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Composite Spectra
Paper 2: HD 88021/2

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Abstract. HD 88021/2 (ADS 7662) is a very close visual binary. The accepted visual orbit, which is of very high eccentricity and graded “reliable”, led to the expectation of a periastron passage in 1981, when there should have been a large difference in radial velocity between the components. No such event took place, and there is little indication that it is likely to occur in the near future. A new interpretation of the visual orbital data leads to an orbit of a different character from those hitherto proposed. A decision between the competing orbits should be possible within a very few years. Meanwhile, the method of spectral subtraction developed in Paper 1 has enabled us to separate the spectra of the two components and to show that their spectral types are K0 III and A2m.

Key words: composite spectra—visual binaries—stars, individual

1. Introduction

In Paper 1 (Griffin 1986) we showed how, by a technique of spectral subtraction, it is possible to disentangle the contributions of the individual component stars to a composite spectrum. Such a spectrum is frequently encountered when a binary star system has an angular separation that is too small to permit the components to be resolved on the spectrograph slit. The system treated in Paper 1 (HR 6902) must have an angular separation of only a few milliseconds of arc and has never been resolved directly. The one treated in the present paper has been known as a difficult visual double star since 1910; its maximum separation is less than 0″.25 and there has been no possibility of observing the spectra of the components separately. Indeed, the measurements simply of its position angle and separation have created such uncertainties that six different orbits have been proposed; even the accepted one is grossly erroneous, as we show from radial-velocity observations.

2. Existing knowledge concerning HD 88021/2

Miss Cannon, in the course of compiling the *Henry Draper Catalogue*, was the first person to examine the spectrum of the object with which we are concerned in this paper. She recognized it as composite, and accordingly invested it with two HD numbers—HD 88021, type F5, and HD 88022, type A2 (Cannon & Pickering 1919). Not many years previously, Aitken (1910) had discovered the duplicity of the system by direct visual observation with the Lick 36-inch refractor; he saw the object as consisting of two equally bright stars only 0".15 apart, and gave it the discoverer's designation A 2145.

Photoelectric *UBV* photometry of the system has been carried out by Häggkvist (1965), Eggen (1965) and Sanders (1966), with results near $V = 6^{m}.66$, $(B - V) = 0^{m}.54$, $(U - B) = 0^{m}.32$.

The comprehensive study of composite spectra by Hynek (1938) included HD 88021/2 as no. 304. Curiously, Hynek classified the system as belonging to his Class I, whose definition is "Composite spectrum arising from a physical binary whose component stars are not resolvable even with the largest instruments . . .", rather than Class III ("Very close physical pair, observable as a binary, but whose component spectra cannot be obtained separately"); and he did so notwithstanding that Aitken (1932) had explicitly pointed out the seemingly obvious fact that "The composite spectrum doubtless is due to the two components of the visual pair .". Hynek also noted that the system was on the radial-velocity programme at Mount Wilson; the interest in it there proved to be rather short-lived, but the results of the four spectrograms taken at Mount Wilson have been published by Wilson & Joy (1950) as a mean velocity and by Abt (1970) with individual details. Radial velocities have also been published by Heintz (1981) from three Kitt Peak spectrograms taken in 1979, and by Beavers & Eitter (1986) from four photoelectric measurements taken in 1977/8. All the published radial velocities are consistent with the hypothesis that HD 88021/2 shows a constant velocity of about +12 km s^{-1}.

Several attempts have been made to classify the spectra of HD 88021 and 88022 from observations of the composite spectrum. Stephenson & Sanwal (1969) and Markowitz (1969) gave the types as G2 III and A2 V; the former authors also derived for the system, from a now-discredited visual orbit (Baize 1957), the improbable total mass of 15.52 $M_{\odot}$. The types gG5 + A2 are quoted in the catalogue of Finsen & Worley (1970), but we have not located the original source. More recently, Abt (1981) has recognized HD 88022 as being a metallic-lined A star: he classified the system as Am + F5 III, and gave the calcium and hydrogen-line types of the early component as A2 and F1 respectively. We shall show below that the Am nature of HD 88022 is confirmed, but that all classifications of the cooler star (HD 88021) have placed it at much too early a type. That is a general tendency in the classification of composite spectra: it seems that the classifier, confronted with a spectrum in which the late-type lines are heavily veiled by the superposition of the more muted spectrum of the early-type component, cannot bring himself to accept that such weak lines could originate from a star of such a late type as is actually the case.

