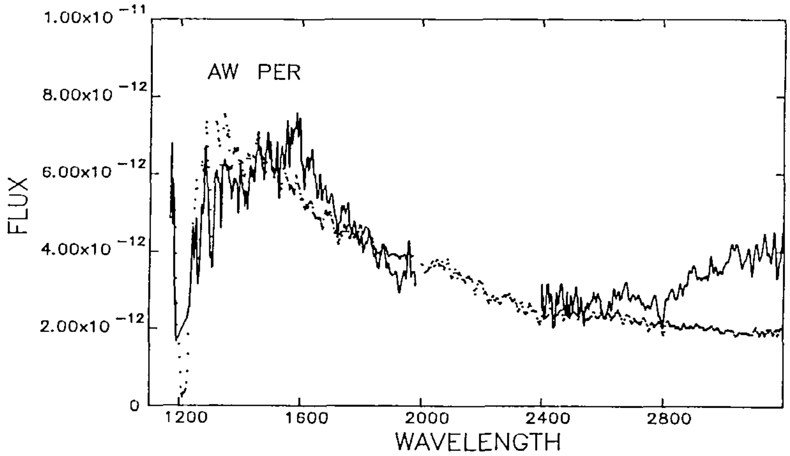

Figure 1 The comparison between AW Per (solid) and a B8V star (dots). The B8V star (18 Tau) has been scaled The contribution from the Cepheid can be seen for wavelengths longer than 2600 Å. All wavelengths are in Å; all fluxes are in ergs sec^{-1} cm^{-2} $Å^{-1}$.

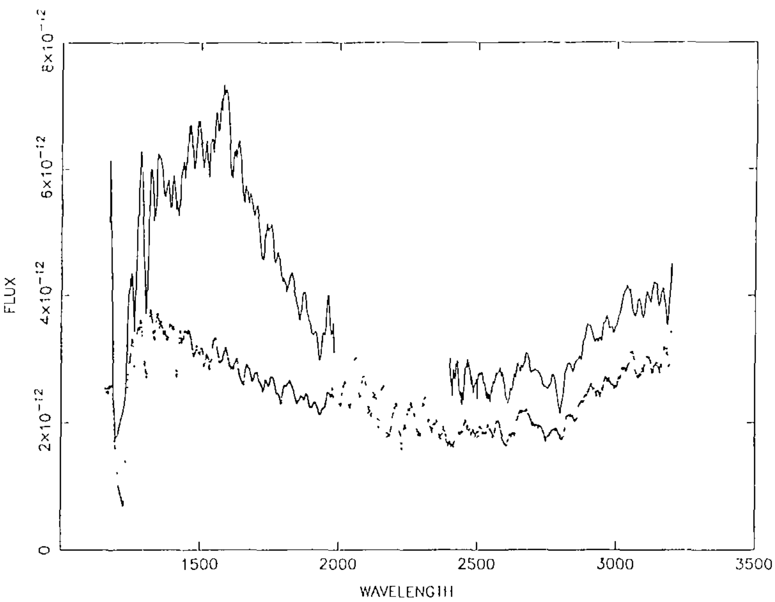

Figure 2. The comparison between AW Per B (solid) and SU Cyg B (dots). The spectra have been scaled according to the difference in absolute magnitude between the Cepheids. See text for discussion.

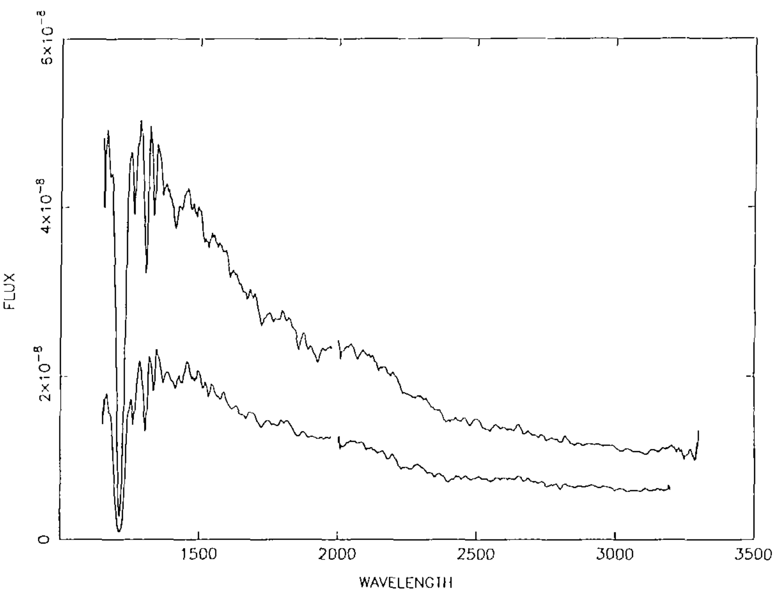

Figure 3. The comparison between a B7V star (top) and a B8V star (bottom). The spectra have been scaled according to the ZAMS absolute magnitude