Composite spectra
Paper 7: HD 190361

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ABSTRACT
HD 190361 is a composite-spectrum binary system in an orbit with a low eccentricity and a period of about 4 yr. We separate the spectra of the component stars and show them to be of types very similar to those in 31 Cyg, i.e. near K4 Ib and B4 IV–V. The relatively small velocity amplitude, together with the rapid rotation and early spectral type of the hotter star, conspire to make the measurement of the radial velocity of the latter somewhat imprecise, but we derive a mass ratio of about 1.8 and deduce that the system is viewed at an inclination of about 36°.

Key words: binaries: spectroscopic – stars: individual: HD 190361.

1 INTRODUCTION
HD 190361 is a seventh-magnitude star in the north-eastern part of the constellation Sagitta. In the Henry Draper Catalogue (Cannon & Pickering 1923) it is attributed a photovisual magnitude of 7.43 and a spectral type of KO. Two slit spectra were taken by Redman (1931) in the course of an investigation of the radial velocities of seventh-magnitude late-type stars near the Galactic equator. Redman commented that the star appeared to be “of early F or even A type, but abnormally red for so early a spectrum”, but it was Stephenson & Nassau (1961) who recognized and first recorded its composite nature, including it in a list of composite-spectrum systems detected on objective-prism plates taken with the Hamburg 80-cm Schmidt and assigning it the spectral types G5 + B6. As far as we are aware there have not been any other published efforts to classify the component spectra. We have not found any published photoelectric magnitudes for the system, although the Hipparcos Input Catalogue (Turon et al. 1992) has an entry for HD 190361 as no. 98791 and lists a V magnitude, from an unidentified source, of 7.000 with a standard error of 0.030.

That HD 190361 is a spectroscopic binary was first demonstrated by Griffin (1970) on the basis of repeated radial-velocity measurements, and the system has been kept on the Cambridge radial-velocity programme ever since. It was noted some time ago (Griffin 1984) to be the last of the nine spectroscopic binaries discovered in the ‘Redman K-star’ programme (Griffin 1970) whose orbit remained to be discussed; preliminary elements have since been given (Griffin 1990) but without any supporting data or discussion. The late-type spectrum must be dominant throughout the blue spectral region because no difficulty was encountered in measuring the radial velocity of the system with a photoelectric spectrometer; the trace obtained is such as would be expected from a star of approximately the assigned HD type of K0.

In this paper we report a spectroscopic investigation of the system, giving an objective classification for the components after separating their spectra by digital subtraction, and attempting to determine the mass ratio and the luminosity difference of the component stars. We commence by determining the orbit from a large number of radial-velocity measurements.

2 RADIAL VELOCITY ORBIT
2.1 Data acquisition
We present in Table 1 the 140 photoelectric radial velocities that have been measured for the star since 1966; most were obtained at Cambridge, but other spectrometers have been used when opportunities have arisen, particularly in recent years. As far as the spectrometer measurements are concerned, the system is single-lined; the mask in the spectrometer correlates only with the spectrum of the late-type component, that of the hot component merely diluting the light and causing the ‘dip’ to be shallower than it would be if the cool star were observable in isolation. We have added to Table 1 the two radial velocities measured by Redman (1931); their dates have not previously been published.

2.2 Orbit solution
Since systematic radial-velocity observations began some 25 years ago, about six orbital cycles have been completed; as the period is about four years and two months, seasonal variations in observing frequency have tended to even out around the orbit. The seasonal gaps are in any case not very long, as the star is well to the north of the ecliptic: Table 1 includes observations in every calendar month except February. Cambridge observations prove to have about twice the rms residuals given by the other spectrometers, so they have...
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<td>1.449</td>
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Sources: R = Redman (1931) photography, not used in orbital solution; all other velocities measured photoelectrically, as follows.

