Composite spectra
Paper 11: $\alpha$ Equulei, an astrometric binary with an Am secondary

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ABSTRACT

The spectrum of the secondary component of the bright composite-binary system $\alpha$ Equ, whose visual orbit is already known accurately, is isolated by the method of spectrum subtraction and classified accurately for the first time. The primary is a normal giant of type $\sim$G7, while the secondary is an Am star of type $\sim$kA3hA4mA9. The system’s mass ratio, $q$, is determined to be $1.15 \pm 0.03$ from measurements of the relative radial-velocity displacements between the components. Random and systematic errors in $q$ are evaluated on the basis of the scatter of results derived from sets of spectra obtained from three different sources, and from tests conducted on independent versions of the secondary’s spectrum. A spectroscopic analysis of a composite system such as $\alpha$ Equ is strongly challenged by the blending of a great many lines that are common to both spectra. Even when the primary spectrum is thought to have been subtracted adequately, a seemingly unavoidable ghost spectrum of faint residuals can bias wavelength measurements of the secondary’s lines. That blending was the principal cause of a history of puzzling and discrepant measurements of $q$ in $\alpha$ Equ. The derived masses of $M_1 = 2.3 M_\odot$, $M_2 = 2.0 M_\odot$ for the giant and dwarf, respectively, constrain the choice of models for fitting evolutionary tracks in the $(\log T_{\text{eff}}, \log L)$ plane; the stellar points fit a single isochrone (for 0.74 Gyr). Both components are found to be slightly over-luminous compared to normal for their supposed luminosity classes. The giant appears to be commencing its first ascent of the red-giant branch. The dwarf has started to evolve away from the main sequence; its $M_V$ is similar to that of a sub-giant.

Key words: binaries: spectroscopic – stars: chemically peculiar – stars: individual: $\alpha$ Equ.

1 INTRODUCTION

The composite nature of the 3.9-mag star $\alpha$ Equ (HR 8131; HD 202447/8) was first reported over 100 years ago (Maury & Pickering 1897), and resulted in its being assigned two separate entries in the HD Catalogue (Cannon & Pickering 1924): 202447 (F8) and 202448 (A3). It was soon recognized as a spectroscopic binary from evidence of radial-velocity (RV) variations (Campbell 1902a,b,c). Interest in the astrophysics of the $\alpha$ Equ system was awakened by the suggestion (Deutsch 1954) that the component stars could have undergone, or be undergoing, extensive mass transfer, even though their separation seemed to be too large for that to be feasible. An examination of new observations of the composite spectrum (Stickland 1976) shed some doubt on that suggestion but did not exclude the possibility that the secondary

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(an A-type dwarf) was more massive than its cooler primary, which appeared to be a G-type giant. However, re-measurement of some of the same observational material and analysis by a different technique (Pike 1978) resulted in a mass ratio $q$ (giant/dwarf) of 1.25, thereby appearing to rule out any mass transfer.

Interest in $\alpha$ Equ has once more been revived, through an accurate RV study of both components (Rosvick & Scarfe 1991) that was closely succeeded by the publication of an interferometric orbit and detailed analysis of the system (Armstrong et al. 1992). The interferometric investigation derived an ‘orbital’ parallax for the binary of $0.01808 \pm 0.00076$ arcsec, i.e. a distance of $55.3 \pm 2.3$ pc, and a set of parameters for the component stars from which their evolutionary status was deduced. However, Armstrong et al. could not determine an unambiguous photometric model for the system, and concluded that ‘With the current state of knowledge for $\alpha$ Equulei, the greatest need is for further spectroscopic observations, with the goal of improving the precision of the velocity curves and of measuring the metallicity.
of the system ...’. Those are in fact the goals of our own investigation; this paper undertakes a careful assessment of the RV orbit, provides accurate information about the spectral types of both component stars for the first time, and reports new measurements of the value of the mass ratio, \( q \).

Since the analysis by Armstrong et al. (1992), \( \textit{Hipparcos} \) (ESA 1997) has measured the parallax of \( \alpha \) Equ as 0.017 ± 0.0008 arcsec, corresponding to a distance of 57 ± 3 pc. That value agrees with the conclusion of Armstrong et al. to within both error bars. The mean parallax of 0.01780 ± 0.00058 arcsec corresponds to a distance modulus of 3.75 ± 0.07 mag, and since the apparent V magnitude of the system is 3.92 (Hoffleit 1982)\(^1\) the absolute magnitude is \( M_V = 0.17 ± 0.07 \) if (as is very probable at such a small distance) there is no appreciable interstellar absorption. \( \textit{Hipparcos} \) has also measured the \( (B-V) \) of \( \alpha \) Equ as 0.549 ± 0.003.

Estimates of the spectral types of the components of \( \alpha \) Equ have tended to err on the side of the combined type, as is very common in this type of work. Bahng (1958), for instance, synthesizing the combined photometry, classified the types as G0 III + A5 V; Kuhl (1963) gave G0 II for the giant, and Markowitz (1969) proposed G2 II–III + A4 V; the Bright Star Catalogue (Hoffleit 1982) still gives the HD types of F8 + A3. From their spectral subtraction over a limited spectral range, Rosvick & Scarfe (1991) concluded that the spectrum of the primary matched that of \( \beta \) Boo (G8 III) better than that of 24 UMa (G2 IV). Armstrong et al. (1992) built on that information, generating a photometric model that incorporated an interferometric measurement of \( \Delta m \), but proposed types of G5 III + A5 V. However, more recent classifications of the primary from infrared spectra give G8 III (Ginestet et al. 1997) or G8 III (Ginestet, Carquillat & Jaschek 1999), and should be relatively reliable for that component since the influence of the secondary spectrum is greatly reduced at those wavelengths. No information is available from any source concerning the spectral type of the secondary on its own.

As part of an on-going project (Griffin 1986a) to derive accurate spectral types and mass ratios for the component stars of composite-spectrum binaries – e.g. Griffin & Griffin 2000a,b (Papers 9 and 10, respectively) – high-quality spectra of \( \alpha \) Equ at 10 Å mm\(^{-1}\) were observed at Mount Wilson several years ago. An opportunity arose more recently to complement those data with two other sets at higher resolution. The study of the physical properties of the component stars in \( \alpha \) Equ reported in this paper is based upon all three sets of spectroscopic observations.

2 RADIAL-VELOCITY ORBIT

The RV of \( \alpha \) Equ was measured first at Lick Observatory at the end of the 19th century, and was soon found to vary; the fact was announced in three similar notes in the \textit{ApJ}, \textit{PASP} and Lick Observatory Bulletins (Campbell 1902a,b,c). The results of the great Lick survey of virtually all stars brighter than \( V = 5.5 \) included 10 measurements of \( \alpha \) Equ, spanning a range of about 25 km s\(^{-1}\). Three velocities were published from the Cape Observatory (Lunt 1919), six from Yerkes by Frost, Barrett & Struve (1929) and two from Victoria (Harper 1934), but real interest in the star seemed to languish until Deutsch (1954) commented on the appearance (later realized to be merely subjective) of interaction between the spectra of the two components. Deutsch derived a preliminary orbit on the basis of only six velocities measured from coude spectrograms obtained at the Palomar 200-inch telescope. By further application of the same procedure as he used to derive the approximate period (he obtained \( P = 97.56 \) d, rather more than a day too short) from the coude velocities, he would have been able to obtain a value accurate to about half an hour if he had made use of the velocities already in the literature.

Beardseley (1969) belatedly published for \( \alpha \) Equ no fewer than 48 velocities, all obtained on different nights in 1911 July–December with the 31-inch Keeler Memorial Telescope at Allegheny, and measured more or less contemporaneously by Z. Daniel. The star was evidently observed on most, if not all, possible nights in that season, and it might appear in retrospect that the ensemble of velocities ought to have been ideal for establishing the orbit, densely covering as it did nearly two cycles of the velocity variation. Beardseley noted that the measures did not support Deutsch’s (1954) period, and thought that the period might be longer, possibly twice the length. In point of fact the Allegheny velocities show almost no variation at all apart from their substantial random scatter.

Unfortunately it now seems likely that not only those measurements, but all of the early ones, were compromised by blending: although the components’ spectra are of considerably different types, many of the same lines are present in both of them, and without the most careful selection of features for measurement the results obtained tend to follow the velocity curve of the cooler star but with more or less muted amplitude. None of the measurements made before those of Deutsch (1954) is even attributed clearly to one component or the other but to the system as a whole; no cognizance seemed to be taken of the fact, known since the 19th century (Maury & Pickering 1897), that there are two stars present, or of the obvious corollary that if their velocities vary then they must do so in anti-phase to one another. In fact the Allegheny measures, and those of Frost et al. (1929), show if anything a slight tendency to follow the sign of the A star’s changes; it may be remarked that both sets of measures appear in papers dealing with A-type stars, so the choice of lines for measurement could be expected to have followed suit.

Even when the measurer is fully alerted to the problem, it remains a very troublesome one, as we have found to our own cost. Its severity is well illustrated by the result of Deutsch’s effort to measure velocities for the A-type star as well as for the G-type component: so severely were his measures affected by blending that the velocity curve that he obtained for the hotter star was barely inverted with respect to that of the cooler one – it had only a quarter of the amplitude, the mass ratio \( q \) (giant/dwarf) being found to be 0.26, with an apparent uncertainty (not quantified by the author) of the same order.

A resolute effort was made by Stickland (1976) to obtain a more realistic velocity amplitude for the A-type component. He measured visually, with a projection device on an otherwise conventional travelling microscope, 46 plates taken with the 30-inch coude reflector at Herstmonceux, mostly at a reciprocal dispersion of 10 Å mm\(^{-1}\), together with 13 high-dispersion plates (including four of those discussed by Deutsch) borrowed from the plate files of the Hale Observatories. He was careful to select, for measurement as G-type lines, ones that had minimal contribution from corresponding features in the A-type spectrum. Unfortunately the reverse mode of selection proved impossible: “Almost all of the lines appearing in A-type spectra and that can usefully be

\(^1\)The V magnitude of 3.92, which we adopt from the Bright Star Catalogue, is averaged from a considerable number of independent measurements found in the literature.
employed for radial velocity determination, also appear in G-type spectra and with generally greater strength, ... and the burden finally fell on Mg II 4481.24 alone. In spite of the fact that the G star certainly makes some contribution at this wavelength, the results were quite encouraging and a velocity curve emerged with an amplitude comparable to that of the G star.' So the whole determination of the A-star’s amplitude fell on a single line that was admitted to be blended but less so than any others that were available. Stickland found $K_1 = 15.67 \pm 0.40 \text{ km s}^{-1}$, $K_2 = 12.49 \pm 0.77 \text{ km s}^{-1}$, and his final result was $q = 0.80 \pm 0.05$. (Subsections 1 and 2 refer to the primary and secondary, respectively.)

Pike (1978) re-measured about two-thirds of Stickland’s Herstmonceux plates, using microdensitometer tracings. He measured the velocity of the cooler star by cross-correlation of a small region chosen to avoid blending with A-star lines as much as possible. When the first region that he tried gave a $K_1$ of only 12.0 km s$^{-1}$, he tried another and obtained $K_1 = 15.63 \pm 0.44 \text{ km s}^{-1}$. He based his velocities of the A-type star solely on the K-line core, and obtained $K_2 = 19.66 \pm 0.84 \text{ km s}^{-1}$, yielding $q = 1.26 \pm 0.06$. The subjectivity and caprice of the amplitudes of the velocity changes of both stars, according to the choice of the measurer and to the method of measurement, even on the same plates, are eloquent testimony to the difficulties presented by $\alpha$ Equ.

Two RV measurements of $\alpha$ Equ, made with a reticon spectrometer at the McDonald 2.1-m coudé, were published by Parsons (1983), and five made with the Fick spectrometer were listed by Beavers & Eitter (1986). In both cases they were made in the course of programmes of a survey character and not on account of any special interest in $\alpha$ Equ; they may be expected to represent largely the velocity of the G-type component.

