
HD 9770, a southern active-chromosphere system

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ABSTRACT
The visual triple system HD 9770 (BB Scii) has been the subject of a four-year programme of UBVRI_C photometry and Hα echelle spectroscopy. Analysis of the data obtained over that period shows that star B, and probably also star A, of HD 9770 is a binary. The A system comprises a K1V star, which may be in a binary system with another K dwarf. The B system is an eclipsing binary of the BY Dra type in which both stars are chromospherically active. An orbital period of 0.476525 ± 0.000013 d has been derived from the light curve in V. Physical parameters derived from analysis of the light curves in UBVRI_C are presented.

Key words: line: formation – line: profiles – stars: activity – binaries: eclipsing – stars: chromospheres – stars: individual: HD 9770.

1 INTRODUCTION
The well-known visual triple HD 9770 (BB Scii) is also listed as SAO 193189, Gliese 60 ABC, CPD-30 P. The HD 9770 system was definitively identified with the Michigan Spectral Catalogue (Houk 1982) makes no mention of H and K emission, but that is presumably because of the lower resolution. The IRAS fluxes of HD 9770 as given by Wolstencroft et al. (1986) and their conversion to magnitudes according to the formulae given by Hickman, Sloan & Canterna (1995) are set out in Table 1; the ROSAT wide-field camera count rates as listed in the NASA HEASARC data base are listed in Table 2 with EUV luminosities as given by Hodgkin & Pye (1994).

Cutispoto et al. (1995) inferred that, in the absence of evidence of a close binary system, the surface activity was probably due to the rapid rotation of a young star. However, the galactic (U,V,W) velocity components that Eggen (1962) calculated for HD 9770 are (+22.2, −5.3, −31.6) km s\(^{-1}\) in Eggen’s left-handed coordinate system, and such velocity components are typical of old disc stars.

The value given by Hodgkin & Pye (1994) for log\(L_{\text{EUV}}\) in the WFC S1 passband equates to a luminosity of \(5.75 \times 10^{21}\) W in that
wavelength range, but this should be recalculated in the light of the Hipparcos parallax. Applying the Hodgkin and Pye conversion formula to the S1 flux of 0.0439 counts s\(^{-1}\) (Table 2), and applying bolometric corrections from Allen (1976, section 99) to the magnitudes for the components of HD 9770 obtained in Section 3, yields a ratio of

\[
\frac{L_{\text{EUV}}}{L_{\text{bol}}} = 2.7 \times 10^{-4}
\]

for the EUV in the S1 passband. The ROSAT X-ray flux (Table 2) of 2.59 counts s\(^{-1}\) yields, for the same value of \(L_{\text{bol}}\), a ratio of

\[
\frac{L_{\text{X}}}{L_{\text{bol}}} = 3.4 \times 10^{-4}.
\]

Such low values are expected if the excess EUV flux associated with chromospheric activity (Armado & Byrne 1997; Wood et al. 1994) has its origin in the secondary component only of HD 9770, while the primary component contributes \(\sim 80\) per cent of the bolometric flux.

Table 1. IRAS fluxes of HD 9770 in the 12, 25 and 60 \(\mu\)m bands, together with magnitudes and colour indices calculated therefrom.

<table>
<thead>
<tr>
<th>Band ((\mu)m)</th>
<th>IRAS flux</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.5706</td>
<td>4.24</td>
</tr>
<tr>
<td>25</td>
<td>0.2611</td>
<td>3.53</td>
</tr>
<tr>
<td>60</td>
<td>0.3577</td>
<td>1.31</td>
</tr>
</tbody>
</table>

IR colours | Indices
[12]–[25] | 0.711 |
[25]–[60] | 2.22 |

Table 2. ROSAT EUV and X-ray fluxes for HD 9770.