Abt & Cardona (1984), who give the same types as Abt (1981), make a clear (if implicit) claim to have taken classification spectrograms of the two stars separately. We feel that that claim must be either inadvertent or mistaken, not merely because of its manifest improbability but also because expert classifiers would never make such a gross error as Abt & Cardona do in respect of the type of HD 88021 if they could see its spectrum in isolation from that of its companion.

2.1 The Visual Orbit

Double-star observers have long known HD 88021/2 as ADS 7662, its number in Aitken's (1932) catalogue, and we shall so designate it in this section. Nobody except Aitken measured the pair between 1910, when he discovered it, and 1937, after he had retired. It has subsequently turned out that the Aitken era was a more interesting and critical time, as far as the orbit is concerned, than the ensuing half-century has been.

A serious difficulty arises in the interpretation of double-star measurements of ADS 7662, inasmuch as the components are so comparable in magnitude as not to be certainly distinguishable from one another. Although the two stars must be of considerably dissimilar colours, observers seem not to have commented upon the fact, and it has not even been known which spectrum is associated with which star. Thus all measured position angles are subject to a 180° ambiguity. (These remarks are not to be construed as any criticism of the double-star observers: it seems amazing to us that anyone can measure pairs of such extreme difficulty. As mere spectroscopists, we have observed the object more than 50 times ourselves and seen it as a single star every time!)

The discovery observation, averaged with two others made shortly afterwards, was reported as giving a separation of 0″.15 in position angle 195°.3 (Aitken 1910). In view of the fact that the components were attributed identical magnitudes, we are at a loss to know why the position angle should have been assigned to the third quadrant and not, as would seem more natural, to the first. The next observations, in 1918 and 1919, are simply reported by Aitken (1932) as "Too close". Although he occasionally recorded objects as "single", "round" and "no elongation" (*cf.* the entries in the ADS for ADS 3264,2178 and 7107), Aitken used the expression "too close" so regularly that we think it must imply that the relevant binary was unresolved on that occasion and not that it was visibly double but so close as not to be measureable.

Aitken subsequently measured our object in 1921, 1923 and 1925 (Aitken 1932) at separations of rather more than 0″.1 and position angles of 89°.2, 77°.0 and 66°.6, thereby establishing that the motion is retrograde, *i.e.* in the direction of decreasing position angle (clockwise on the sky). His final observation (Aitken 1937) was made in 1933 and gave the position angle as 240°.5.

Between 1937 and 1975 several observers measured ADS 7662. The position angle was generally considered to lie in the third quadrant, but to what extent that became merely a matter of convention is not clear; some observers saw a small difference of magnitude, ranging up to $0^{m}.4$ (Worley 1962), between the components. During that whole 40-year interval the separation of the system was near 0″.2 and the position angle declined only very slowly, from about 230° to 200°. In 1975 the age of speckle interferometry dawned for ADS 7662 (McAlister 1977); it is no disparagement of the filar-micrometer heroes to say that since then, with much larger telescopes and much more complicated equipment, the system has been well observed with a new degree of reliability. The position angle has continued to decrease slowly, and the system has at last been closing in separation. The observations are plotted in Fig. 1 to give an impression of the material available for determining the orbit.

As the data of Fig. 1 have unfolded, ADS 7662 has provided embarrassment to a succession of orbit computers, as may be seen from Table 1. The first three orbits (Eggen 1946, Baize 1956, 1957) accepted the 1921–1925 observations as being in the first quadrant, and in order to fulfil Kepler's (1609) second law (equal areas in equal