The most recent effort to obtain RVs for $\alpha$ Equ was made by Rosvick & Scarfe (1991), who measured 38 high-dispersion (2.4 Å mm$^{-1}$) photographic spectrograms exposed in the blue and near-ultraviolet at the coudé focus of the 48-inch reflector of the Dominion Astrophysical Observatory, Victoria (DAO). The lines of the G-type star were measured from the blue region of the plates by eye, with an oscilloscopic device that superimposed ‘forward’ and ‘reverse’ tracings of individual spectral lines of the star or the comparison spectrum, so the operator would have been able to reject lines that appeared asymmetrical. The RV amplitude $K_1 = 16.232 \pm 0.065 \text{ km s}^{-1}$ that was derived should therefore be the most accurate to date, and we have adopted it here, after a small modification (see below). Rosvick & Scarfe measured the velocities of the A star with a completely different technique based on microphotometer tracings of the ultraviolet region. The spectrum of a late-type standard star, $\beta$ Boo (G8 III), which was intended to be analogous to the $\alpha$ Equ G star, was subtracted from the composite spectrum, and the resulting difference spectrum was cross-correlated with that of a sharp-lined A star, 68 Tau, to obtain the relative radial velocity. A systematic difference which was manifest in the velocity zero-points of the two components was removed by adding 1.2 km s$^{-1}$ to all the measured A-star velocities. Presumably owing to differences in photographic density levels, not all of the plates were measured for both components. The standard error of the 35 individual measurements of the G star was 0.27 km s$^{-1}$, while that of the 26 A-star velocities was 2.39 km s$^{-1}$.

2.1 New radial velocities

We have attempted to measure the velocities of both components of the $\alpha$ Equ system with RV spectrometers. It will be recalled that one of the advantages of that method, at least in normal circumstances, is that the whole spectrum of a star is effectively collapsed into a single line profile. Where there are two or more stars present in an apparently unresolved image on the entrance slit of the spectrometer, each of the spectra is of such a type as to cross-correlate in a significant fashion with the mask within the instrument appears as one ‘dip’ in the observed trace. Any blending between components is immediately apparent, and can be accurately disentangled when the dips are, or ever become, sufficiently well separated for the exact profiles of the individual components to be determined. That property and advantage of the spectrometer method has been well illustrated in its application to Capella (Griffin 1986b), a binary system that is not without points of similarity to $\alpha$ Equ.

Unfortunately the method does not work so well in the case of $\alpha$ Equ, the radial velocities of whose components are never sufficiently separated for the dip profile of the A-type star to be visible in its entirety. Fig. 1 shows a trace taken with the Cambridge Coravel at a node, when the velocity difference between the components was at its maximum. It is seen that the G star gives a reasonably strong dip (notice, however, the suppressed zero of the ordinates – the depth of the dip is actually only about 14 per cent of the ‘continuum’), whereas the A star gives only a very broad and very shallow one. Worse, the two dips are still blended together even at this maximum separation, and one wing of the A-type dip remains hidden within the G-type one, so the exact width, and therefore the exact central position, of the broad dip is very difficult to determine.

In spectrometer traces that have not been integrated to the S/N ratio level shown in Fig. 1, it is easy to overlook the signature of the A star altogether; in any case it is straightforward at all phases to measure the velocity of the G star as if one were dealing with a single-lined trace. To do so, however, is to ignore the fact that its blending with the broad weak dip of the A star ‘drags’ the measured velocity to some extent; the effect is inevitably systematic, acting always towards the -$g$-velocity, so the eventually derived value of $K_1$ is too small. Moreover, exactly the same effect of blending, although insufficiently recognized and never accounted for, has always been present in all of the measurements that have ever been made in the past on ordinary spectrograms. Although in some cases an effort has been made to select for measurement as G-star lines ones whose contribution from the A star can be expected to be small, the effect is still bound to be

![Figure 1](https://academic.oup.com/mnras/article-abstract/330/2/288/1081607)

**Figure 1.** A typical RV trace for $\alpha$ Equ made with the Cambridge Coravel. The computed profiles fitted to the individual dips are shown as dotted lines.
present there. In fact it must be expected usually to be worse than Fig. 1 might suggest, because in the RV spectrometer the strength of the A-star dip is minimized by the cross-correlation being performed with a mask that, for the A star, is of an inappropriate spectral type (Arcturus, K2 III). The implied automatic favouring of the G-star lines in comparison with the A-star ones is more or less equivalent to the judicious selection, in the measurement of a photographic spectrogram, of lines whose contribution from the A star is especially small.

When we began systematic research on composite-spectrum binaries in 1981, \( \alpha \) Equ was naturally one of the objects on the observing programme, and was at first observed regularly with the original Cambridge RV spectrometer (Griffin 1967). Opportunities were also found to obtain a few observations with the spectrometer made by Griffin & Gunn (1974) for use at the coude focus of the Palomar 200-inch telescope. The Palomar traces demonstrated that the A-type component was weakly visible in the cross-correlation function. Those traces could be reduced as double-lined, but the exact width to be assigned to the broad and very shallow A-type ‘dip’ could not be reliably established. What was established was that blending would entail a systematic under-estimation of the amplitude of the G star’s velocity variation, as has been outlined above, and that that would happen whether or not the A-type dip was explicitly visible in the traces. For that reason the Cambridge observations were made with decreasing enthusiasm and frequency, and were eventually given up altogether. For a considerable time the writers were fortunate in having access to the Geneva Observatory’s Coravel spectrometers at Haute-Provence and sometimes at the European Southern Observatory (ESO), but the maximum scanning range of those instruments was considered to be inadequate for observations of \( \alpha \) Equ. It was decided not to attempt any further RV observations until the Cambridge Coravel, which has almost unlimited scanning range, became operational.

That decision was a correct one, but it involved an unexpectedly long delay, and in the event the instrument has still not enabled us to solve the problem satisfactorily. The difficulty is that the rotational velocity of the A-type star cannot be determined as reliably and precisely as we would like. It is too large in relation to the amplitudes of the velocity variations for the whole of the corresponding dip profile ever to be clear of the relatively strong G-star feature, even at nodal passages. Perversely, however, the dip is not so wide as to project substantially beyond the wings of the G-star one at times of conjunction, which would otherwise offer good opportunities to establish the exact width of the broad depression. What we can say on the basis of the Cambridge Coravel observations is that the value of \( v \sin i \) for the hot star must be close to 27 or 28 km s\(^{-1}\), and is unlikely to be outside the range 25–30 km s\(^{-1}\).

In Table 1 we set out the radial velocities that we have measured for \( \alpha \) Equ, giving the 18 obtained with the Cambridge Coravel, six from Palomar, four from Haute-Provence, one from ESO, and 24 obtained at Cambridge with the original spectrometer. Before discussing those particular observations, we present an orbit solution showing not only them but all of the measurements that have been published previously for \( \alpha \) Equ, the intention being to obtain as broad a consensus as possible. Counting each measurement of each component separately, there is a total of 318 velocities. For reasons adumbrated above, many (64) of them have had to be given zero weight in the solution; the rest have been weighted in such a way as to make their weighted variances tolerably comparable. We refrain from publishing what would necessarily be a large table setting out the velocities and the phases and residuals of all those observations, but we offer in Fig. 2 a plot showing the whole ensemble, with the different series of data distinguished by the different symbols used to plot them.
provides a key to relate the symbols to the sources and to give the weights and empirically determined zero-point offsets attributed to each. Velocities of the A-type component have been globally down-weighted by a factor of 25 in comparison with those of the G-type star. In Table 3 we give the orbital elements from the plenary solution. We do not recommend those elements as the best obtainable, since a major aim of this paper is critically to re-assess the values of $K_1$ and $K_2$. Among the elements in Table 3, however, the period in particular is more accurate than is obtainable from more restricted sets of data, stemming as it does from radial velocities extending over more than 100 years, and we adopt the rounded value of 98.81 d, exactly, to impose as a fixed period upon all other orbit solutions discussed here.

We return now to a discussion of the radial velocities given in Table 1. The 24 measurements made with the original spectrometer at Cambridge have unavoidably been reduced as if they were single-lined, and in that respect are exactly comparable with all the measurements previously published by others as velocities of the G star. An orbit is readily derived from them alone: it proves to have an RV amplitude, $K_1$, of $15.4 \pm 0.3 \, \text{km s}^{-1}$.

Two of the Cambridge Coravel observations in Table 1 do not allow a useful measurement of the hot star without some help. The other 16 were first reduced altogether independently of one another, with all seven of the reduction parameters (the positions, depths and projected rotational velocities for each dip, plus the continuum height) left free. The indicated projected rotational velocities of the A star ranged from 22 to 32 km s$^{-1}$, with one exceptional value (near a conjunction) of 19. Generally there were noticeable idiosyncrasies in the traces that gave values near either extreme; it takes little departure from an idealized trace to have a significant effect on a feature as broad and shallow as that of the hot star in $\alpha$ Equ. The mean value of the A-star $v \sin i$ was taken as 27 km s$^{-1}$, and a fresh set of reductions made with that value imposed uniformly on all the traces. The resulting velocities are the ones listed in Table 1. The six Palomar velocities in that table were reduced as double-lined at the time that they were made. Unfortunately, substantial changes since then in computing hardware and software have prevented us from re-reducing them analogously to the recent Cambridge observations, with a fixed rotational parameter, which is the more regrettable because some of them are excellent traces.

The double-lined data in Table 1 lead to an orbit with $K_1 =$ 16.48 ± 0.09, $K_2 =$ 17.1 ± 0.4 km s$^{-1}$, giving $q =$ 1.04 ± 0.03. That orbit is the origin of the phases and residuals listed against the data in Table 1, and is illustrated in Fig. 3, where filled symbols are

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**Figure 2.** ‘Plenary solution’ of the orbit of $\alpha$ Equ. All radial velocities of which we are aware, published here or previously, are plotted, although (as is obvious from the figure) not all of them could usefully contribute to the solution of the orbit. The key to the symbols, data sources and weightings is given in Table 2. Orbital elements corresponding to this figure (but not recommended for adoption as the best ones) are given in Table 3.

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**Table 2.** Sources of radial velocities of $\alpha$ Equ (in chronological order of first measurement), the weights and empirically determined zero-point offsets applied in the ‘plenary solution’, and the corresponding symbols used in the illustration of that solution (Fig. 2).

<table>
<thead>
<tr>
<th>Observatory</th>
<th>n</th>
<th>Wt*</th>
<th>Offset</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lick</td>
<td>10</td>
<td>0.01</td>
<td>0.0</td>
<td>open circle</td>
<td>Campbell &amp; Moore (1928)</td>
</tr>
<tr>
<td>Cape</td>
<td>3</td>
<td>0.00</td>
<td>0.0</td>
<td>open triangle</td>
<td>Lunt (1919)</td>
</tr>
<tr>
<td>Allegheny</td>
<td>48</td>
<td>0.00</td>
<td>0.0</td>
<td>plus</td>
<td>Beardsley (1969)</td>
</tr>
<tr>
<td>Yerkes</td>
<td>6</td>
<td>0.00</td>
<td>0.0</td>
<td>asterisk</td>
<td>Frost et al. (1929)</td>
</tr>
<tr>
<td>DAO</td>
<td>2</td>
<td>0.00</td>
<td>0.0</td>
<td>open star</td>
<td>Harper (1934)</td>
</tr>
<tr>
<td>Hale</td>
<td>25</td>
<td>0.10</td>
<td>+0.8</td>
<td>circle with + in it</td>
<td>Stickland (1976)</td>
</tr>
<tr>
<td>DAO</td>
<td>61</td>
<td>1.00</td>
<td>+0.8</td>
<td>filled star</td>
<td>Rosvick &amp; Scarfe (1991)</td>
</tr>
<tr>
<td>RGO</td>
<td>75</td>
<td>0.05</td>
<td>+2.3</td>
<td>open square</td>
<td>Stickland (1976)*</td>
</tr>
<tr>
<td>Pick</td>
<td>5</td>
<td>0.10</td>
<td>+0.8</td>
<td>large open circle</td>
<td>Beavers &amp; Eitter (1986)</td>
</tr>
<tr>
<td>McDonald</td>
<td>2</td>
<td>0.10</td>
<td>0.0</td>
<td>multiplication sign</td>
<td>Parsons (1983)</td>
</tr>
<tr>
<td>Cambridge (old)</td>
<td>24</td>
<td>0.10</td>
<td>0.0</td>
<td>open diamond</td>
<td>This paper</td>
</tr>
<tr>
<td>Palomar</td>
<td>12</td>
<td>1.00</td>
<td>0.0</td>
<td>filled circle</td>
<td>This paper</td>
</tr>
<tr>
<td>OHP/ESO</td>
<td>9</td>
<td>1.00</td>
<td>0.0</td>
<td>filled triangle</td>
<td>This paper</td>
</tr>
<tr>
<td>Cambridge (new)</td>
<td>36</td>
<td>1.00</td>
<td>-0.7</td>
<td>filled square</td>
<td>This paper</td>
</tr>
</tbody>
</table>

*The weights given are for the primary star. In general the weight attributed to measures (where existing) of the secondary were 1/25 as great. Exceptionally, weights 10 times as great (2/5 those of the primary) were used for the 29 secondary velocities re-measured by Pike (1978) from Stickland’s (1976) 10 Å mm$^{-1}$ Royal Greenwich Observatory (RGO) plates. Stickland measured the primary on 39 such plates, and also on seven 20 Å mm$^{-1}$ RGO plates which are distinguished in Fig. 2 by smaller symbols although their zero-point and standard deviation have proved to be similar to those of the higher dispersion.
used for the data that went into the solution and open ones for those that did not. The larger amplitude given for the primary star by the double-lined velocities, in comparison with the 'old' Cambridge measurements whose single-lined nature excluded them from the solution shown in the figure, is obvious. Also excluded from the calculation of the orbit were three particularly 'wild' velocities of the secondary. Although the formal uncertainties of the amplitudes given above are quite small, we cannot recommend such an orbital solution based solely on our own measurements with RV spectrometers: their phase distribution leaves much to be desired, and the extreme weakness of the signature of the secondary leaves the computed velocity amplitude vulnerable to non-random errors, of which the 'wild' results that were arbitrarily rejected serve as a warning.

