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PHOTOMETRY OF THE ACTIVE-CHROMOSPHERE ECLIPSING BINARY, HD 9770

The visual triple system HD 9770 comprises two K dwarf stars (A and B) in a well-determined 4.559-year orbit, together with a third star (C), an M dwarf, with an orbital period of 111.8 years. The semi-major axes are $0''.171$ for AB and $1''.419$ for AB-C (Hirshfeld & Sinnott, 1985). The parallax is given as $0''.052 \pm 0''.007$ by Jenkins (1963). The spectral types according to Edwards (1976) are K3 V (A), K4 V (B) and M2 V (C). The M dwarf is more than 4 magnitudes fainter in V than the combined light from AB. According to the compilation of Hirshfeld and Sinnott (1985) the visual magnitudes of the three stars are 7.8, 7.9 and 11.5 for A, B and C respectively, although the angular proximity of the objects in the sky must make these figures approximate only.

The system ABC contains at least one active chromosphere star, as shown by EUV emission from both the ROSAT (Pounds et al., 1993; Pye et al., 1995) and EUVE all-sky surveys (Malina et al., 1994; Bowyer et al. 1994). The definitive identification of the ROSAT WFC source 2RE013501–295430 with the star HD 9770 (Gliese 60 A,B,C) was made by Mason et al. (1995), based in part on 1-Å resolution spectra recorded in 1991–92 on the SAAO 1.9-m telescope at the H and K lines, which show some H and K emission (approximate equivalent width of emission 0.2 Å). The emission may be variable both in strength and radial velocity. On the other hand the Michigan Spectral Catalogue (Houk, 1982) gives a spectral type of K1 V and there is no mention of H and K emission — presumably because of lower resolution.

The galactic (U, V, W) velocity components for HD 9770 calculated by Eggen (1962) are $(+22.2, -5.3, -31.6)$ km/s. Such velocity components are typical of old disk stars, so we do not infer any chromospheric emission arising from extreme youth.

HD 9770 appears in a list of suspected variable stars by Petit (1980), but neither the magnitude range nor the type of variability are specified. Cutispoto et al. (1995) subsequently found an amplitude in V of about 0.07 mag. and a period of 6.29 ± 0.24 days.

Photoelectric photometry has been carried out in the $UBV(RI)_C$ system since 1992 Nov. 3 on the SAAO 0.5-m telescope at Sutherland, S.A. and on the two 0.61-m telescopes at MJUO, Tekapo, N.Z. The comparison and check stars selected were respectively HD 9349 and HD 9576.

Our observations have confirmed that the system is indeed variable, with an amplitude from maximum to minimum of about 0.25 mag. in V. We have found that one of the visual binary components is itself an eclipsing binary for which the ephemeris of primary eclipse is