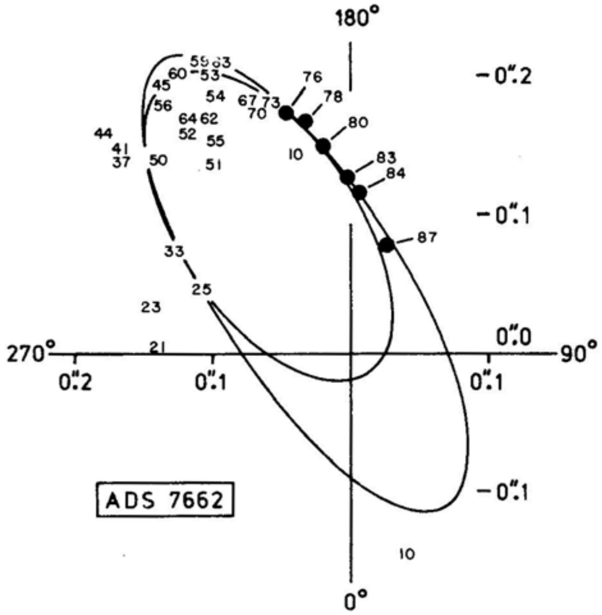

Figure 1. The relative angular positions of the components of ADS 7662 as a function of time The origin of the coördinate system represents the constant position of the primary star, which we shall show in Section 4 to be likely to be the cooler star in the system. The mean position angle and angular distance of the secondary is represented by the last two digits of the year of observation (observations made at the end of a calendar year have been attributed to the following year). Aitken's observations of 1921, 1923 and 1925 are plotted with the quadrdrant reversed. The speckle-interferometry measures made since late 1975 by McAlister and his colleagues (McAlister 1977, McAlister & Fekel 1980, McAlister & Hendry 1982, McAlister *et al.* 1983, McAlister (private communication 1988)) appear to us to be of such reliability that we have elected to portray them differently, as large dots with the year noted beside them. The orbit ellipse must pass very close to them, but it obviously cannot pass equally close to all of the other measurements, and the form of the orbit is still uncertain. The most recent published orbit (Tokovinin 1987) is shown as the smaller ellipse. It accepts the discovery observation of 1910 in its published quadrant at position angle 195°, and demands a very high eccentricity in order to achieve a change of nearly 300° in angle by the time of the next observation in 1921, which however it cannot match in distance at all. We think that another type of possible orbit, which has only moderate eccentricity and therefore requires no special assumption to avoid predicting large radial-velocity changes, is that shown schematically by the larger ellipse. The quadrant of the discovery observation has then to be reversed, to position angle 15° where it is shown near the bottom of the Figure.

times) they necessarily predicted angular motions of several degrees a year. When such motions failed to materialize, such orbits became progressively more untenable, until Baize (1957) proposed an alternative interpretation by transposing the components for the measurements of 1921–1925, placing the position angles in the third quadrant. A more plausible orbit resulted, and the subsequ ent one by Finsen (1977) represented an attempt to improve on it in detail while retaining the same principle. Even so, the orbital motion continued to fall behind expectation, with Finsen's orbit just as with its predecessors, and it seemed certain that the upward trend in periods assigned to ADS 7662 (*cf.* Table 1) must continue. Recently this has in fact happened, with a new

Table 1. Orbital elements successively attributed to ADS 7662.

Element	Eggen 1946	Baize 1956	Baize I 1957	Baize II 1957	Finsen 1977	Tokovinin 1987
P (years)	43.0	48.0	53.73	60.0	64.7	71.1
T (date)	1973.10	1976.5	1981.23	1976.88	1981.75	1990.0
e	0.61	0.54	0.60	0.94	0.949	0.86
a (arcsec)	0.25	0.215	0.21	0.19	0.240	0.129
i (degrees)	103.8	108.5	107.6	124.1	115.8	180.0
ω (degrees)	71.4	54.9	54.9	104.8	104.5	87.9
Ω (degrees)	57.4	58.4	57.8	157.0	161.2	122.1

orbit published by Tokovinin (1987), which has managed to put off the periastron passage until 1990. Recent speckle measurements kindly communicated to us in advance of publication by Dr H. A. McAlister suggest that the orbital motion is already lagging about one year behind Tokovinin's one-year-old prediction.

3. Radial velocities, and the light they shed on the orbit

In 1976 Dr J. Dommanget was kind enough to send us an early draft of his second *Catalogue d' Éphémérides* that was eventually published in 1982 (Dommanget & Nys 1982). It showed the expected variations, as functions of time, of the relative radial velocities of the components of visual binary stars whose orbits had been computed. We noticed that HD 88021/2 was a case where alternative orbits—those of Baize (1957)—led to entirely different radial-velocity behaviours, which would readily be distinguished by just a few measurements. It was an exceptionally good time, just then, to make such radial-velocity measurements, inasmuch as the dramatic periastron passage predicted on the basis of orbit II (eccentricity 0.94) was due to take place at epoch 1976.9 and involved a sudden change of more than $60 \mathrm{km s}^{-1}$ in relative velocity.