The data given in Table 1 exhibit a systematic difference, i.e. a difference in zero-point, between the observations made at Cambridge with the original spectrometer and those obtained with the Coravel. The difference is unwelcome, since both series of data were supposedly reduced in the same way, via the same reference stars, to the scale long adopted (Griffin 1969) in Cambridge. It may arise from a colour dependence of the zero-point, such as has long been documented (e.g. Scarfe, Batten & Fletcher 1990) in the cases of other Coravel spectrometers and has recently been admitted by their operators (Udry, Mayor & Queloz 1999); insufficient experience has yet been gained with the Cambridge instrument to permit an informed discussion of the question, but for present purposes the discrepancy is probably immaterial and has been countered by applying an arbitrary offset of $-0.7 \text{ km s}^{-1}$ to the Coravel measurements.

In an effort to quantify the effect of blending between the spectra of the two components we performed an experiment on the 16 traces obtained with the Cambridge Coravel that could be reduced independently of one another. They are by no means well distributed in phase for the purpose of calculating an orbit, being mostly in the immediate vicinity of one node; the intrinsic precision of the measurements of the G star, however, does produce from those 16 observations alone a result with an agreeably small formal uncertainty, showing a velocity amplitude of $16.34 \pm 0.09 \text{ km s}^{-1}$ for the primary star. The solution was run as double-lined, with a tiny weight for the A star so that all that the A-star velocities really did was to determine the amplitude of that component, which came out at $16.79 \pm 0.55 \text{ km s}^{-1}$, giving a mass ratio $q$ of 1.03 $\pm$ 0.03. The selfsame observations, when reduced as single-lined, yielded an amplitude of $16.04 \pm 0.09 \text{ km s}^{-1}$ for the G star. Thus the effect of blending between the spectra of the two stars resulted in that instance in an under-estimation of the velocity amplitude of the cool star by 0.30 km s$^{-1}$. That quantity pertains to observations mostly made near the nodes of the orbit, and might not be fully representative of those made at other phases; a larger value seems to be called for if one judges by the smaller value of $K_1$ given by the velocities obtained with the original spectrometer. The directly measured value of 0.30 km s$^{-1}$ for the effect may, however, be expected to be reasonably typical of the error in cases where the spectrum has been measured 'as observed' but care has been taken to reduce as far as possible, by choice of lines for measurement, the effect of blending by the hot star. In particular, we applied it directly to the G-star amplitude of 16.23 km s$^{-1}$ found by Rosvick & Scarfe (1991), which then became 16.53 km s$^{-1}$. In view of the poor phase distribution of our own double-lined observations, we prefer to rely more on that last value, and conclude with the adoption for $K_1$ of a value of 16.53 $\pm$ 0.10 km s$^{-1}$.

3 SPECTROSCOPIC OBSERVATIONS

Table 4 is a catalogue of the spectroscopic observations of α Equ that were used in this paper. The Mount Wilson (MW) observations were made photographically at 10 Å mm$^{-1}$ with the 32-inch camera and 46B grating (600 line mm$^{-1}$) of the coude spectrograph of the 100-inch reflector. The observations made in 1999 at the DAO were recorded at the coude focus of the 1.2-m telescope on a SITe-2 CCD, using the 96-inch camera, mosaic grating (830 line mm$^{-1}$) and 962B image slicer, and were timed to cover both nodal passages of the system in turn. Since the maximum wavelength range of each CCD observation was 62 Å, observations were made at four different grating settings in order to sample a variety of classification-sensitive features within the range covered by the photographic spectra. The eight photographic spectra from the DAO, also corresponding to velocity nodes, had been acquired with the 96-inch camera at the coude focus of the 1.2-m telescope;
they are a subset of the DAO plates analysed by Rosvick & Scarfe (1991), and were kindly lent by Dr C. D. Scarfe (who made the observations).

The S/N ratios of the CCD spectra were measured as 50–200; those of the photographic spectra were in the range 30–60. All three types showed a significant gradient of recorded intensity with wavelength, a combination of the effects of intrinsic spectral flux, grating blaze, detector efficiency, etc.

The MW plates were processed, digitized, intensity-calibrated and reduced in the manner described elsewhere (Griffin 1979); spectra were extracted in steps of 50 mA˚ from all 3850 to 4650 Å. The eight photographic plates from the DAO were digitized with the DAO’s PDS microdensitometer; intensity calibrations were derived from stepped-slit spectrograms recorded on each plate, and spectra covering the region all 3850–4600 Å were extracted in steps of 10 mA˚. The DAO exposures occupied two separate plates placed end-to-end in the plate-holder, and the spectra derived from them have a gap of 30–40 Å in the region all 4160–4200 Å. The CCD observations were reduced from FITS-format images to one-dimensional spectra with IRAF. The wavelength scale in every case was that of the rest-frame of the primary (a Equ A).

It was decided that spectra could be averaged in cases where the primary’s velocity was very similar. Thus in the MW set the three spectra from 1985 June 15 were averaged (giving double weight to the low-noise IIIa-J exposure Ce 24264), while in the DAO set 5089 was combined with 9240, 9044 with 11503, and 9203 with 10180 plus 10181. The CCD spectra extracted from files 9999 and 10000 were averaged, as also were those from 10185 and 10255, and 13821 and 13900.

Two libraries of standard late-type giant spectra were available to this project: (1) an extensive set of observations, at either 10 or 8.8 Å mm⁻¹, accumulated prior to 1985 during the currency of this work at MW and subsequently supplemented with observations made at Calar Alto, and (2) a small set of standard spectra, thought to resemble that of a Equ A, observed during the two 1999 runs at the DAO with the same equipment and grating settings as were used for the observations of a Equ.

The immediate objectives of the spectroscopy, the analysis of which is described in detail below, are to determine the precise spectral type of the hot-dwarf secondary (a Equ B) (Section 4), measure the RV displacements of the secondary spectra and thence derive the mass ratio (Section 5), derive an accurate photometric model of the binary (Section 6), deduce the properties of the individual components (Section 7), and examine the evolutionary status of the a Equ system (Section 8). First we describe the preparation of the spectra of a Equ B, upon which the succeeding sections necessarily depend.

### 4 THE SPECTRUM OF a EQU B

#### 4.1 Isolating the spectrum

The spectrum of the hot secondary in a composite-spectrum binary can be isolated by the technique of digital subtraction, as described...
by Griffin (1986a) and subsequently applied in all the spectroscopic papers in this series so far. In essence, one selects an appropriate standard spectrum as a surrogate for the primary component, and subtracts a suitable fraction of it from the composite spectrum in order to remove the primary’s features as completely as possible. The importance of aligning carefully both primary and surrogate in the same wavelength frame is evident. It is also important that the instrumental characteristics of the composite spectra and the standard spectra are extremely similar, if not identical.

Spectral subtractions are reasonably straightforward when the secondary is hotter than early A, since the blue spectral region of such stars normally contains stretches of continuum whose appearance guides the effectiveness of subtracting different fractions of a given standard. The procedure becomes increasingly difficult to judge when the secondary is of a cooler type because many of the lines in a late-A dwarf are also present in a late-type giant. Even though the secondary spectrum may contain stretches of continuum at longer wavelengths, the disentangling there is confused by worsening noise, because increasing fractions of the dominant primary need to be subtracted. As discussed in Paper 9, where those problems were encountered fairly acutely, there may be rather little to guide the subtractions of different G-type standards in such a situation, and the choice of the best standard can then be a difficult one. If the RV separation is sufficiently great that the component spectra can be resolved in velocity, it can be advantageous to make observations at high dispersion; that was the prime motivation for the spectroscopy of $\alpha$ Equ carried out at 2.4 Å mm$^{-1}$ in 1999. However, confusion is still likely if the lines of the dwarf are narrow as well as plentiful, and is further exacerbated if the dwarf is an Am star since its metallic-line spectrum is then even more similar to that of the giant. All those problems are present in the case of $\alpha$ Equ, and together they explain why the early analyses of this fourth-magnitude binary yielded somewhat discordant results.

Knowledge of the spectral type of the secondary, as well as the primary, is of fundamental importance for modelling the binary. Its classification requires the examination of as wide a region of the spectrum as possible, so we commenced by disentangling the 10 Å mm$^{-1}$ MW spectra. The high-dispersion CCD spectra were also separated in a similar manner, although with the purpose of isolating limited regions of the secondary spectrum for RV measurement rather than of classifying the spectral type. The subset of high-dispersion photographic DAO spectra included observations at both nodes of the orbit, but had lower S/N ratios than either the MW or the CCD spectra. They were manipulated so as to simulate each of the other data sets in turn, in order to provide independent versions of the secondary spectrum for use in the error analysis (Section 5.3).

4.1.1 Mount Wilson spectra (10 Å mm$^{-1}$)

Trial subtractions showed that $\alpha$ Equ A is a late-G giant, the best match from the available standards being the spectrum of 31 Vul, classified as G7 III (Keenan & McNeil 1989). Fig. 4 illustrates the subtraction procedure in the region of $H_g$. We note parenthetically that the strength of the G band in the vicinity of $\lambda\lambda 4300$–4330 Å, which is a prominent feature in late-G giants, differs too much from star to star to be reliable as a precise indicator of effective temperature $T_{\text{eff}}$ or luminosity, and finding a close match for the

Figure 4. Separation of the spectrum of the secondary component in the region of $H_g$. An appropriate fraction of the spectrum of the surrogate primary (31 Vul, panel a) has been subtracted from the composite spectrum (panel b), uncovering the spectrum of the secondary, $\alpha$ Equ B (panel c). Panel d shows the spectrum of $\epsilon$ Ser as a comparison for the secondary.

molecular band as well as for the atomic lines can be a question more of luck than of judgment. In this case we appear to have been fortunate.

4.1.2 DAO photographic spectra, convolved to 10 \( \text{Å mm}^{-1} \)

Since no spectra were available to provide a surrogate for the full spectral region at 2.4 \( \text{Å mm}^{-1} \), the high-dispersion spectra were convolved with an appropriate broadening function to make their resolution appear as similar as possible to that of the MW spectra at 10 \( \text{Å mm}^{-1} \). Those versions were then treated in exactly the same way as the MW spectra by subtracting appropriate fractions of the spectrum of 31 Vul.