<table>
<thead>
<tr>
<th>WFC Passband filter (A)</th>
<th>Flux ((\text{counts s}^{-1}))</th>
<th>(\log L_{\text{EUV}}) ((\text{ergs s}^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 60–140</td>
<td>(4.9 \times 10^{-3})</td>
<td>28.76</td>
</tr>
<tr>
<td>S2 110–200</td>
<td>(5.2 \times 10^{-3})</td>
<td>28.94</td>
</tr>
<tr>
<td>PCSP X-ray flux</td>
<td>2.594</td>
<td></td>
</tr>
</tbody>
</table>

EUV to optical flux ratio 1.53

2 THE LIGHT CURVES

Single-channel photoelectric photometry in the \(UBVRI_{\text{c}}\) system of the unresolved AB + C system was obtained in 1992 and 1993 using the SAAO 0.5-m telescope and from 1993 to 1996 using the two 0.6-m MJUO telescopes.

V data obtained in 1994 July revealed that one of the components of the AB visual binary system is itself an eclipsing binary for which the ephemeris of primary eclipse is

\[
\text{HJD} = 2448930.6448 + (0.476525 \pm 0.000013) \times E
\]

as previously reported by Watson et al. (1995) and Bromage et al. (1996). The phased light curve (Fig. 2) shows that the primary eclipse has a depth about 0.22 mag, whereas that of the secondary eclipse is about 0.18 mag – indicating that they are indeed two different eclipses and the above ephemeris is to be preferred to one in which the period is half as long and the secondary eclipse is not visible. It also appears that the orbit is close to circular, since the eclipses are of comparable duration and the phase of the central secondary eclipse is 0.50.

Table 3 lists the orbital and photometric periods of all of the pairs of K-type dwarfs listed in the second catalogue of chromospherically active binary stars of Strassmeier et al. (1993). Except for DH Leo, they all have periods of several days. In DH Leo, as in HD 9770, the system of interest is a close
binary in a triple system, and the orbital period is 1.070 d. The close binary in DH Leo is listed as having Hα emission above the continuum.

2.1 Variability due to spots and tidal distortion

The out-of-eclipse magnitudes show considerable scatter over the four years of observation. 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 time-scales of years. Most of the data came from 1994 observations at MIOU, and the scatter for that year is clearly less than that for all the photometric data considered together (see Fig. 2).

The phased \((B-V)\) light curve (Fig. 3) constructed from observations made at SAAO in 1992 (the highest quality colour photometry available) shows a considerable scatter out of eclipse – again suggesting the presence of substantial and variable cooler surface regions on one or both of the eclipsing stars. If one or a pair of active stars with extensive surface spots is present in this close binary system with a half-day period, we might hope to find photometric evidence of a rotation period also of the order of half a day. The observations show a greater brightness between phases 0.6 and 0.9 than between phases 0.1 and 0.4, which might be due to the presence of spots non-uniformly distributed in longitude. The considerable scatter in the 0.6 to 0.9 interval would then be attributed to variation in spot numbers over the long time of the observations, and possibly also to the drift in orbital phase of the rotationally modulated spot wave. There is less scatter in the 0.1 to 0.4 interval in which the brightness shows a single peak at about phase 0.3 – which is suggestive of, but hardly proves, tidal distortion.

3 Physical parameters of the stars

The flatness of the light curves out of eclipse and the fact that the eclipses occur at even intervals of \(\sim 0.5\) of phase and are of similar duration indicate a well-detached system in a circular orbit, or at least one with negligible eccentricity. The slightly different depths of the two eclipses imply a small difference in mean surface flux density, or equivalently effective temperature.

The combined light of the HD 9770 system becomes bluer during both eclipses. This is a small (0.02–0.05 mag), but definite, effect that can be seen most clearly in the \((U-B)\), \((B-V)\), \((V-R)\) and \((V-I)\) light curves of Cutispoto et al. (1997) and in the \((V-I)\) light curve of Tagliaferri et al. (1999). The increased blueness of the combined light from the AB system during both primary and secondary eclipses indicates that the light from the star not involved in the eclipsing system is bluer than the light from either of the eclipsing stars, and therefore that the third light comes from star A, star B being the eclipsing binary. The contribution of the dim M2 V star HD 9770 C can be ignored since, at \(V \approx 11.5\) mag, it contributes only \(\sim 1.5\) per cent of the combined light of the system.