Cambridge (Griffin 1967); P = Palomar (Griffin 1974); V = Victoria (Fletcher et al. 1982); E = Haute-Provence (Coravel)
been attributed weight 1/4. The single measurement made with the ESO Coravel gives a residual much larger than those of the 19 Haute-Provence Coravel measures and has been rejected. The orbital solution is illustrated in Fig. 1, and the elements are as follows:

\[ P = 1513.0 \pm 1.2 \text{ d} \]
\[ T = \text{MJD} 45000 \pm 28 \]
\[ \gamma = -6.18 \pm 0.06 \text{ km s}^{-1} \]
\[ a_1 \sin i = 202.2 \pm 1.8 \text{ Gm} \]
\[ K = 9.65 \pm 0.08 \text{ km s}^{-1} \]
\[ f(m) = 0.140 \pm 0.004 M_\odot \]
\[ e = 0.071 \pm 0.011 \]
\[ \omega = 337^\circ \pm 7^\circ \]
\[ \text{rms residual (weight 1)} = 0.43 \text{ km s}^{-1}. \]

3 SPECTROSCOPY

3.1 Observations

In order to make a preliminary assessment of the character of HD 190361, a spectrogram of modest dispersion (20 Å mm\(^{-1}\)) was taken on 1981 November 20 UT with the coude spectrograph of the Mount Wilson 100-inch reflector. The observation showed that the components have extremely different colours, the spectrum in the violet changing in appearance very suddenly from a B type to a very late type within a short span of wavelength. A late-type component that is luminous enough to overwhelm thus the light of a B star is necessarily a supergiant.

Bright composite systems containing a cool supergiant primary and a B-type secondary are not very common, and most of those investigated in detail so far are found to display some evidence of the chromosphere of the supergiant, or its wind, or both. The few systems that happen also to show eclipses (\(\xi\) Aur, 31 and 32 Cyg) are well-known examples and exhibit spectacular spectral changes during the so-called ‘chromospheric eclipse’ phases, when phase-dependent absorption features are superimposed on the composite spectrum. Those chromospheric features are unique providers of valuable information about the density, temperature, scaleheight and local velocities of the material at different heights in the chromosphere. Many of the other systems on this composite-spectrum programme have been observed photometrically around their respective dates of conjunction in the hope that they will show eclipses, and, although photometric observers had already reported (private communication) that there was no visible evidence of any geometrical eclipse at the relevant epochs in HD 190361, our interest was nevertheless focused on it because of its strong similarity, both in the spectral types of the components and also in regard to its mass function, to \(\delta\) Sge (M2 II + B9). \(\delta\) Sge had for a long time been suspected (Hynek 1942) to be a system of the \(\xi\) Aur type, showing chromospheric and possibly bodily eclipses, and was still thought so to be at the time of our spectroscopic investigations; there was a possibility that HD 190361 might show some evidence of chromospheric eclipse. However, it has since been shown (Tokovinin 1986; Baize 1988; Griffin 1991) that \(\delta\) Sge has an inclination to the line of sight of only about 40°, and that the phase-dependent changes which appear in the Ca K line are most probably due to the wind of the supergiant and to the interaction of the secondary with it (Thiering 1993; Eaton et al. 1995). Even in the light of current perceptions of \(\delta\) Sge, there remains the chance that HD 190361 might manifest evidence of at least a circumbinary wind.

In the summer of 1982, when the HD 190361 system was close to a node and the radial-velocity difference between its components would have been maximal, two 10 Å mm\(^{-1}\) spectrograms were obtained on consecutive nights (August 22 and 23 UT) with the 100-inch telescope. In 1989 an opportunity arose to make a further observation at a date (September 16 UT) close to a conjunction at which the primary star would be nearer to the observer than the B-type component, thus offering a check on the possibility of at least chromospheric eclipses. This last spectrogram, generally similar to the 1982 ones, was taken with the Calar Alto 2.2-m telescope and coude spectrograph at a reciprocal dispersion of 9 Å mm\(^{-1}\). According to the above orbital elements the exposure was made about 9 d after the exact time of conjunction, but in relation to the probable dimensions of the supergiant primary and the likely extent of its chromosphere, as judged from studies of stars such as \(\xi\) Aur (Schröder, Griffin & Griffin 1990), that would have been quite close enough to conjunction for chromospheric absorptions to be apparent if the orbital inclination were anywhere near 90°.