$$HJD = 2448930.6448 + 0.476525 \times E$$

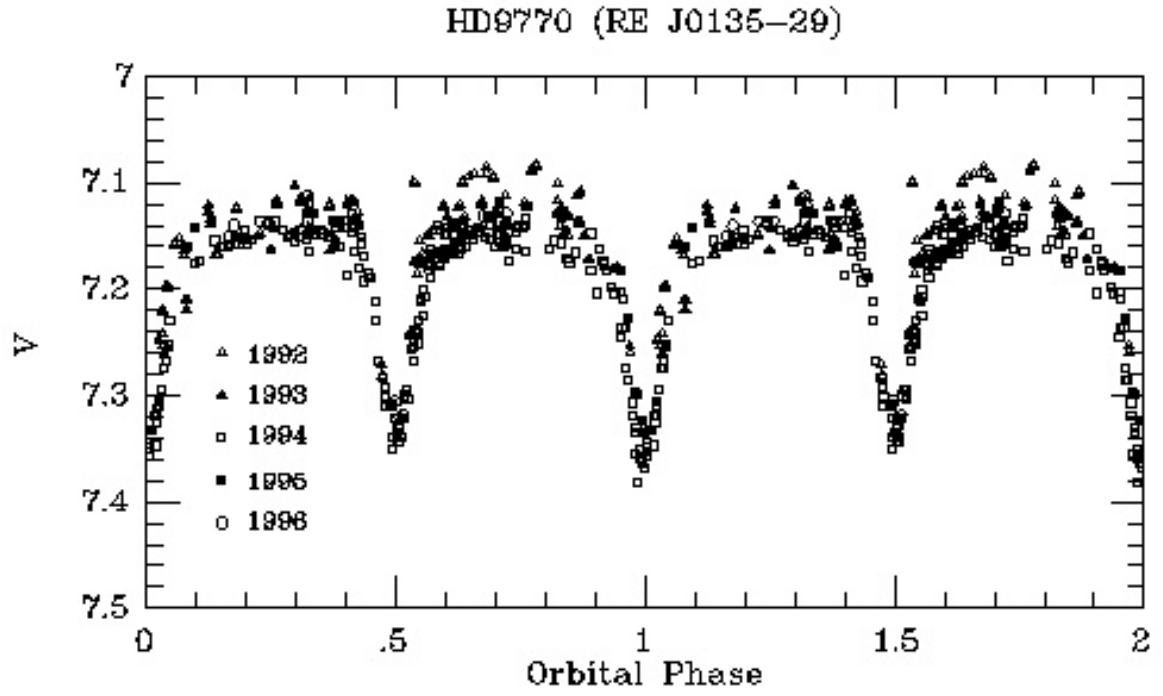

Figure 1. Phased V light curve from SAAO and MJUO photometry of HD 9770

Our phased light curve (Figure 1) shows that the primary eclipse has a depth of about $0\overset{\mathrm{m}}{.}22$, whereas the secondary eclipse is about $0\overset{\mathrm{m}}{.}20$. We therefore prefer the above ephemeris to one in which the period is only half as long and the secondary eclipse is not visible. The orbit appears to be close to circular, as the phase of central secondary eclipse is 0.50 and the eclipses are of comparable duration. We therefore deduce that the two stars in the eclipsing binary system are of very similar spectral type, presumably both K dwarfs. Hence the visual binary system AB must contain three K dwarfs all of comparable mass. If the stars were of equal magnitude and the third star not participating in the eclipses were absent, then the primary eclipse depth would be $0\overset{\mathrm{m}}{.}35$ instead of $0\overset{\mathrm{m}}{.}22$, suggesting that the eclipses are not total.

In addition to the variability due to the eclipses, there is considerable scatter over the four years of our observations in the out-of-eclipse magnitudes. The combined magnitude of the system ABC was as bright as 7.10 in 1992, but about 7.14 in 1994. Such variations are typical in active-chromosphere binary stars, because of the variation in spot numbers on timescales of years. Some of the scatter may also arise because of the drift in orbital phase of the rotationally modulated spot wave.

Much of our data came from 1994 observations at MJUO. The scatter for this year is clearly less than for all the photometric data considered together (see Figure 1).

We find no evidence for the 6.29-day variation reported by Cutispoto et al. (1995).

It is noted that the orbital period of $11^{\mathrm{h}}26\overset{\mathrm{m}}{.}2$ found for the eclipsing binary system is the shortest of any active-chromosphere binary listed in the catalogue of Strassmeier et al. (1993), although several have periods of about half a day.

Although the AB visual binary has a well-determined orbit, the uncertain parallax renders a mass with quite large error bars. It is

$$M_{\mathrm{A}} + M_{\mathrm{B}} = 1.71^{+0.93}_{-0.54} M_{\odot}$$

The higher mass limit is $2.64M_{\odot}$, corresponding to a parallax of about 0.″045. Since we anticipate that the AB system in practice contains three K dwarfs of spectral type about K3 V or K4 V, whose masses should therefore each be about $0.75M_{\odot}$, a total mass of about $2.25M_{\odot}$ might be expected for the AB system. This total mass is entirely consistent with the AB orbit and the parallax, given the rather large parallax uncertainty. The Hipparcos parallax will soon constrain the total mass of this system to a much narrower range. The orbit of the AB-C system is not well enough determined to add much useful information to the total mass.