The available spectral classifications of the A and B components indicate that these components consist of main-sequence stars. Calculated from the measured Hipparcos parallax, \(\pi = 0.04229\) arcsec \(\pm 0.00147\) arcsec (which implies a distance modulus of 1.869 mag) and magnitudes \(H_p\) = 7.511 and \(H_p\) = 8.941 (Schrijver 1997, vols 5 and 10), the absolute magnitude of star A (after conversion from Hipparcos to Johnson magnitudes) is \(M_V = 5.50\) and that of the component B is \(M_V = 6.93\). Thus \(M_V = 7.69\) for the two individual components of B, which for main sequence stars corresponds to spectral class K6 dwarfs having a colour index of \((B-V)_0 = 1.2\), mass \(M_A = 0.69\) M\(_\odot\), and \(T_{\text{eff}} = 4590\) K (Schmidt-Kaler 1965). This implies a colour index of star A, given the Tycho colour index for the unresolved AB system of \((B-V)_{0,AB} = 0.909\) (Schrijver 1997, vol. 5), of \((B-V)_{0,AB} = 0.84\). Such a colour index is consistent with the star being of spectral type K1 as given by Houk (1982) with a visual magnitude \(V \approx 7.7\) mag brighter than expected for a zero-age main sequence star of that spectral type [canonical \((B-V)\) and \(M_V\) values taken from Gray 1992, table B1].

3.1 Wilson–Devinney analysis

The \(UBVRI_{\text{c}}\) light curves were analysed with a modified version of the Wilson & Devinney (hereinafter ‘WD’) code (Wilson 1979, 1994). The modifications add the option to model the stellar surface fluxes with Kurucz stellar atmosphere models (Kurucz 1993) in addition to the built-in blackbody and Carbon & Gingerich (1969) model approximations.

With the mass ratio \((q)\) set to unity, \(T_{\text{eff,primary}} = 4590\) K and with the orbital period fixed at 0.476 525 d, the semi-major axis was adjusted to obtain components of mass \(M = 0.69\) M\(_\odot\). The bolometric albedos and gravity darkening coefficients were set to appropriate values for convective envelopes (0.5 and 0.3, respectively) while limb-darkening coefficients were taken from tables created from Kurucz solar metallicity models (Kurucz 1993).

The parameters solved for were the orbital inclination, the effective temperature of the secondary component, the surface potentials of both components, the phase offset and the monochromatic luminosities of the primary component, and the third light contributions for each of the five \(UBVRI_{\text{c}}\) light curves. The five light curves were analysed simultaneously using the Method of Multiple Subsets (Wilson 1979, 1994) in order to circumvent the strong correlation between third light and the inclination. It was necessary to analyse all the available data together, despite the significant scatter from year to year caused, presumably, by spot activity on one or the other, or perhaps both, of the components of the binary system. No one year by itself had sufficient data obtained over a short enough period of time to make a meaningful analysis possible.

The preliminary analysis suggested that B\(_2\) is slightly cooler than B\(_1\). Therefore, based on the resultant colours for the A, B\(_1\) and
B$_2$ components, the individual spectral types of the three components were re-estimated to be K1/2V, K3/4V and K4/5V, respectively. (Reassuringly, these preliminary colours differ insignificantly from the colours derived from the finally adopted solution.) This suggests a mass ratio for the eclipsing system of $q = 0.966$ and an effective temperature for B$_1$ of $T_{\text{eff,primary}} = 4660$ K. With these new estimates the semi-major axis was re-adjusted to obtain the appropriate masses and then further iterations were performed. At this stage the adjusted parameters were also broken into a third subset containing the two surface potentials.