4.1.3 CCD spectra (2.4 \( \text{Å mm}^{-1} \))

The subtraction technique was applied to the CCD observations with a view to isolating cleanly the individual lines of the secondary spectrum, rather than trying to classify the types of either component star. If the length of available spectrum is rather short, the quality (S/N ratio, cosmic ray blemishes) of the individual spectra can assume an undue importance when selecting the surrogate that generates the best-looking residual spectrum. From the somewhat limited selection of late-type standards that could be reached during the two observing runs for \( \alpha \) Equ, it was found that \( \eta \) Psc (G7 IIIa) gave the closest match to the spectrum of the primary, although \( \epsilon \) Sct (G8 IIa) was also an acceptable surrogate; both are MK standards (Keenan & McNeil 1989).

The choice of those stars was made empirically, and a subsequent check on their properties revealed some surprises. Their 

\[ \text{Hipparcos} \]

parallaxes show that both have absolute magnitudes near \(-1.1\), as much as 1.8 mag brighter than the \( \alpha \) Equ primary for which they are substitutes. Moreover, \( \eta \) Psc has long been known as a very close and very unequal visual binary (Burnham 1879); \n
\[ \text{Hipparcos} \]

gives \( \Delta m = 3.68 \pm 0.07 \) mag in the \n
\[ \text{Hipparcos} \]

magnitude system (not far from \( V \)). The light contributed by the secondary (which, judged by its \( M_V \) of \(-2.6\), is most likely an early-F dwarf) is therefore only about 3 per cent of the total, and is probably innocuous in the present use of the spectrum of \( \eta \) Psc.

By adopting first \( \eta \) Psc and then \( \epsilon \) Sct as the surrogate, two versions of the secondary spectrum were recovered for each of the four wavelength settings. The use of interchangeable surrogates was also an important precaution for avoiding an autocorrelation spike at zero velocity-shift (see Section 5.3.4).

4.1.4 DAO photographic spectra (2.4 \( \text{Å mm}^{-1} \))

The high-dispersion photographic DAO spectra were sampled in the four wavelength regions corresponding to the CCD observations. The spectrum of the primary was removed by subtracting the CCD spectra of first \( \eta \) Psc and then \( \epsilon \) Sct.

4.2 The spectral type of \( \alpha \) Equ A

31 Vul, the surrogate primary selected at 10 \( \text{Å mm}^{-1} \), has been classified as G7 III (Keenan & McNeil 1989) or G7.5 III Fe–I (Ginestet et al. 1994). The spectral type of \( \alpha \) Equ A was therefore judged to be G7 III, which is very near the infrared classification of G8 III (Ginestet et al. 1997) or G8 III+ (Ginestet et al. 1999). The fact that 31 Vul may be slightly abnormal (it has been classified in various catalogues as a CN-weak giant and as a marginal Ba star) and that it appears to be a single-lined spectroscopic binary (Beavers & Eitter 1986; de Medeiros & Mayor 1999) probably does not affect that judgment, but may have contributed towards the difficulties (discussed more fully in Section 5.3) arising from imperfect subtraction of the primary’s lines.

4.3 The spectral type of \( \alpha \) Equ B

In order to maximize the S/N ratio of our spectrum of \( \alpha \) Equ B, we aligned and averaged the various versions of it which had been extracted at 10 \( \text{Å mm}^{-1} \). Alignment of the spectra within the same velocity frame required knowledge of the mass ratio (\( q \)). Our determination of \( q \) is discussed in Section 5, so at this point we have to anticipate that result.

Each version of the spectrum of \( \alpha \) Equ B extracted at 10 \( \text{Å mm}^{-1} \) (four in the MW set and eight in the DAO set) was individually shifted by an appropriate amount to bring it to zero velocity, and a straight mean of each set was generated. The two sets were then merged by averaging those two means. In consideration of the number of spectral elements contributing to each set, the emulsion types and the general quality of the spectra, it was felt that equal weighting was the most equitable. The spectrum of \( \alpha \) Equ B is reproduced in Fig. 5. It bears the hallmarks of an Am star (Conti 1970); compared to the Balmer-line type its metallic-line spectrum is significantly later, while its K line is slightly (although not very appreciably) earlier. The category classified as Am does in fact encompass quite a wide dispersion in both metal enhancement and K-line weakness. Fig. 5 includes the spectrum of the Am star \( \epsilon \) Ser for comparison purposes.

Accurate classification of such a secondary spectrum is made difficult by the heterogeneity and rotational broadening of the standards themselves, and was compounded in the present instance by insufficient samples of Am and normal-A stars. However, it is possible to determine \( T_{\text{eff}} \) unambiguously from the Balmer-line profiles, independently of the metallic lines, by spectrum synthesis. Comparisons with synthetic spectra, adapted from a set generated for a different project (Verschueren, David & Griffin 1999), indicated that \( T_{\text{eff}} \) corresponding to the Balmer lines in \( \alpha \) Equ B is close to, or just above, 8000 K, while the metallic lines correspond to a somewhat lower temperature and the Ca II K line to a slightly higher one.

In comparison to 95 Leo – A3 V; \( (B - V) = 0.11 - \alpha \) Equ B is a little hotter, its metal lines (particularly Sr II at \( \lambda \lambda 4077 \) and 4215 \( \text{Å} \)) are stronger, and its K line is deeper with narrower wings, indicating an Am type. A cursory inspection shows that, even in comparison with the Am star \( \epsilon \) Ser (kA2hA5mA7; Gray & Garrison 1989) as shown in Fig. 5, lines of Sr II, Y II, Zr II, Ba II and Ce II are enhanced in \( \alpha \) Equ B, so its Am nature is not in doubt. Its Balmer lines are generally similar to those of the Am dwarf 60 Leo (A0.5mA3 V; Gray & Garrison 1987), although while its metal lines are mostly slightly stronger, its K line and rare-earth lines are more substantially enhanced. It appears to be slightly hotter than the Am star \( \alpha \) Cnc (kA5hA5mA0; Gray & Garrison 1989), but nevertheless shows very similar ratios between the Balmer lines, K line and metal lines. Its Balmer lines are about one sub-class warmer than those of \( \epsilon \) Ser, while both its metal-line spectrum and its K line represent a slightly later type. We concluded that \( \alpha \) Equ B is an Am dwarf of spectral type near kA3hA4mA9; it is therefore a classical Am star according to the definition by Kurtz (1976). Comparison with a synthetic spectrum indicated that its lines are
rotationally broadened by $\sim 25$ km s$^{-1}$, in close agreement with the value of $v \sin i = 27$–28 km s$^{-1}$ determined from the RV traces.

5 THE MASS RATIO OF $\alpha$ EQU

5.1 Methods of determination

The mass ratio, $q$, of a binary system is readily derived from the RV differences between the component stars, since $q = M_1 / M_2 = -v_2 / v_1$, where $v$ is the velocity relative to the $\gamma$-velocity. In the subtraction procedure applied in this paper, the secondary spectrum takes on the wavelength scale of the rest-frame in which it is isolated, i.e. that of the primary, so its wavelength shift within that frame is equivalent to its RV displacement from the primary. The values of $v_1$ (the primary’s velocity) at the times of the spectroscopic observations are determined from the orbit; the velocity ratio $v_2 / v_1$ of the two stars, and their mass ratio, then follow.

The RV of the secondary star can be measured by cross-correlation in one of two ways: either (A) against the spectrum of an appropriate early-type standard, or (B) against a different, independent version of itself. The advantages and disadvantages of the two methods have been discussed in detail elsewhere (Paper 10). The advantage of Method B is the chance to employ a longer velocity baseline than in Method A (up to a factor of 2 is possible in the case of a circular orbit), with concomitant improvement in accuracy; systematic errors in the wavelength scale of the template spectrum are also avoided. On the other hand, if the template is a well-observed standard its recorded spectrum is likely to have a higher S/N ratio than is available for any of the secondary spectra, so random errors are likely to be smaller in Method A. Ideally, both methods should be applied.

5.2 Measurements

The RV shifts of $\alpha$ Equ B measured by Method A are given in Table 5, while the results obtained with Method B are listed in Table 6.

Spectra of two stars – $\epsilon$ Ser and 60 Leo – were used alternatively as templates for Method A. Both stars were mentioned in Section 4.3 as matching $\alpha$ Equ B reasonably well in most aspects, except for a fairly considerable disparity in K-line strength between $\alpha$ Equ B and 60 Leo. However, because of problems connected with the rotational broadening of $\epsilon$ Ser (see Section 5.3.5), the results from sections 2(b) and 2(d) in Table 5 were zero-weighted.

In the case of the CCD spectra, the RV values were derived separately from the individual regions to allow for the small differences in velocity of the primary at their various exposure dates, and then combined; only the mean values are shown here. The secondary spectra extracted from the DAO high-dispersion photographic spectra, restricted to resemble the four regions of CCD spectra, were treated in the same way as the CCD secondary spectra. The DAO plates included three separate groups of spectra at Node 2 in which the respective values of the primary’s velocity were too disparate for the spectra to be averaged. Those groups were therefore handled separately, the individual spectra being identified as DAO1 (5089–9240), DAO2 (9044–11503), and DAO3 (10 786). Since DAO3 only contained one spectrum, it was not used for the cross-correlations in high-dispersion mode. The existence of multiple groups at that node provided particular advantages for the error analysis (Section 5.3).

For the high-dispersion material, the different versions of secondary spectra generated with alternative surrogate primaries were identified as CCDa, DAO1a, DAO2a and CCDb, DAO1b,
DAO2b, according to whether the adopted surrogate was (a) \( \eta \) Psc or (b) \( \epsilon \) Sct. We derived mean values of \( q \) from the separate sets by averaging the individual measurements with equal weighting.

In Table 5 the nodal phases are identified simply as ‘Node 1’ and ‘Node 2’. In Table 6 the sense of the mutual displacements is immaterial for the present purpose, so the signs have been omitted. Both tables show values of \( q \) derived from either node, combined with equal weighting. They also give the mean values of \( q \) for each set of cross-correlations and for the different windows used, and (in the final column) an unweighted mean of the independent results.

Sets 1c (Table 5), and 1b and 2c (Table 6) were therefore zero-weighted.

Some sets of measurements in Tables 5 and 6 show better internal consistency than others, and there are some systematic differences. The values in Table 6 show generally smaller scatter than those in Table 5, probably reflecting the advantage of Method B mentioned above. However, such measurements of \( q \) are particularly prone to errors caused by the subtraction process. The next section discusses the nature, sources and magnitudes of the systematic and random errors which may affect our results.

5.3 Errors in the determination of \( q \)

The precision of a measurement of the secondary’s RV is limited by both random and systematic errors. Inasmuch as all the spectra of \( \alpha \) Equ B under consideration contain errors of subtraction, which

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**Table 5. RV measurements of \( \alpha \) Equ B determined by Method A (standard template cross-correlation).**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Source</th>
<th>Template spectrum</th>
<th>RV of giant (km s(^{-1}))</th>
<th>Measured RV of dwarf (km s(^{-1}))</th>
<th>Mass ratio ( q ) Window 1</th>
<th>Mass ratio ( q ) Window 2</th>
<th>Mean ( q ) per window and template</th>
<th>Mean ( q ) per set</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windows 1 (W1) and 2 (W2) include ( \lambda \lambda 3782-4643 ) \AA; Window 2 omits the Balmer lines and the K line</td>
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<td></td>
<td></td>
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<td></td>
</tr>
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</table>

(a) Photographic spectra

<table>
<thead>
<tr>
<th>Node 1</th>
<th>MW</th>
<th>( \epsilon ) Ser</th>
<th>+13.0</th>
<th>-28.3</th>
<th>-28.4</th>
<th>1.19 (1)</th>
<th>1.18 (1)</th>
<th>1.15</th>
<th>1.15</th>
<th>1.15</th>
<th>±0.03</th>
</tr>
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<tbody>
<tr>
<td>Node 2</td>
<td>MW</td>
<td>( \epsilon ) Ser</td>
<td>-16.5</td>
<td>+35.1</td>
<td>+35.3</td>
<td>1.13 (2)</td>
<td>1.14 (2)</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
<td>±0.03</td>
</tr>
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</table>

(b) Photographic spectra

<table>
<thead>
<tr>
<th>Node 1</th>
<th>MW</th>
<th>60 Leo</th>
<th>+13.0</th>
<th>-27.1</th>
<th>-27.0</th>
<th>1.08 (1)</th>
<th>1.08 (1)</th>
<th>1.13</th>
<th>1.13</th>
<th>1.13</th>
<th>±0.04</th>
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<td>Node 2</td>
<td>MW</td>
<td>60 Leo</td>
<td>-16.5</td>
<td>+35.5</td>
<td>+35.7</td>
<td>1.15 (2)</td>
<td>1.16 (2)</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
<td>±0.04</td>
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(c) Photographic spectra