We therefore placed the system immediately upon our observing programme with the Cambridge radial-velocity spectrometer (Griffin 1967). The first observation was made at just about the time predicted for periastron. It soon became apparent that little, if any, change was occurring in the radial velocity of the giant component of the system, which was presumed to be the only one to which the spectrometer would respond.

Meanwhile, Baize's (1957) orbits were superseded by Finsen's (1977); by that time 'Baize I' was completely untenable on the evidence of the continuing visual observations alone, and the new orbit was of much the same form as 'Baize II' but even more extreme and with the dramatic periastron passage postponed until 1981.75. Van Dessel (1979) drew attention to the urgent need for radial-velocity coverage, but again the predicted event failed to materialize.

The object has continued under systematic observation right up to the time of writing, and we present in Table 2 the 54 radial-velocity measurements that we have made of it photoelectrically in 1976–1988. A graph of them (Fig. 2) shows a very slight downward trend; a straight line fitted by least squares to the observations has a slope

Table 2. Photoelectric radial velocities of HD 88021, observed at Cambridge except where otherwise noted.

Date	Velocity $km\,s^{-1}$	Date	Velocity $km\,s^{-1}$
1976 Nov 29.18	+11.3	1982 Apr 14.90	+12.0
1977 Jan 30.08	12.2	May 11.88	11.5
Mar 14.98	12.6	Oct 27.24	11.2
Apr 13.93	13.1	Nov 24.56*	12.2
May 24.90	13.6	1983 Jan 19.09	12.3
June 1.91	13.7	Feb 10.25†	13.2
Nov 1.19	12.2	Apr 15.87	12.7
1978 Jan 23.07	12.5	May 6.88	12.7
Mar 13.07	11.6	Dec 3.14	11.0
Apr 15.93	14.8	1984 Jan 2.14	12.1
Oct 12.22	12.5	Apr 15.92	11.0
Nov 16.19	13.2	1985 Jan 14.12	11.9
1979 Jan 3.15	12.6	Feb 24.00	13.3
Mar 1.04	11.8	1986 Jan 4.46*	12.1
Apr 28.89	13.8	Feb 27.01	11.2
May 13.90	13.5	Apr 10.86‡	12.4
June 7.15*	13.6	May 5.87	13.1
Nov 24.18	13.2	Dec 12.18	11.8
Dec 31.10	11.3	1987 Jan 31.10	11.1
1980 Jan 23.11	11.9	Feb 21.01	10.5
May 4.89	13.3	Mar 20.92	11.2
Dec 7.21	12.9	May 4.86	11.4
1981 Jan 15.08	13.2	Nov 8.38§	11.3
Apr 20.91	12.3	Dec 8.22	11.5
May 19.17*	13.4	1988 Jan 8.14	10.1
1982 Jan 11.10	12.6	Feb 1.40†	10.5
Mar 5.02	+11.7	May 21.90	+12.5

* Observed with 200-inch telescope (Griffin & Gunn 1974).
† Observed with DAO 48-inch telescope (Fletcher *et al.* 1982).
‡ Observed with 'Coravel' (Baranne, Mayor & Poncet 1979) at OHP.
§ Observed with 'Coravel' at ESO.

of -0.14 ± 0.03 km s^{-1} per annum, so the trend may certainly be regarded as significant. If the assumption is made that the trend is satisfactorily represented by the linear relationship whose slope has been calculated, the total change of radial velocity during the $11\frac{1}{2}$ years covered by the observations is approximately 1.6 km s^{-1}.

We are not alone in failing to see a periastron passage: it is evident from Fig. 1 that the 'visual' (actually speckle) measurements have not shown one either. It would be somewhat presumptuous of spectroscopists to put forward a new visual orbit; but we may perhaps be allowed to offer some qualitative remarks on the present situation, as we see it, concerning the orbit.