The conjunction spectrogram does in fact show a strong, sharp K line, but it is very similar in character to the sharp feature also seen in regard to its mass function, to \(\delta\) Sge (M2 II + B9). \(\delta\) Sge had for a long time been suspected (Hynek 1942) to be a system of the \(\xi\) Aur type, showing chromospheric and possibly bodily eclipses, and was still thought so to be at the time of our spectroscopic investigations; there was a possibility that HD 190361 might show some evidence of chromospheric eclipse. However, it has since been shown (Tokovinin 1986; Baize 1988; Griffin 1991) that \(\delta\) Sge has an inclination to the line of sight of only about 40°, and that the phase-dependent changes which appear in the Ca K line are most probably due to the wind of the supergiant and to the interaction of the secondary with it (Thiering 1993; Eaton et al. 1995). Even in the light of current perceptions of \(\delta\) Sge, there remains the chance that HD 190361 might manifest evidence of at least a circumbinary wind.

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![Figure 1. The observed radial velocities of HD 190361 plotted as a function of orbital phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Cambridge observations, which are in the majority but are less accurate than the others, are represented by filled circles; data from other sources are shown as filled squares, apart from one rejected point which is identified by the open circle. Arrows near the top of the diagram indicate the phases at which were taken the photographic spectrograms upon which the discussion in this paper is based.](https://academic.oup.com/mnras/article-abstract/285/3/472/1446032)
Figure 2. Prints of small parts of photographic spectrograms of HD 190361 and (for comparison purposes) the late-type supergiant star ξ Cygni. Panels (a,a) show the spectrum of the iron arc. The two strips of panel (b) come from separate spectrograms of HD 190361 taken on consecutive nights in 1982 August. The three strips in panel (c) are three prints all from the same spectrogram of HD 190361, obtained near conjunction in 1989 September; the replication is intended to facilitate comparison of that spectrogram with the others. Panel (d) shows ξ Cyg, which seems to be a good match for the late-type component of HD 190361. The spectra reproduced in (a) and (b) were taken at a reciprocal dispersion of 10 Å mm$^{-1}$ with the coudé spectograph of the Mount Wilson 100-inch reflector; those in (c) and (d) come from the analogous instrument, which gives 9 Å mm$^{-1}$, at the Calar Alto 2.2-m telescope. The sharp absorption lines in the spectra of HD 190361 at H and K are almost certainly interstellar. Photometric reduction (Fig. 3) shows that their profiles are similar at the two epochs, and their heliocentric wavelengths did not change between the epochs, unlike those of the stellar lines which change with orbital phase; in the montage above we have aligned the stellar spectra, so it is the interstellar lines that appear to have shifted.
in the spectra taken far from conjunction in 1982 [Fig. 2 (opposite p. 474) and Fig. 3] and is not due to chromospheric absorption. The spectral type of the secondary is too early to contribute any appreciable amount of Ca II, and the entire feature must be interstellar. Table 2 compares the measured velocities of the feature on the two different occasions with the orbital velocities of the component stars. It demonstrates that, within the errors of measurement, the sharp feature is stationary to within the accuracy of the measurements, it does not therefore arise in the spectra of either component. It is not surprising to see substantial interstellar absorption in HD 190361: its Galactic latitude is about $-6^\circ$, and the apparent distance modulus is probably somewhat more than 10 mag, suggesting an actual distance of the order of 1 kpc.

3.2 Isolation of the spectra

The component spectra of HD 190361 were separated by the technique of digital subtraction developed by Griffin (1986). The method involves the careful subtraction of the primary spectrum from the composite one through the use of a surrogate primary; the residue is the spectrum of the secondary component. Since neither the spectral type nor the luminosity of the primary is known beforehand, a comprehensive library of standard spectra is necessary to provide an adequate selection for trial subtractions. Subtractions must be essayed in regions of the spectrum that contain both temperature-sensitive and luminosity-sensitive features, and usually involve spans of some hundreds of angstroms. Because the subtraction procedure lowers the signal but (quadratically) sums the noise, it is important that the standard spectrum, at least, has a high signal-to-noise ratio. In addition, the results can be adversely affected by unavoidable differences between spectrographs, so it is preferable that both the composite spectrum and its late-type surrogate be observed with the same equipment.