Several thousand iterations of adjusting each parameter subset in turn were performed. As a consequence of the low degree of correlation between the adjusted parameters in each subset, the iterations migrated only very slowly even as the overall weighted-sum of the squares of the residuals fell slowly but constantly. Throughout these iterations the suggested parameter corrections were typically comparable with, or somewhat smaller than, their standard errors, as reported by the WD code. The solution adopted as representative is that for which all the suggested parameter corrections became smaller than their respective standard errors by a factor of ten for six consecutive iterations. This solution has a very slightly cooler but larger secondary star, though by only ~2 per cent in $T$ and ~7 per cent in $R$. Table 4 lists the physical parameters of the adopted model, while Table 5 lists the corresponding photometry.

The achieved precision of the synthetic-light-curve fits to the observations, measured as the rms of the residuals between the observations and models, was only of the order of 3–5 per cent. This is due mainly to the inherent scatter from epoch to epoch, presumably caused by changing spot patterns on the surfaces of the active stars in the system. Also, owing to this scatter and assuming that one or other or both components of B is indeed the active system, the parameters reported here in some sense represent the ‘mean, equivalent non-active stars’. To deduce the true properties of the components of the eclipsing binary would require the modelling of light curves obtained over a short time period relative to the time-scale on which the pattern of activity changes. Furthermore, there remain large uncertainties in some of the derived properties of the binary system and its components; nevertheless, some useful insight has been gained.

Notwithstanding the relatively low precision of the curve fits, the effective temperature of the secondary component relative to the adopted effective temperature of the primary is well defined, with an uncertainty of just 0.4 per cent. This is due to the strong temperature dependence of relative flux with respect to wavelength over the near-ultraviolet/near-infrared regime at these cool stellar temperatures. Changing the effective temperature of the secondary by as little as 100 K (i.e. 2 per cent of its value) produces a markedly worse fit to the observed light curves, especially in $U$. For much the same reasons, the light contribution from star A, i.e. third light (neglecting star C), is also well defined with an uncertainty of not more than 5 per cent. The ratio of the radii (i.e. $R_2/R_1$) by contrast is not well defined, the uncertainty deriving chiefly from the large scatter at orbital phases corresponding to ingress into and egress from eclipses. However, $R_1$ and $R_2$ are anti-correlated so that the total stellar surface area is rather better defined with an uncertainty of ~6 per cent.

As mentioned above, visual photometry has been obtained by a number of workers. Table 6 tabulates that of Edwards (1976), Bessell (1990), Schrijver (1997, vols 5 and 12) and Cutispoto et al. (1995) as well as the results derived here based on the SAAO and MJUO photometry and light curve analysis. As can be seen, there is good agreement with respect to the photometry for the combined A+B system. There is also reasonable agreement between Edwards and the present project’s results for the $V$ mag of the individual components ($V_1$ and $V_2$). However, these are in quite significant disagreement with the Hipparcos measurements.

One might quite reasonably expect that the high-resolution space-based results of Hipparcos should be preferred over the poorer seeing ground-based results, which, at least in the case of the SAAO and MJUO observations, did not resolve the C component from the A + B system, let alone the individual A and B components.
B components themselves. However, a few simple calculations are enough to cast uncertainty over the accuracy of the *Hipparcos* measurements of $V_A$ and $V_B$. The $V$ light curve in Fig. 2 clearly indicates depths of approximately 0.22 and 0.18 mag for primary and secondary eclipses, respectively. The $Hp$ light curve measured by *Hipparcos* (Schrijver 1997, vol. 12) similarly shows two eclipses with depths of at least 0.18 mag, although phase coverage during minima is quite sparse. A beautiful $V$ light curve by Tagliaferri et al. (1999) shows two eclipses of more or less equal depths of 0.16 mag, although the primary eclipse is probably made a little shallower than usual by a brightening of the system that starts at an orbital phase of approximately 0.7 and quite possibly lasts throughout the primary minimum and through to an orbital phase of perhaps 0.1.