<table>
<thead>
<tr>
<th>Node 1</th>
<th>DAO1</th>
<th>60 Leo</th>
<th>-16.5</th>
<th>+36.1</th>
<th>+36.1</th>
<th>1.19 (2)</th>
<th>1.20 (2)</th>
<th>1.19</th>
<th>1.21</th>
<th>1.20</th>
<th>±0.04</th>
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<td>DAO</td>
<td>60 Leo</td>
<td>-15.9</td>
<td>-34.1</td>
<td>-34.3</td>
<td>1.15 (2)</td>
<td>1.16 (2)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
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<td>60 Leo</td>
<td>-16.0</td>
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<td>+36.0</td>
<td>1.23 (1)</td>
<td>1.25 (1)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

2. Spectra at 2.4 \AA\ mm\(^{-1}\).

Window 1 includes the region \( \lambda \lambda 3910-4321 \) \AA; Window 2 includes \( \lambda \lambda 4027-4321 \) \AA

(c) CCD bump spectra

<table>
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<tr>
<th>Node 1</th>
<th>CCDa</th>
<th>60 Leo</th>
<th>+16.3</th>
<th>-34.9</th>
<th>-35.6</th>
<th>1.14 (2)</th>
<th>1.18 (2)</th>
<th>1.12</th>
<th>1.13</th>
<th>1.12</th>
<th>±0.05</th>
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<tbody>
<tr>
<td>Node 2</td>
<td>CCDb</td>
<td>60 Leo</td>
<td>-16.5</td>
<td>+34.6</td>
<td>+34.1</td>
<td>1.10 (2)</td>
<td>1.07 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node 2</td>
<td>CCDb</td>
<td>60 Leo</td>
<td>-16.5</td>
<td>+34.7</td>
<td>+34.2</td>
<td>1.10 (2)</td>
<td>1.08 (2)</td>
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(d) Photographic spectra

<table>
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<tr>
<th>Node 1</th>
<th>DAOa</th>
<th>60 Leo</th>
<th>+15.9</th>
<th>-33.7</th>
<th>-34.1</th>
<th>1.12 (2)</th>
<th>1.15 (2)</th>
<th>1.13</th>
<th>1.13</th>
<th>1.13</th>
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<td>DAOb</td>
<td>60 Leo</td>
<td>+15.9</td>
<td>-33.4</td>
<td>-33.8</td>
<td>1.10 (2)</td>
<td>1.13 (2)</td>
<td>(2)</td>
<td>(2)</td>
<td>(2)</td>
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</tr>
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<td>DAOa1</td>
<td>60 Leo</td>
<td>-16.5</td>
<td>+35.3</td>
<td>+35.1</td>
<td>1.15 (2)</td>
<td>1.13 (2)</td>
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<td></td>
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<tr>
<td>Node 2</td>
<td>DAOa2</td>
<td>60 Leo</td>
<td>-15.2</td>
<td>+32.5</td>
<td>+32.1</td>
<td>1.14 (2)</td>
<td>1.11 (2)</td>
<td></td>
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<tr>
<td>Node 2</td>
<td>DAOa1b</td>
<td>60 Leo</td>
<td>-16.5</td>
<td>+35.2</td>
<td>+35.1</td>
<td>1.14 (2)</td>
<td>1.14 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node 2</td>
<td>DAOa2b</td>
<td>60 Leo</td>
<td>-15.2</td>
<td>+32.5</td>
<td>+32.3</td>
<td>1.14 (2)</td>
<td>1.13 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weighted means

| (1)  | (2)  | 1.13 | 1.14 | 1.14 |    |

Notes: 1. Numbers in parentheses are weightings.
2. The ‘uncertainty’ quoted for each mean is simply the semi-amplitude of the range.

 DAO2b, according to whether the adopted surrogate was (a) \( \eta \) Psc or (b) \( \epsilon \) Sct. We derived mean values of \( q \) from the separate sets by averaging the individual measurements with equal weighting.
are considered here to be purely random, it is not formally possible
to separate the different types of error completely. Nevertheless,
because the lines in \( \alpha \) Equ B are plentiful and fairly narrow,
random errors should be small enough to permit a realistic
assessment of systematic errors in this instance.

This investigation of \( \alpha \) Equ is supported by a much greater
quantity and variety of observational material than is normally
available for our spectroscopic studies of composite spectra.
Although incomplete in some aspects, the error analysis is
discussed in some detail in this paper since it constitutes a guide for
the more limited general case. We note that not all of the errors
identified here will have the same impact on other composite-
spectrum analyses; for instance, spectra of \( \alpha \) Equ B are particularly
prone to processing errors, for reasons that owe more to the nature
of the secondary’s spectrum than to the manner in which the
procedures are handled.

5.3.1 Types of errors, and their sources

The errors can be identified through the different forms in which
they are encountered: internal errors, which are present in the
original spectra before subtraction is carried out, processing errors
incurred by subtraction and re-normalization, and measuring errors
arising from the application of the cross-correlation method. Each
type of error affects the position, and possibly the symmetry, of the
cross-correlation (CCF) peak, whence it is transmitted to the
measurement of the RV of the secondary star.

5.3.2 Internal errors

Internal errors in an individual spectrum stem from inaccuracies in
the wavelength scales and the continuum levelling in the spectra of
the composite (and hence of the secondary), surrogate and
template. The sources of internal errors have been discussed in
detail by Griffin, David & Verschueren (2000), who point out that
whilst errors in wavelength scale are systematic in nature from the
point of view of an individual spectrum, they occur as random
errors in this type of work since there is no correlation, or at most
only a very weak one, between the various sources.

5.3.3 Processing errors

Processing errors are caused by mismatch between the primary and
surrogate spectra, and originate in the subtraction procedure. If the
notes: 1. Numbers in parentheses are weightings. 1b and 2c are not independent results.
2. The ‘uncertainty’ quoted for each mean is simply the semi-amplitude of the range.

Table 6. RV measurements of \( \alpha \) Equ B determined by Method B (mutual cross-correlation).

<table>
<thead>
<tr>
<th>Phase and source of spectrum</th>
<th>Phase and source of template</th>
<th>( \DeltaRV ) of giant ((\text{km s}^{-1}))</th>
<th>Measured RV of dwarf ((\text{km s}^{-1}))</th>
<th>Mass ratio (q) Window 1</th>
<th>Mass ratio (q) Window 2</th>
<th>Mean (q) per window W1</th>
<th>Mean (q) per window W2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node 2, MW</td>
<td>Node 1, MW</td>
<td>29.5</td>
<td>63.0</td>
<td>63.0</td>
<td>1.14 (2)</td>
<td>1.15 (2)</td>
<td>1.17</td>
</tr>
<tr>
<td>Phase .272, MW</td>
<td>Node 1, MW</td>
<td>15.1</td>
<td>33.6</td>
<td>33.3</td>
<td>1.23 (1)</td>
<td>1.21 (1)</td>
<td>(2)</td>
</tr>
<tr>
<td>(b)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node 2, DAO</td>
<td>Node 1, DAO1</td>
<td>32.4</td>
<td>70.6</td>
<td>71.0</td>
<td>1.18 (2)</td>
<td>1.20 (2)</td>
<td>1.19</td>
</tr>
<tr>
<td>Node 2, DAO</td>
<td>Node 1, DAO2</td>
<td>30.8</td>
<td>68.0</td>
<td>68.7</td>
<td>1.19 (4)</td>
<td>1.21 (4)</td>
<td>(0)</td>
</tr>
<tr>
<td>Node 2, DAO</td>
<td>Node 1, DAO3</td>
<td>31.9</td>
<td>70.2</td>
<td>70.9</td>
<td>1.20 (2)</td>
<td>1.22 (2)</td>
<td>(0)</td>
</tr>
<tr>
<td>Node 1, MW</td>
<td>Node 2, DAO</td>
<td>32.4</td>
<td>70.2</td>
<td>70.7</td>
<td>1.17</td>
<td>1.18</td>
<td>1.17</td>
</tr>
<tr>
<td>(c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Node 2, CCDa</td>
<td>Node 1, CCDa</td>
<td>32.8</td>
<td>69.5</td>
<td>70.0</td>
<td>1.12 (2)</td>
<td>1.14 (2)</td>
<td>1.14</td>
</tr>
<tr>
<td>Node 2, CCDb</td>
<td>Node 1, CCDa</td>
<td>32.8</td>
<td>69.7</td>
<td>70.2</td>
<td>1.13 (2)</td>
<td>1.14 (2)</td>
<td>(2)</td>
</tr>
<tr>
<td>Node 2, CCDa</td>
<td>Node 1, CCDa</td>
<td>32.8</td>
<td>69.7</td>
<td>70.0</td>
<td>1.13 (2)</td>
<td>1.14 (2)</td>
<td>(2)</td>
</tr>
<tr>
<td>Node 2, CCDb</td>
<td>Node 1, CCDb</td>
<td>32.8</td>
<td>69.5</td>
<td>70.1</td>
<td>1.12 (2)</td>
<td>1.14 (2)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

Notes: 1. Numbers in parentheses are weightings. 1b and 2c are not independent results.
2. The ‘uncertainty’ quoted for each mean is simply the semi-amplitude of the range.

2. Spectra at 2.4 Å mm\(^{-1}\). Window 1 includes the region \( \lambda \lambda 3910–4321 \) Å; Window 2 includes \( \lambda \lambda 4027–4321 \) Å

(a) CCD spectra

| Node 2, DA0a                  | Node 1, DA0b                  | 32.4                            | 69.7                            | 70.3              | 1.16 (2)          | 1.17 (2)          | 1.16              |
| Node 2, DA02a                | Node 1, DA0b                  | 31.1                            | 66.9                            | 67.3              | 1.15 (2)          | 1.16 (2)          | (2)               |
| Node 2, DA01b                | Node 1, DA0a                  | 32.4                            | 69.8                            | 70.3              | 1.16 (2)          | 1.17 (2)          | (2)               |
| Node 2, DA02b                | Node 1, DA0a                  | 31.1                            | 67.9                            | 68.3              | 1.18 (2)          | 1.20 (2)          | (2)               |

(b) Photographic spectra

| Node 1, CCDa                 | Node 2, DA01b                 | 32.8                            | 70.4                            | 71.2              | 1.15 (2)          | 1.18 (2)          | 1.16              |
| Node 1, CCDb                 | Node 2, DA02b                 | 31.5                            | 68.7                            | 69.5              | 1.18 (2)          | 1.21 (2)          | (0)               |
| Node 1, CCDa                 | Node 2, DA01a                 | 32.8                            | 70.4                            | 71.1              | 1.15 (2)          | 1.17 (2)          | (0)               |
| Node 1, CCDb                 | Node 2, DA02a                 | 31.5                            | 67.7                            | 68.2              | 1.15 (2)          | 1.16 (2)          | (0)               |

Unweighted means of 3 independent sets (1a, 2a, 2b)

<table>
<thead>
<tr>
<th>Weightings per window W1</th>
<th>Weightings per window W2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15</td>
<td>1.16</td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

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secondary is of a sufficiently late type that most of its lines are common to those in the late-type primary, it is difficult to be certain that a subtraction has not left any residuum of the primary’s spectrum. Even when the separation in RV between the two components is considerable, the crowding of lines in the secondary’s spectrum tends to obliterate faint but tell-tale traces of the primary lines. The system of \( \alpha \) Equ unfortunately falls into that category, so processing errors are likely to be significant. On the other hand, the relatively high density of lines in a cool secondary spectrum should help to reduce random errors in the measurement of \( q \).

### 5.3.4 Measuring errors

These are errors generated by the cross-correlation itself. Noise in the spectra, and weak or broad cross-correlation peaks, will give rise to random errors in the position of the CCF centroid, while the choice of spectral window employed or any continuum truncation that has been applied can cause bias, as discussed by Griffin et al. (2000).