Test subtractions on the spectra of HD 190361 showed that the spectrum of the primary matches very closely that of the supergiant standard 31 Cyg, whose spectral type is K4 IV–V (Keenan & McNeil 1989). The spectra of HD 190361 had been acquired with both the Mount Wilson and Calar Alto spectrographs, and spectrograms of 31 Cyg were also obtained with both instruments. Fig. 3 illustrates how the subtraction process success fully uncovers the spectrum of the hotter component, while Fig. 4 illustrates the whole of the spectrum derived in this way. The only significant difference that can be discerned between the 1982 and 1989 spectra is in the position of the sharp interstellar feature, whose displacement is entirely explained by the change in radial velocity of the primary relative to the site of the interstellar absorption. No evidence of wind interaction, nor any change of purely stellar or circumstellar origin, was seen.

Table 2. Comparison between measured velocities of the sharp Ca II K feature and the radial velocities of the component stars (velocities in km s$^{-1}$).

<table>
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<tr>
<th>Date of Observation</th>
<th>Observed velocity of sharp feature relative to giant</th>
<th>Giant Radial Velocity</th>
<th>Feature Radial Velocity</th>
<th>Dwarf Radial Velocity</th>
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</thead>
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<tr>
<td>1982 Aug. 23</td>
<td>$-4.9 \pm 0.8$</td>
<td>$+2.6$</td>
<td>$-2.3$</td>
<td>$-22.0$</td>
</tr>
<tr>
<td>1989 Sept. 16</td>
<td>$+3.5 \pm 0.8$</td>
<td>$-5.1$</td>
<td>$-1.6$</td>
<td>$-8.2$</td>
</tr>
<tr>
<td>Change in velocity</td>
<td></td>
<td>$-7.7$</td>
<td>$+0.7$</td>
<td>$+13.8$</td>
</tr>
</tbody>
</table>

The sharp feature is stationary with respect to the measurements, and does not appear to originate in the spectrum of either star.

4 PHYSICAL PROPERTIES OF THE COMPONENT STARS

4.1 Spectral types

The giant component (HD 190361 A) is very similar in spectral type to that of 31 Cyg but also to the primaries in P Cyg and 31 Cyg. The primary of P Aur has been variously classified as near K4 IV–II (Wellmamn 1951; Bahng 1958; Burnashev 1983) or K2 II (Hünsch & Reimers 1993), and that of 31 Cyg as K3 or K4 I (McKellar & Petrie 1958), K3.5 Ib (Herczeg & Schmidt 1963) or K4 I (Wright 1970).

The spectrum of the dwarf component (HD 190361 B), on the other hand, is definitely earlier in type than the secondary of P Aur, and looks to be very similar both in line strength and in line shape to that of 31 Cyg B (Fig. 3); in Wright's (1970) review of the literature the spectral type of 31 Cyg B is quoted as B4 IV–V. It could not satisfactorily be drawn with the spectra of HD 190361 B and 31 Cyg B superimposed, as the noise levels in the two spectra are too similar (see Fig. 3). The comparison spectrum drawn is a low-noise hybrid B4 V that was generated by averaging 51 Cyg (B2 V) and π Cet (B7 V) — the only examples of suitable B-type spectra presently available to this programme. The spectrum of π Cet was first blurred by 50 km s$^{-1}$ to match that of 51 Cyg, then combined with it in the ratio of 2:3, and the resulting spectrum was further blurred in order to approximate a rotational velocity of 130 km s$^{-1}$. The match is not as close as with 31 Cyg B; it is tolerable for the Balmer lines but is less good for the He I lines at λλ 4026 and 4471 Å, seeming to display greater rotational broadening for the He I lines than for the H I lines. However, without having a greater selection of standard spectra one cannot identify the source of any peculiarities.