It is assumed that two eclipses of at least 0.16 mag in depth in $V$ or (more or less equivalently) in $Hp$ are required. In the case where an eclipsing binary has two minima of equal depth, the maximum depths possible occur when the two eclipses are total, i.e. two components with exactly equal surface flux densities and radii in an orbit seen precisely edge on (inclination equals 90°). If the *Hipparcos* $Hp$ mag for the system ($Hp_A + B = 7.2533 \pm 0.0024$) and the individual components ($Hp_A = 7.5111 \pm 0.058$ and $Hp_B = 8.941 \pm 0.217$) are adopted, and half the light of component B is apportioned to each of two components ($B_1$ and $B_2$) with exactly equal surface flux densities and radii (i.e. $Hp_B = 8.941 \pm 0.217$), then the total system brightness during a total eclipse is $Hp_A + B_{1+2} = 7.3745 \pm 0.0024$ mag. Comparing this with the total system brightness out of eclipse implies the maximum depth for two eclipses of equal depth is only 0.1212 \pm 0.0291 mag, which is inconsistent with the requirement that the depths be at least 0.16 mag.

If the condition of both eclipsing components having equal surface flux densities is relaxed, then one eclipse will become deeper while the other becomes shallower. If either (or both) the conditions of equal radii and a 90° inclination are relaxed, both eclipses become shallower. In the case of HD 9770 there do indeed appear to be slightly unequal surface flux densities for the two eclipsing components (since the eclipses are probably of different depths) and hence (assuming main sequence stars of the same age), the two components will almost certainly have unequal radii and, in that case, it is even more difficult to reconcile the *Hipparcos* individual magnitudes for components A and B with the light curves. Therefore, on the basis of the overwhelming evidence of the light curves (SAAO and MJUO, the *Hipparcos* one and that of Tagliaferri et al. 1999), it is concluded that the *Hipparcos* individual magnitudes for components A and B must be in error and that those derived from the light curve analysis as listed in Table 6 are to be preferred.

### 3.2 The A star of HD 9770

The published orbital parameters of the AB visual binary system (Hirshfeld & Sinnott 1985), combined with the *Hipparcos* parallax of 0.04229 arcsec, yield a total mass for the system of $M_{AB} = 3.18 \pm 0.36 M_\odot$. The total mass of an AB system consisting of stars of the masses given in Table 4, i.e. $M_1 \approx 0.71 M_\odot$ and $M_2 \approx 0.68 M_\odot$, and a K1 star somewhat evolved off the zero-age main sequence at $M \approx 0.76 M_\odot$, is only $\approx 2.4 M_\odot$.

In the absence of a large colour excess, any attempt to account for the missing mass by assuming a large interstellar extinction is rejected, and there are no supporting grounds for assuming large errors in the *Hipparcos* parallax or published orbital parameters that might account for it. Instead, it is suggested that the missing mass is to be found in star A; i.e. that it is also a binary system, but not eclipsing.

For consistency with the *Hipparcos* colour index and the Michigan Spectral Catalogue classification (Houk 1982), it is suggested that the A1 primary star is a K1 star on the main sequence, $V = 6.1$ and $M \approx 0.76 M_\odot$, while the A2 secondary is a K3/4 main sequence star of $V \approx 6.8$ and $M \approx 0.72 M_\odot$. The total mass of such a system would be $\approx 1.48 M_\odot$, giving a total mass of the AB double-binary system of $\approx 2.86 M_\odot$, which is within the range of masses consistent with the *Hipparcos* parallax and the published orbital parameters for the AB system.