The degree to which measuring errors are in effect largely processing errors depends on a considerable extent upon the spectral type of the secondary star. Mismatch between the primary and its surrogate generates weak residual lines (ghost spectrum) in the rest-frame of the primary component, i.e. at zero velocity. If the extracted secondary spectrum has a metallic-line-type of \( \sim \) mid-A or later, cross-correlating it with a corresponding mid-A dwarf spectrum will pick up a signal from the ghost spectrum which will generate a cross-correlation peak at zero velocity, causing a bias (drag) in the measured CCF centroid position.

Even if the subtraction has left no ghost spectrum, another problem will arise if the two secondary spectra that are cross-correlated against one another (Method B) were both derived by subtraction of the same surrogate primary from the composite spectrum, since a zero-velocity autocorrelation peak will be generated by the identical components of the noise patterns in the two secondary spectra. As explained in Paper 9 (Griffin & Griffin 2000a), the problem can be avoided by the use of alternative surrogates, or independent observations of the same one, and it was for that reason that \( \eta \) Psc and \( \epsilon \) Scru were both used as surrogates in the subtractions involving the high-dispersion observations; different versions of the secondary spectrum at the two nodes could then be cross-correlated against one another without risking a systematic error from an autocorrelation signal.

The systematic errors caused by primary-spectrum mismatch will be reduced if the measured and the autocorrelation CCFs are well resolved, as will occur if the velocity displacement between the component stars is large, the spectral resolution is sufficiently high, and the secondary has narrow lines and thus generates a narrow CCF. (An autocorrelation peak is normally very sharp on account of the high frequencies associated with noise.) For \( \alpha \) Equ the difficulty of achieving correct subtractions may have been exacerbated by the lack of a wide variety of observed standards with types near G7 III. For both Method A and Method B the spectra of \( \alpha \) Equ B were therefore blanked off above 95 per cent of the continuum height, as a precautionary measure to reduce autocorrelation drag. The full effects cannot of course be entirely eliminated, since the ghost lines do not occur only in the continuum.

The uncertainty in our measurement of \( q \) in \( \alpha \) Equ is therefore expected to be dominated by systematic errors, which include the drag of the autocorrelation peak, the choice of windows for cross-correlation, and bias arising from applying the 95 per cent cut-off.

The following section investigates the relative importance of the different errors and the extent to which they jointly limit the accuracy and precision of our results.

#### 5.3.5 Assessment of errors in \( q \) for \( \alpha \) Equ

Internal errors in the subtraction procedure are assessed by comparing results derived from different spectra that have been processed identically, i.e. with the same surrogate. Processing errors are isolated by comparing independent analyses of the same original spectra, i.e. using different surrogates. Comparisons of the averaged results from different sources of original data provide a measure of the total random error, while tests on the cross-correlation method itself expose any bias (systematic error).

Assessment of our different measurements of \( q \) is hampered by the fact that the true value of \( q \) is not known. Additional tests were therefore carried out in null mode, i.e. by cross-correlating different versions of the \( \alpha \) Equ B spectra from the same node, when the RV displacement is strictly zero. That option was possible for the CCD and the DAO spectra, but not for the MW spectra.

This error analysis largely refers to the high-dispersion measurements, since more than one observation of the composite spectrum had been made at high dispersion for at least one node. A more thorough analysis would require the set of standards to include alternative surrogates that are apparently identical— a condition that becomes harder to meet the higher the dispersion employed. It is also a difficult requirement to meet in advance.

<table>
<thead>
<tr>
<th>Nature of test</th>
<th>Average ( \Delta q )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal errors (random)</strong></td>
<td></td>
</tr>
<tr>
<td>Same surrogate, different versions of ( \alpha ) Equ B:</td>
<td></td>
</tr>
<tr>
<td>DAO spectra at 2.4 ( \AA ) mm(^{-1})</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td>DAO spectra at 10 ( \AA ) mm(^{-1})</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td><strong>Systematic errors</strong></td>
<td></td>
</tr>
<tr>
<td>Window choice (systematic error)</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td>Cut-off at 95 per cent (systematic error)</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td><strong>Cross-correlation errors specific to Method A</strong></td>
<td></td>
</tr>
<tr>
<td>Using different templates, CCD spectra</td>
<td>( \pm 0.03 )</td>
</tr>
<tr>
<td>Using different templates, 2.4 ( \AA ) mm(^{-1}) plates</td>
<td>( \pm 0.04 )</td>
</tr>
<tr>
<td>Comparison of results from different nodes:</td>
<td></td>
</tr>
<tr>
<td>MW spectra</td>
<td>( \pm 0.05 )</td>
</tr>
<tr>
<td>DAO spectra at 10 ( \AA ) mm(^{-1})</td>
<td>( \pm 0.07 )</td>
</tr>
<tr>
<td>CCD spectra (versus ( \alpha ) 60 Leo)</td>
<td>( \pm 0.06 )</td>
</tr>
<tr>
<td>DAO spectra at 2.4 ( \AA ) mm(^{-1}) (versus 60 Leo)</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td>CCD spectra (versus ( \epsilon ) Ser)</td>
<td>( \pm 0.14 )</td>
</tr>
<tr>
<td>DAO spectra at 2.4 ( \AA ) mm(^{-1}) (versus ( \epsilon ) Ser)</td>
<td>( \pm 0.10 )</td>
</tr>
<tr>
<td><strong>Processing errors measured by Method B</strong></td>
<td></td>
</tr>
<tr>
<td>Different surrogate, same versions of ( \alpha ) Equ B:</td>
<td></td>
</tr>
<tr>
<td>CCD</td>
<td>( \pm 0.00 )</td>
</tr>
<tr>
<td>DAO, 2.4 ( \AA ) mm(^{-1})</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td><strong>Total random error</strong></td>
<td></td>
</tr>
<tr>
<td>DAO plates versus CCD, same surrogate</td>
<td>( \pm 0.01 )</td>
</tr>
<tr>
<td>DAO plates versus CCD, different surrogates</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td>MW plates versus DAO plates at 10 ( \AA ) mm(^{-1})</td>
<td>( \pm 0.02 )</td>
</tr>
<tr>
<td>Method A compared to Method B</td>
<td>( \pm 0.02 )</td>
</tr>
</tbody>
</table>

*‘versus’ means ‘cross-correlated against’.*

since the most appropriate spectral type for the surrogate only becomes known once the reduced and calibrated spectra are being subtracted. The tests are not fully rigorous, in that every cross-correlation measurement contains contributions from internal errors and processing errors. Even if the same surrogate is employed in different subtractions and the same ghost spectrum is present, its relative strength in a secondary spectrum will depend slightly upon the actual fractions that are subtracted; however, these differences are of second order in comparison with the effect of primary-spectrum mismatch itself.

Table 7 lists the different ways in which \( \Delta q \), the average range in \( q \), was determined from the available data; as mentioned above, the values of \( \Delta q \) are not necessarily independent. The results from Method B appear to be more precise than those from Method A. The difference between Methods A and B is a measure of the average discrepancy found between the values of \( q \) as derived from the three independent sources of spectra (see Tables 5 and 6), and reflects one aspect of the ‘total’ error in \( q \).

Neither the identity of the surrogate nor the manner in which the subtractions were performed appears to have had a particularly deleterious effect upon our measurements of \( q \) for \( \alpha \) Equ. In view of the difficulties experienced in finding the best surrogate match and in performing the subtractions optimally, that conclusion is somewhat reassuring.

However, the choice of cross-correlation template in Method A does appear to have had a systematic effect on the measurement of \( q \). Lines in 60 Leo are narrower than those in \( \epsilon \) Ser; their respective \( \sin i \) values have been measured as 14 and \( \sim 35 \, \text{km s}^{-1} \) (Griffin et al. 2000). The lines in \( \alpha \) Equ B are slightly broader than in 60 Leo but narrower than in \( \epsilon \) Ser; \( \sin i \) for \( \alpha \) Equ B was found to be 27 km s\(^{-1} \) from the widths of the Coravel dips (Section 2.1), or 25 km s\(^{-1} \) from a detailed match with synthetic spectra (Section 4.3). Griffin et al. (2000) found that when spectral-type mismatch \( \Delta T \) is minimal, the error in an RV measured by spectrum cross-correlation is entirely dominated by random errors (internal errors) in the spectra. They also demonstrated how even a modest rotational broadening of \( \sim 20-35 \, \text{km s}^{-1} \) in the template spectrum can cause systematic cross-correlation errors for sharp-lined stars when spectrum mismatch is present. The likelihood of errors in the wavelength scale of the template also begins to rise when its lines are a little broadened; an error of only 1 pixel (10 mA˚, on the wavelength scale of the template also begins to rise when its lines are a little broadened; an error of only 1 pixel (10 mA˚, or 0.75 km s\(^{-1} \)) in our high-dispersion spectra) corresponds to a 0.05 error in \( q \) if the measured RV displacements are about 30 km s\(^{-1} \), i.e. similar to those for \( \alpha \) Equ B measured by Method A. In our high-dispersion results we therefore zero-weighted cross-correlations that used the spectrum of \( \epsilon \) Ser as the template.

The substantial differences in the strengths of the Ca II K line in \( \alpha \) Equ B and 60 Leo are equivalent to spectrum mismatch, so that spectral region should be avoided; measurements made with Window 1 were therefore given lower weight than those made with Window 2. In other cases the K-line cores of the primary and/or the surrogate are affected by chromospheric emission, and after subtraction the nett anomaly will appear as an artefact in the spectrum of the secondary star. In many binaries (although probably not \( \alpha \) Equ) the K line is of course also perturbed by an interstellar contribution.

In their studies of A-type spectra, Griffin et al. (2000) showed that truncating the object and template spectra at 95 per cent can bias an RV measurement by up to 0.2 km s\(^{-1} \), presumably through unequal treatment of lines that are close to 5 per cent deep. The purpose of avoiding the continuum region here was principally to reduce the effect of autocorrelation drag. However, the spectrum of \( \alpha \) Equ B contains rather little continuum and rather many lines, so the effect of autocorrelation drag will not have been totally avoided by cutting off the continuum. Nevertheless, at longer wavelengths our spectra show significant stretches of continuum, and it was felt on balance that truncating the spectra was a desirable precaution to take. The amount of bias introduced by truncation is fairly small; a velocity difference \( \Delta \text{RV} \) of 70 km s\(^{-1} \) between two secondary spectra was found to be reduced on average by 0.5 km s\(^{-1} \) when the spectra were truncated to 95 per cent of the continuum, i.e. \( \Delta q = 0.015 \).

The total random error was estimated from cross-correlation tests carried out on independent (CCD or photographic) secondary spectra observed at high dispersion at the same node. The result (\( \pm 0.02 \)) is in fact reflected precisely in the overall difference between the two methods: 1.14 (Table 5), or 1.16 (Table 6). By combining quadratically the total random error and the systematic errors introduced by truncation (\( \pm 0.015 \)) and window selection (\( \pm 0.01 \)), we derived a total error in \( q \) of \( \pm 0.03 \).

5.3.6 Factors affecting the uncertainties for \( \alpha \) Equ

From the foregoing, we conclude that the poorer performance of Method A is due as much to the proportional increase in errors associated with measuring smaller values of \( \Delta \text{RV} \) as to the effects of spectrum mismatch between \( \alpha \) Equ B and the template (60 Leo). On the other hand, the A-type template spectrum used in Method A is pure; the same cannot be said of any of the spectra employed as templates in Method B.

If \( \Delta \text{RV} \sim 70 \, \text{km s}^{-1} \) (see Table 6), an error of 0.7 km s\(^{-1} \) in the measured RV translates into \( \Delta q \approx \pm 0.02 \). As \( \Delta \text{RV} \) decreases, the corresponding error in \( q \) rises (to 0.07 when \( \Delta \text{RV} = 20 \, \text{km s}^{-1} \), and 0.14 when \( \Delta \text{RV} = 10 \, \text{km s}^{-1} \)). Interference from an autocorrelation peak may also become more serious for smaller \( \Delta \text{RV} \).

An error in the value of \( K_1 \) given by the RV orbit can be an important source of systematic error in \( q \), and there is no internal check for it in this study except perhaps the observation that \( q \) derived by Method B tended to be higher than that derived by Method A.

There is evidence that the CCD spectra give slightly more precise values of \( q \) than the photographic spectra, although not by the margin that might be expected from their superior S/N ratios. We conclude that the dominant uncertainties are not internal errors (which reflect the quality of the original spectra) but processing errors, which in the case of \( \alpha \) Equ can largely be attributed to the general similarity between the two component spectra.