There is little apparent Ca II K-line emission from HD 190361 A because that region of the composite spectrum is heavily dominated by the spectrum of the secondary (Fig. 3, panel b). The actual level of activity is likely to be very similar to that in 31 Cyg since there does not seem to be any residual signature at that wavelength in the spectrum of the secondary, except for what may be obscured by the interstellar feature.

4.2 Mass ratio of the system

The mass ratio of the components in a binary system is just the inverse of their orbital velocity ratio; it can in principle be determined at almost any phase, although clearly it is best measured at a node when the component stars are at maximum separation in radial velocity. The wavelength scales of the secondary spectra as uncovered here from the composite ones are in the rest frame of the primary, and, since the velocity of the primary relative to the γ-velocity of the system is known from the radial-velocity orbit, the mass ratio of the system can be determined from our spectra.

Attempts were made to measure the radial velocity of the secondary by cross-correlating its spectrum with the B4 V spectrum illustrated in Fig. 4. The secondary's velocity is difficult to measure because its spectrum has few features, none of which can yield a precise measurement of the radial-velocity displacement between it and the primary, and moreover the velocity amplitude of the system is small. In the 1982 spectrum (phase .134, near to maximum separation) taken at Mount Wilson the only usable lines are the Balmer lines λλ 3889, 4010 and 4340 Å; a 3970 Å is contaminated with interstellar Ca II H. The derived mass ratio $q$ had the value of 1.8 ± 0.2, although that error is only the internal precision of the derivation and the actual error is expected to be considerably larger.
Figure 3. Separation of the component spectra of HD 190361. An appropriate fraction of the spectrum of the surrogate primary ξ Cyg (panel a) has been subtracted from the raw composite spectrum taken at Mount Wilson (panel b), uncovering the spectrum of the secondary (HD 190361 B) (panel c). The two lowest panels contain comparisons for the secondary: a hybrid B4 V in panel (d), and 31 Cyg B in panel (e). The Mount Wilson spectrum had to be given a long exposure because of thick cirrus cloud and bears obvious, though unimportant, contamination by Hg I emission at λ4047 Å reflected from lights in the Los Angeles conurbation.
Figure 4. 1000 Å of the uncovered spectrum of HD 190361 B. The smoother spectrum is that of an artificial standard B4 dwarf; it was created by averaging, in the ratio 2:3, suitably prepared spectra of 51 Cyg (B2 V) and π Cet (B7 V).
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We are very grateful to Mount Wilson Observatory, where at the
Heidelberg, for observing time at the Calar Alto 2.2-m telescope.

ACKNOWLEDGMENTS

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it gives the difference in luminosity between the standards whose

such ratios with those determined from Willstrop's (1965) normal­
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check of the spectral types of the components, but more importantly

given the difference in luminosity between the standards whose

combined fluxes best model the observed ones. In practice a number
of tolerable but not excellent models combining standards of late K
and early B types was found, all with the secondary about 3.7 times,
or 1.4 mag, fainter than the primary at \( \lambda 5500 \) \( \AA \). According to
Schmidt-Kaler (1982) a dwarf of spectral type B4 has \( M_V \approx -1.4 \),
so the luminosity of the giant is around \( M_V = -2.8 \), characteristic
(according to the same source) of a mid-K supergiant in the
luminosity class Ib–II. The combined \( M_V \) of such a system would be
-3.1, giving an apparent distance modulus a little over 10 mag. It
is therefore not surprising that, at such a distance and near to the
Galactic plane, substantial interstellar Ca ii absorption is seen in the
spectrum (Fig. 3).

In the absence of even the most basic photometry, it is unfortu­
nately not possible to determine the amount of interstellar redden­
ding present and to offer an accurate photometric model for the
system. In general terms we expect the system to look like a
considerably reddened analogue of 31 Cyg.

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