### 4 HIGH-RESOLUTION SPECTROSCOPY

Spectra centred on the He z line were obtained from 1993 October to

<table>
<thead>
<tr>
<th>Magnitude or index</th>
<th>Edwards</th>
<th>Bessell</th>
<th>Schrijver</th>
<th>Cutispoto et al. (1997)</th>
<th>SAAO and MJUO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{A+B}$</td>
<td>7.09</td>
<td>7.11</td>
<td>7.11</td>
<td>7.240</td>
<td>7.11</td>
</tr>
<tr>
<td>$V_A$</td>
<td>7.72</td>
<td>7.37</td>
<td>7.37</td>
<td></td>
<td>7.64</td>
</tr>
<tr>
<td>$V_B$</td>
<td>7.99</td>
<td>8.80</td>
<td></td>
<td></td>
<td>8.20</td>
</tr>
<tr>
<td>$(B-V)_{A+B}$</td>
<td>0.92</td>
<td>0.909</td>
<td>0.92</td>
<td>0.93</td>
<td>0.58</td>
</tr>
<tr>
<td>$(V-R)_{A+B}$</td>
<td>0.545</td>
<td>0.54</td>
<td>0.54</td>
<td></td>
<td>0.55</td>
</tr>
<tr>
<td>$(R-I)_{A+B}$</td>
<td>0.525</td>
<td></td>
<td>0.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$(V-I)_{A+B}$</td>
<td>1.070</td>
<td>0.95</td>
<td>1.07</td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>
1996 August, and additional spectra in the region of the lithium Al6708 resonance doublet were obtained during 1994.

4.1 The metal-line spectrum

The high-resolution spectra contain mainly Fe i lines, which, as can be seen in the cases of the Al6569, 6574 and 6575 lines in Fig. 4, are weak. V i lines in the Al6200 region, and the few Ca i, Ni i and Ti i lines included in the spectra, are also weak. The same metal lines in comparison spectra of e Eri (HR 1084, K2 V, \(v\sin i < 17 \text{ km s}^{-1}\), Hoffleit & Jaschek 1982), obtained using the same instruments, typically have a core depth about 0.1 of the continuum flux greater than the lines of the HD 9770 system. The metal lines do not show any significant broadening. Measured FWHMs vary by \(\pm 0.075 \text{ Å}\) relative to the same lines in the spectrum of e Eri.

Only one metal-line spectrum appears to be present and this can be accounted for by the dominance of the light of the A1 type-K1 star, while the continuum flux from the eclipsing B stars, together with the smearing-out effect of rotational broadening on the lines in the spectra of the B stars is responsible for the weakness of the A1 star’s and the two B stars’ metal lines.

4.2 Radial velocities

The WD analysis did not directly yield information on the orbital velocities of the stars, but the amplitude of variation \(k\) may be calculated on the assumption of a circular orbit and using the data in Table 4:

\[
k = \frac{2\pi a \sin i}{P} = 37.6 \pm 0.1 \text{ km s}^{-1}.
\]

Radial velocities were computed on a line-by-line basis using unblended metal lines (in the Hα spectra, the Al6200, 6219, 6394 and 6569 Fe i lines and the Al6768 Ni i line) and applying the standard midas procedures for precession of coordinates and barycentric correction.

If the metal lines are those of the bright, non-eclipsing star A1, one would not expect to see high-frequency variations corresponding to the orbital motion of the eclipsing binary B stars, but rather the orbital period of the presumed A system superimposed on the 4.559-y period of the AB system and the 111.8-y period of the AB × C system.

The measured velocities, plotted in Fig. 5, do not show any short-period variation, and their total range is much smaller than the amplitude calculated above for the variations in the orbital velocity of the eclipsing B stars. By extrapolation from Dommanget & Nys (1982), a maximum in the relative radial velocities of the A and B systems should have been evident in early 1996 (~JD 245 0150). The measured velocities do show a maximum very approximately at that time, though few \(\text{échelle}\) spectra with good S/N were obtained and the scatter is large. Radial-velocity variation due to the orbital motion of the A system alone may have been lost in the noise, or may be small because of a small angle of inclination of the orbital plane of the system.