We also note a tendency for our value of \( q \) to depend slightly upon the type of observational material, being smaller for CCD spectra than for photographic ones taken with the same spectrograph. It is possible that the difference is in some way attributable to the smallness of spectral regions observed by the chip. (The CCD in question has since been replaced by one of approximately twice the spectral coverage.)

The reason for smoothing to generate semblances of low-dispersion spectra from the 2.4 Å mm\(^{-1} \) DAO photographic observations was to assist the spectral classification of \( \alpha \) Equ B. The smoothing was performed with a simple broadening function without regard to details of the instrumental profile of the spectrograph in question. Tables 5 and 6 show similar systematic differences between the results derived from modified DAO spectra and those from the MW ones. The measurements from the modified DAO spectra were in any case zero-weighted because of redundancy with the results from the high-dispersion versions.
However, those sets assisted the error analysis insofar as they included multiple exposures per node.

From consideration of the above arguments, the best value for \( q \) as determined in this paper is judged to be \( 1.15 \pm 0.03 \).

### 5.3.7 Previous determinations of \( q \)

The RV measurements and analyses for \( \alpha \) Equ contributed by Deutsch (1954), Stickland (1976), Pike (1978) and Rosvick & Scarfe (1991) were summarized in Section 1, where it was argued that some determinations of \( q \) were biased by blending between the lines of the two component spectra. Deutsch called \( \alpha \) Equ ‘another Capella’ because of the curious visual effects of blending between the spectra of the two components, although in fact (Fig. 4) the secondary’s lines are not so much broad and asymmetrical as very plentiful, and mostly heavily blended with those of the primary; Deutsch’s value of \( q = 0.26 \) reflects the effect of that blending.

Stickland, in his analysis (and re-analysis of some of Deutsch’s plates), derived \( K_2 \) solely from measurements of the close doublet of Mg II at 4481 Å, although (as he admitted) ‘the G star certainly makes some contribution’ to that feature. Fig. 6 bears out that statement; the original dispersion was very similar to that used by Stickland. The thin line in each of the two panels is the observed composite spectrum at opposite nodes, while the thick line is the secondary spectrum as extracted from the composite one. Although the bulk of the irregular feature near 4481 Å in the composite spectrum can be attributed to the secondary, it is clear that lines from the primary distort its profile and contribute to its measured velocity. The standard error of 0.77 km s\(^{-1}\) given for Stickland’s value of \( K_2 = 12.49 \text{ km s}^{-1} \qquad (q = 0.80) \) does not include the larger systematic error due to dragging by the primary’s lines.

Pike’s (1978) application of a cross-correlation technique to scans of Stickland’s plates certainly improved the precision for \( K_1 \). However, the CCF that he derived for the secondary had a weak signal (high random error), so he based his A-star velocity measurements on the Ca II K line alone, warning that his measurement of \( q = 1.25 \pm 0.08 \) was likely to be a lower limit on account of blending with the G-star lines. In fact that influence may be fairly small (see Fig. 7); his error in \( q \) is probably dominated by random errors stemming from the considerable natural width of the K line.

Rosvick & Scarfe (1991) were the first to isolate the spectrum of the secondary in order to measure its RV, and their results are therefore likely to be the most accurate to date. They applied their procedure to the region \( \lambda \lambda 4000–4080 \) Å and cross-correlated the residue against 68 Tau, an A-type dwarf which was classified at low dispersion as A2 IV–V (Gray & Garrison 1987) but whose high-dispersion analysis (Adelman 1994) shows conclusively its Am nature. Rosvick & Scarfe applied their subtraction procedure to 26 observations covering all phases and derived \( q = 1.14 \pm 0.06 \), which appears to agree very well with the result of the present paper. However, we argued in Section 2 for a correction of \( +0.3 \text{ km s}^{-1} \) to their value of \( K_1 \) to allow for residual effects of dragging by the primary’s lines; application of that correction would reduce their value of \( q \) to 1.126. We note that our own measurement of \( q \) from a sample of the same DAO plates is 1.13 — see Table 6, 2(c); the result in 2(d) is very similar, but was zero-weighted as explained in Section 5.3.5.

In order to evaluate the significance of that close agreement, it is necessary to examine the actual errors affecting Rosvick & Scarfe’s value. The \( \sigma \) \( q \) of \( \pm 0.046 \text{ km s}^{-1} \) derived by them, and which was subsequently adopted at face value by Armstrong et al. (1992), is only the formal random error derived from the scatter in the double-lined orbit solution. Examination of Rosvick & Scarfe’s table of A-star velocities shows that their derivation of \( q \) is heavily affected by one somewhat errant value; giving that measurement low weight alters their solution for \( q \) by \( -0.03 \). Their value of \( q \) would then be 1.10, but the two investigations would still agree to within their stated error bars.

Rosvick & Scarfe (1991) acknowledged the likelihood of substantially greater systematic errors stemming from uncertainties in their reduction procedures, and although they did not investigate it quantitatively they suggested that the true error in \( K_2 \) was ‘probably more on the order of 2 or 3 km s\(^{-1}\)’. An error of \( \pm 2 \text{ km s}^{-1} \) in \( K_2 \) translates to an uncertainty of \( \pm 0.12 \) in \( q \). It would not be surprising if Rosvick & Scarfe’s A-star velocities were affected to some extent by remnants of the primary’s lines resulting from an imperfect match between primary and surrogate spectrum; their cross-correlation measurements on the extracted secondary spectra of \( \alpha \) Equ B were confined to 10 lines, all but one of which have stronger counterparts in the spectrum of the giant.

### 6 PHOTOMETRIC MODEL FOR \( \alpha \) EQU

The subtraction procedure yields the ratio of the fluxes of the two components of a composite spectrum as a function of wavelength. A comparison between those flux ratios for \( \alpha \) Equ and normalized measurements of stellar fluxes (Willstrop 1965) indicated that the luminosity of \( \alpha \) Equ B is lower in \( V \) than that of \( \alpha \) Equ A by a factor of 0.63–0.65, i.e. \( \Delta m_V = 0.47–0.50 \). That value agrees well with the value of \( 0.47 \pm 0.06 \) measured interferometrically at \( \lambda 5500 \) Å by Armstrong et al. (1992). The best match with Willstrop’s standards was found by combining spectral types G8 III + Am.

For our photometric model we therefore took \( \Delta m_V = 0.47 \), and a
combined $M_V$ of $0.17 \pm 0.07$ corresponding to the distance modulus derived from the mean parallax measurement (Section 1); we adopted the colour indices of 31 Vul for the primary, and those of $\alpha$ Cnc for the secondary, taking measurements from Johnson et al. (1966). The colours for $\alpha$ Equ have been measured as $(B - V) = 0.52$, $(U - B) = 0.30$ (Johnson et al. 1966); the Hipparcos value for $(B - V)$ is 0.549. The resultant model (Table 8, Model 1) yielded colours that are near to the observed ones but are both a little too blue.

The cause for the discrepancies is not difficult to find. The model is simple and contains no theoretical assumptions. Interstellar reddening is not likely to be significant either for the model stars or for $\alpha$ Equ. The uncertainty in $\Delta m_V$ is not sufficient by itself to account for the discrepancies between Model 1 and observation, so the colours chosen for the model stars must be in error. Since the model colours used for the dwarf are those of an appropriate Am star, there is little ground for altering them by the amounts required. On the other hand, some redward adjustment to the colours adopted for the giant might well be expected because of the slightly abnormal atmosphere of the surrogate giant, 31 Vul. The Bright Star Catalogue (Hoffleit 1982) notes it as ‘CN –1’, while Ginestet et al. (1994) offer the qualification ‘Fe–1’. Analysts disagree as to whether the metallicity of 31 Vul is almost solar, e.g. $[\text{Fe/H}] = -0.04$ (Luck 1991), or slightly deficient: $[\text{Fe/H}] = -0.23$ (McWilliam 1990). However, whether or not its metal lines are generally weak, the reduced blanketing by the violet CN bands will cause its measured colours to be slightly bluer than those of a star with more normal CN line-strengths. If the CN band is weak, the reduced blanketing by the violet CN bands will also be weakened, so both $U$ and $B$ will be affected.

Spectroscopic analyses of 31 Vul give $T_{\text{eff}} = 5060 \, \text{K}$ (McWilliam 1990) or $5100 \, \text{K}$ (Luck 1991), whereas according to Flower (1996) its $(B - V)$ of 0.82 corresponds to 5230 K. For $T_{\text{eff}} = 5100 \, \text{K}$, the same transformation gives $(B - V) = 0.87$. We therefore reddened $(B - V)$ and $(U - B)$ for the giant star by +0.05 (Model 2, Table 8), and recovered the observed colours for $\alpha$ Equ almost exactly.

Our values for $M_V$ for both components are between 0.2 and 0.4 mag brighter than is listed for the corresponding stellar types (Schmidt-Kaler 1982). However, there is little scope for errors of that size in the empirical values. The Hipparcos and the orbital parallaxes agree within their quoted uncertainties. The period of the system is not a simple sub-multiple of a year, so it is unlikely that the movement of the photocentre of the binary could have caused a systematic error in the Hipparcos parallax measurement. The individual values of $M_V$ thus appear to be quite tightly constrained, and since the uncertainty in $\Delta m_V$ is only +0.06 we conclude that both stars are slightly over-luminous for their deduced spectral types. There is indeed evidence (Section 8) that the secondary has evolved away from the main sequence.

### 7 PHYSICAL PARAMETERS

The assessment of the evolutionary status and age of $\alpha$ Equ (Section 8) requires knowledge of the physical parameters ($T_{\text{eff}}$, $M_{\text{bol}}$, $R$, $L$, $M$) of the component stars. $M_{\text{bol}}$ and $L$ are determined from $M_V$ and from the bolometric correction (BC) corresponding to $T_{\text{eff}}$, as described below for the two stars individually. $T_{\text{eff}}$ is therefore of central importance.

The mass function, $f(m) = M_2 \sin^3 i / (1 + q)^2$, is evaluated as $0.0463$. With $i = 28^\circ5 \pm 1^\circ1$ (Armstrong et al. 1992), we obtain $M_2 = 2.0 \pm 0.23 \, M_\odot$, so $M_1 = 2.3 \pm 0.27 \, M_\odot$. The errors were derived quadratically from the uncertainties in $i$ and $q$.

The separation, $a$, between the component stars is given by $a \sin i (1 + q) / \sin i$. The orbit gives $a \sin i = 22.46 \, \text{Gm}$, whence $a = 101 \, \text{Gm}$, or 145 $R_\odot$. The system is therefore well detached.

#### 7.1 Giant component

In the light of the discussion in Section 6 and the results for Model 2 (Table 8), we adopted $T_{\text{eff}} = 5100 \pm 150 \, \text{K}$ for $\alpha$ Equ A. The BC (Flower 1996) is $-0.26 \pm 0.06$, so $M_{\text{bol}} = 0.45 \pm 0.09$; the uncertainty also includes $\pm 0.07$ in $M_V$. The derived radius of $\alpha$ Equ A is then $R_1 = 9.2 \pm 0.7 \, R_\odot$, its luminosity $\log L_1 / L_\odot = 1.72 \pm 0.04$, and its surface gravity $\log g = 2.9$. The uncertainties in $R$ and $L$ were calculated by combining quadratically the independent uncertainties in $T_{\text{eff}}$ and $M_{\text{bol}}$. The results are listed in Table 9, together with estimates of the corresponding uncertainties.