A programme of high dispersion échelle spectroscopy using the 1-m McLellan telescope at MJUO has been undertaken on HD 9770 since 1993 March. Most of the data are at Hα, which shows a fairly normal K dwarf profile without obvious Balmer emission, but the central depth is only 0.45, consistent with the presence of the two other stars which may have some chromospheric emission (Figure 2). Radial velocities have been measured from the Hα and metallic lines, and the results will be reported in a subsequent paper (Watson et al., 1997). The velocities show only small variations around +32.5 km/s, showing that the sharp-lined spectrum being measured is from the third K star which is not part of the eclipsing binary system.

IUE spectra were also recorded in 1996 August, from both the long wavelength camera at high dispersion and the short wavelength camera at low dispersion. These spectra show chromospheric emission lines consistent with the EUV emission and the chromospheric emission at H and K. They will also be discussed in our subsequent publication.

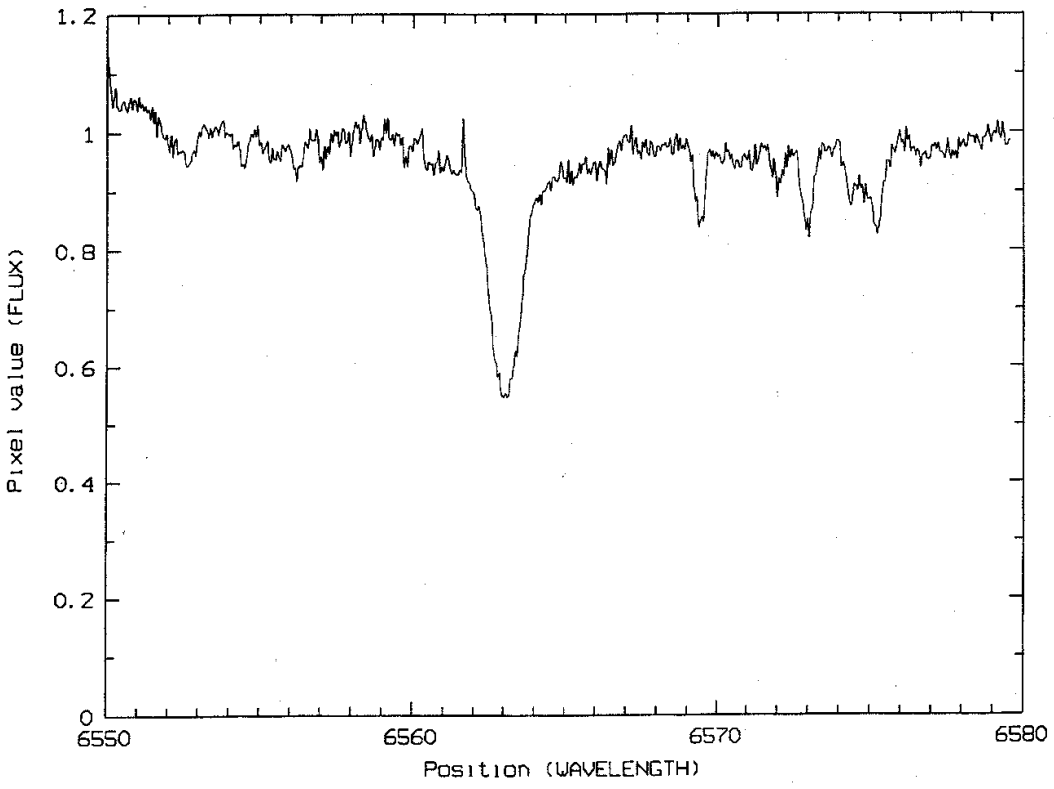

Figure 2. Typical MJUO Hα échelle spectrum of HD 9770

We note that the two eclipsing K stars are expected to show a radial-velocity amplitude of about 340 km/s and, assuming they are tidally locked, rotational line broadening in each star of about 80 km/s. Such broad diffuse lines may be present in our échelle spectra, but we need to study the spectra further to be certain of this. Figure 2 shows the dominant sharp lines, which are clearly those of the third K dwarf outside the eclipsing binary.

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