4.3 Hα line

The Hα absorption line (Fig. 4) shows a FWHM of 1.11 \(\pm 0.13 \text{ Å}\) which is suggestive of a K-type star, but the flux in the line centre is consistently 0.56 \(\pm 0.02 \) of the adjacent continuum, suggesting that the observed feature may be an Hα absorption line from the stars A that is considerably filled in by the continuous spectra from the stars B. The FWHM and core depth were unvarying within the limits specified over the whole of the observation period.

Photometry using wide- and narrow-band Hα filters similarly
shows Hα flux varying only by 0.04 mag over the whole of the observation period, with no periodicity and, in particular, no correlation with the orbital phase of the eclipsing system.

In order to remove the third light of the K-type star or stars A, which apparently dominated the spectra, a spectrum of ε Eri, scaled to match the core depth of the $\lambda 6569 \text{Fe} \text{I}$ line in the HD 9770 Hα spectra, was subtracted from the HD 9770 spectra. The results of this process for a selection of orbital phase values are shown in Fig. 6. All of the spectra were obtained during eclipses or else after primary and before secondary eclipse: no spectra were obtained after secondary and before primary eclipse. It is clear, however, that spectra obtained out of eclipse show an almost completely filled-in Hα line. In the spectra obtained from orbital phase 0.113 to orbital phase 0.440, as the primary star is approaching and the secondary star receding, the spectra exhibit a very weak absorption feature to the blue side of a barely-discernible broad emission feature, while the primary eclipse shows an apparently exactly filled-in line, and the secondary eclipse possibly shows weak absorption masked by a telluric line. Given the motions of the two stars, it appears that the primary is responsible for the absorption feature and the secondary for the emission feature. We conclude that both of the eclipsing stars are active, the B1 primary with chromospheric emission in Hα almost strong enough completely to fill in its own Hα absorption, while the B2 secondary is more active, with chromospheric emission in Hα sufficiently strong to show a small net emission in its own spectrum and completely to fill in the combination of its own absorption and the weakened absorption of the B1 primary during primary eclipse.

4.4 Rotational broadening

If, as is expected having regard to their putative age, the two eclipsing stars are rotating synchronously with their orbital motion, and they have the radii confirmed by the Wilson–Devinney analysis, they should exhibit a rotational $v \sin i$ of $\sim 75 \text{ km s}^{-1}$. The consequent large rotational broadening, of the order of 3 Å, combined with noise in the spectra, has almost completely smeared out the metal lines in the spectra of the active stars, though some traces of the $\lambda 6573 \text{Ca} \text{I}$ line and/or $\lambda 6575 \text{Fe} \text{I}$ line may be seen when not masked by telluric absorption.

5 CONCLUSION

The light curve in $V$ shows that one of the components of the AB visual binary system in HD 9770 is an eclipsing binary system with an orbital period of $0.476525 \pm 0.000013 \text{ d}$. The colour index changes during eclipses imply that the B component of HD 9770 is the eclipsing system.

From the light curve analysis, there is a well-defined difference of $105 \pm 20 \text{ K}$ between the effective temperatures of the two eclipsing stars. While their relative radii are not defined with high precision, the total surface area of the two eclipsing stars is better determined and, with colour photometry, is consistent with the system consisting of a pair of K3 to K5 dwarfs. Échelle spectra of the Hα line indicate that both stars of the eclipsing binary system are active, the secondary being more strongly active, at least in Hα, than the primary. The light curve in $V$ shows short-period variability characteristic of fast-rotating spotted stars, and we conclude that the eclipsing binary system is a BY Dra-type system consisting of two K-type dwarfs and having the shortest orbital period of any known system of that type. The inclination of the system obtained from the light curve analysis is $i = 86 \pm 4^\circ$.

On the basis of the measured magnitudes and colour index, the published orbital parameters and the Hipparcos parallax, it is concluded that the A component of HD 9770 is probably also a binary system, consisting of K1 and K3 V stars, possibly with a small angle of inclination. The whole HD 9770 system thus comprises five stars, two of them in the active BY Dra system B, two in the non-active system A, and the (presumed) single star C of type M2 V.

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