### Table 8. Photometric model for $\alpha$ Equ.

<table>
<thead>
<tr>
<th>Object</th>
<th>$M_V$ (m)</th>
<th>$(B - V)$ (m)</th>
<th>$(U - B)$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary (G7 III)</td>
<td>0.71</td>
<td>0.82</td>
<td>0.47</td>
</tr>
<tr>
<td>Secondary (A4; Am)</td>
<td>1.18</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Combined</td>
<td>0.17</td>
<td>0.49</td>
<td>0.28</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary (G7 III)</td>
<td>0.71</td>
<td>0.87</td>
<td>0.52</td>
</tr>
<tr>
<td>Secondary (A4; Am)</td>
<td>1.18</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Combined</td>
<td>0.14</td>
<td>0.52</td>
<td>0.30</td>
</tr>
<tr>
<td>$\alpha$ Equ (observed)</td>
<td>0.17</td>
<td>0.53</td>
<td>0.30</td>
</tr>
</tbody>
</table>

### Table 9. Physical parameters of the components of $\alpha$ Equ.

<table>
<thead>
<tr>
<th>Star</th>
<th>Type</th>
<th>$M_V$ (m)</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>BC   (m)</th>
<th>$M_{\text{bol}}$ (m)</th>
<th>$R$ ($R_\odot$)</th>
<th>$\log L$ ($L_\odot$)</th>
<th>$M$ ($M_\odot$)</th>
<th>$(B - V)$ (m)</th>
<th>$(U - B)$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>G7 III</td>
<td>0.71</td>
<td>5100</td>
<td>$-0.26$</td>
<td>$0.45$</td>
<td>9.2</td>
<td>1.72</td>
<td>2.3</td>
<td>0.87</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\pm 0.07$</td>
<td>$\pm 150$</td>
<td>$\pm 0.06$</td>
<td>$\pm 0.09$</td>
<td>$\pm 0.7$</td>
<td>$\pm 0.04$</td>
<td>$\pm 0.3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td>0.96</td>
<td>5200</td>
<td></td>
<td></td>
<td>8.2</td>
<td>1.64</td>
<td>2.45</td>
<td>0.86</td>
<td>0.49</td>
</tr>
<tr>
<td>Secondary</td>
<td>A4m</td>
<td>1.18</td>
<td>8150</td>
<td>$+0.02$</td>
<td>$1.20$</td>
<td>2.6</td>
<td>1.42</td>
<td>2.0</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\pm 0.07$</td>
<td>$\pm 200$</td>
<td></td>
<td>$\pm 0.07$</td>
<td>$\pm 0.2$</td>
<td>$\pm 0.03$</td>
<td>$\pm 0.2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td></td>
<td>1.22</td>
<td>8180</td>
<td></td>
<td></td>
<td>2.6</td>
<td>1.44</td>
<td>2.1</td>
<td>0.12</td>
<td>0.13</td>
</tr>
</tbody>
</table>

7.2 Dwarf component

Determining $T_{\text{eff}}$ for $\alpha$ Equ B is complicated by the metallic-lined nature of its spectrum. It was indicated in Section 4.3 that a synthetic spectrum calculated for $T_{\text{eff}} = 8000$ K gave a close match to the Balmer-line profiles in the extracted spectra of $\alpha$ Equ B, but the model used solar abundances and therefore did not allow for any rise in $T_{\text{eff}}$ from back-warming due to the extra metal-line absorption. The value of $T_{\text{eff}} = 8150$ K, corresponding to $(B-V) = 0.14$ in Flower’s transformation, is therefore reasonably close to the Balmer-line temperature, and will be adopted here; its quoted uncertainty of $\pm 200$ K is equivalent to $\pm 0.03$ in $(B-V)$, which may represent the uncertainties in Table 8. The BC for that $T_{\text{eff}}$ (Flower 1996) is $+0.02$. The derived radius of the secondary is then $R_2/R_\odot = 2.6 \pm 0.2$ and the luminosity is $\log L_2/L_\odot = 1.42 \pm 0.03$, the uncertainties including contributions of $\pm 0.07$ from $M_v$ and 0.01 from the BC. That value for the radius is about 30 per cent above the average for a mid-A dwarf (Andersen 1991), and supports the over-luminosity (found in Section 6) of at least 30 per cent above the average for a mid-A dwarf (Andersen 1991), and is in fact close to that quoted for a sub-giant. The calculated surface gravity ($\log g = 3.93$) is also slightly on the low side for a mid-A dwarf.

8 EVOLUTIONARY STATUS OF $\alpha$ EQU

8.1 Evolutionary tracks

In Fig. 8 the positions of the component stars in the $\log T_{\text{eff}}, \log L$ plane are compared to theoretical evolutionary tracks calculated from models and routines now in the public domain (Pols et al. 1998). The grids of models used here include overshooting, as recommended by their authors. The routines handle the effects of core overshooting and any rotationally-induced meridional mixing by what is described as ‘a simple overshooting prescription’, leading to a single parameter (overshooting length) that varies slightly with stellar mass. The choice of models was limited to pairs whose masses conformed to the values given in Table 9. Although metallicity is an additional variable parameter, the uncertainties associated in the present case with the measured quantities, and with the evolutionary theory itself, precluded unambiguous evidence of non-solar metallicity, so the curves in Fig. 8 represent models with solar metallicity. The error bars shown are those recorded in Table 9, where the physical parameters of the relevant models are also included.

The primary appears to be just commencing its first ascent of the red-giant branch. We recall that the photometric model (Section 6) indicated that the giant is over-luminous by $\sim 0.2-0.3$ mag. Table 9 also shows that the star is 0.25 mag brighter in $M_v$ than the model; however, about 0.1 mag of that difference is due to the larger BC values used in the evolutionary models. The secondary has already evolved away from the main sequence; its $M_v$, $R$ and $\log g$ are indeed characteristic of a sub-giant.

The conclusions drawn from Fig. 8 do depend upon the assumption, yet to be verified, that the overall metallicity of both components is approximately solar. Increased metallicity (to $Z = 0.03$) improves considerably the fit to the point for the secondary star, but worsens it substantially for the primary. However, it seems unlikely that the overall metallicities of the components of such a binary will not be the same.

8.2 Isochrones

Comparisons with theoretical isochrones calculated from the same sets of models (Pols et al. 1998) indicated that both points could be fitted satisfactorily to the isochrone calculated for solar metallicity and log(age) = 8.87 (Fig. 9), i.e. age since the ZAMS = 0.74 Gyr.

Comparisons with other sets of isochrones published in tabular form (Bertelli et al. 1994) gave results that were generally very similar to those above, but the degree of detail that could be fitted was limited by the coarseness of the grid.

Armstrong et al. (1992) estimated the age of the $\alpha$ Equ system to be near 0.6 Gyr, though they admitted some difficulty in fitting a unique isochrone to their stellar points and in assigning spectral types that were consistent with their photometric model. Those difficulties seem to have stemmed from the presumption that the secondary is a normal dwarf.

Figure 8. The $\log L, \log T$ positions deduced for the component stars are compared to theoretical evolutionary tracks for 2.1 and 2.45 $M_\odot$ and solar metallicity ($Z = 0.02$), calculated from models and software supplied by Pols et al. (1998).

Figure 9. Comparison between the $\log L, \log T$ positions of the component stars, and an isochrone calculated for 0.74 Gyr and solar metallicity from models and software supplied by Pols et al. (1998). The agreement for both points suggests their coeval formation.
9 SYNOPSIS, AND CONCLUDING REMARKS

The accurate visual orbit determined for α Equ interferometrically (Armstrong et al. 1992) yielded accurate values for the system's orbital inclination, magnitude difference (∆mᵥ) and distance. The last two have been confirmed independently: ∆mᵥ by the spectroscopic analysis described above, and the distance by the Hipparcos parallax.

Binary stars in which both components have accurately known parameters are of immense value as test-beds for quantitative stellar-evolution calculations (Schröder, Pols & Eggleton 1997). The best-measured stars for that purpose to date include members of the small group of ζ Aur stars (eclipsing composite-spectrum systems), since their eclipse photometry and spectroscopy can lead to precise determinations of their geometry (Griffin et al. 1990). However, their low rates of eclipse ingress and egress together with the possibility of intrinsic photometric variations in some of the luminous primaries give rise to errors in the determinations of radii, with possibly other uncertainties related to limb-darkening. α Equ A has more modest luminosity and is therefore less affected by those problems, and although it does not offer the advantages of eclipses we should now rank α Equ A among the more precisely measured evolved stars, and the α Equ system as one of the more accurately studied binaries containing an evolved component.

In this paper we have isolated 800 A˚ of the spectrum of the secondary, and have shown that the secondary star has strong Am characteristics -- a factor which was no doubt instrumental in preventing Armstrong et al. from reaching satisfactory agreement with theoretical models. We have determined the mass ratio, q, from measurements of the RV of the isolated (almost pure) secondary spectrum, and demonstrated the ability of the subtraction technique to furnish superior precision for q compared to methods that measure the secondary spectrum in the presence of the primary. We have placed tight constraints on the choice of theoretical models for the component stars, and have been able to show that the stars are coeval, at 0.74 Gyr. The information currently at our disposal is insufficient to show whether there could be any causal link between the evolutionary status, binary membership and enhanced surface metallicity of the secondary star; this study of α Equ has, however, contributed one of the many data points upon which such an investigation must be based.

We have discussed the systematic ‘dragging’ (towards the primary’s velocity) that can occur in measurements of the secondary as a result of blending with the primary’s lines, a problem that is particularly acute in a system such as α Equ interferometrically (Armstrong et al. 1992) yielded accurate values for the system’s orbital inclination, magnitude difference (∆mᵥ) and distance. The last two have been confirmed independently: ∆mᵥ by the spectroscopic analysis described above, and the distance by the Hipparcos parallax.

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We have discussed the systematic ‘dragging’ (towards the primary’s velocity) that can occur in measurements of the secondary as a result of blending with the primary’s lines, a problem that is particularly acute in a system such as α Equ where the primary and secondary spectra have many lines in common, and we have shown that some degree of dragging is likely even if most of the primary’s spectrum has been removed. The high density of lines in α Equ B means that remnants of primary spectrum are unusually difficult to discern, except perhaps in brief continuum regions at the longest wavelengths studied (see Fig. 5); unfortunately, the S/N ratio in the extracted spectra deteriorates towards the red as the flux level of the secondary decreases. In fact, the presence of ghost primary lines in extracted spectra of α Equ B threatens to cause problems even when the RV separation between the components is maximal. Systematic errors in q in such a system may therefore be substantially greater than random errors.

Our determination of q by cross-correlation took advantage of spectra observed at opposite orbital nodes, while the error analysis took advantage of spectra observed independently at the same node. The error analysis investigated all the errors likely to affect our determination of q, and included a comparison of results derived from spectra taken with different equipment. Our value of q = 1.15 ± 0.03 is very close to the value obtained by Rosvick & Scarfe (1991) but has greater precision. Applying to Rosvick & Scarfe’s value the universal blending correction that we derived from our own results makes that agreement less good.

The separation of the component spectra led to an accurate classification of the spectral types of α Equ as G7 III + Am (kA3hA4mA9), despite compromises in the choice of standards because of the individuality both of late-G giants and of mid-Am dwarfs. Our photometric model yielded slightly bluer colours for the system than those observed, probably because the surrogate standard for the giant was a weak-CN star.

Spectroscopic analyses of the component stars should now be undertaken in order to determine their atmospheric parameters (T eff, metallicity), with particular emphasis on details of the Am phenomenon. An Am-type spectrum is characterized by an enhancement of some metallic lines and a decrease of others, compared to a non-Am star of the same T eff, but not necessarily by an overall metal enhancement (Adelman et al. 1997); diffusion is widely considered the chief agent responsible for redistributing the elements in the atmosphere. A chemical analysis of α Equ B will be particularly interesting in view of the fact that the age of the components is unusually well known. Our extracted spectra (see Fig. 4), which clearly show enhancements in rare-earth lines, should be adequate as starting material, the first goal being a fully consistent set of values for T eff, log g and R2. For the giant, abundance investigations require high-dispersion spectroscopy at red wavelengths; continuum-level corrections can be calculated from the flux ratios measured by Armstrong et al. (1992) for the component stars. The results for both stars will also provide valuable tests of the models from which the evolutionary tracks were calculated, particularly with regard to the prescription of convective ‘overshooting’.

A different approach to the analysis of composite spectra is to employ a technique of robotic disentangling, e.g. Korel (Hadrava 1995). A major advantage of that method (particularly for a system such as α Equ) lies in the fact that it does not require a standard spectrum, so there can be no ghost primary spectrum to influence the measurement of the RV shift in the secondary. On the other hand, it requires an adequate sample of high S/N ratio observations of the same wavelength region(s) at phases on both sides of conjunction. The spectra described in this paper are insufficient to support such an investigation, which must therefore be the subject of a future paper on the α Equ binary.

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