The speckle observations of the last decade show the system to be following a path not very different from that expected on the basis of Finsen's (1977) orbit but far too slowly. If the real orbit is basically similar to Finsen's and simply requires minor

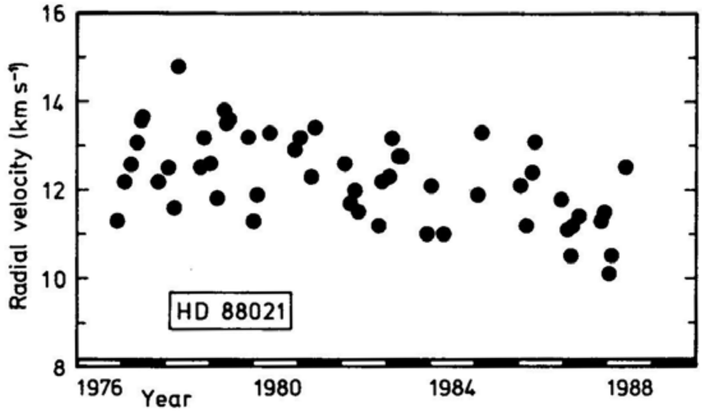

Figure 2. Radial-velocity measurements of HD 88021 plotted as a function of time.

refinement, the latest date which can reasonably be held to correspond to one complete revolution from Aitken's discovery observation is about 1983. Periastron supposedly took place less than seven years after discovery: no plausible modification to the orbit can delay it much beyond 1990, and therefore we must now be within about two years (at most) of the periastron passage which Finsen regarded as due in 1981. Reference to the radial-velocity ephemeris (Dommanget & Nys 1982) shows that in the decade from 12 to 2 years before periastron the relative radial velocities should have changed by about l0 kms^{-1}. If a reasonable assumption is made about the relative masses, the velocity of the late-type component should have shown a steady change amounting to at least 4 km s^{-1} during the last decade. That simply has not happened. It should be mentioned that Tokovinin (1987) has avoided any embarrassment over the lack of radial-velocity change by adopting an orbital inclination of exactly 180°, so no change at all would ever be expected; but there would seem to be an element of artificiality in such a choice of inclination, and in any case *some* change of velocity has in fact been witnessed.

Summarizing the above evidence, we may say that the abrupt periastron passage that was due to take place in 1981, only four years after the prediction of it was made, has manifestly failed to take place even within eleven years; and the radial velocities have changed very slowly, offering little support to the idea that a sudden periastron passage is imminent now. Despite the grading of Finsen's (1977) orbit in the recent catalogue of visual binary orbits (Worley & Heintz 1983) as "reliable", we think that there is a possibility of re-interpreting the visual data in terms of a quite different orbit of no more than modest eccentricity.

The slowness of the motion in position angle during the last 50 years admits of no uncertainty in the continuity of the quadrant. That same slowness obliges us to agree with the reversal, first proposed in orbit II of Baize (1957), of the published quadrant of Aitken's (1932) observations in 1921–1925. We now suggest reversing the quadrant of the discovery observation (Aitken 1910) as well. The necessity for a very rapid change of position angle and a very high eccentricity then disappears, and a relatively sober orbit with a period of about 110 years results. We cannot make it fit Aitken's first three measurements very well in distance: the position angles can be matched, but then the distances need to be even smaller than Aitken measured, especially for the 1921 observation. That observation is only a single night's measure; Aitken himself (1935, p. 74) says that such a measure "deserves small weight", and in an illustration of an orbit computation he rather sportingly chooses an example (*loc. cit.*, p. 103) in which he is obliged to reject two such measures made by himself. It is only too apparent that no orbit solution can fit perfectly all the observations. In fact, we should point out that the new orbit by Tokovinin (1987) fits the 1921 and 1923 measures even worse than ours does: it gives a computed separation of less than 0″.06 in 1921, so the binary should then have been completely unresolved and the observation (although it gives an acceptable position angle) would have to be dismissed as imaginary.

Baize (1957) noted that the negative residuals in angular separation in the 1950s were "irreducible", whatever orbit one adopted; the same remains true today. On the other hand, most of the pre-1950 measurements equally obstinately give positive residuals. An open-minded consideration of the data shown in Fig. 1 would lead to the conclusion that the ellipse representing the orbit ought to be shorter and fatter than those drawn there. Unfortunately, such an orbit would violate the discovery observation. Rejection of that particular observation is far too radical a proposition to be seriously put forward by us; but Tokovinin's rejection of Aitken's next two measurements is to be seen as a resort only one degree less desperate. Fortunately, it seems almost certain that we shall not have to wait very long for a definite resolution of this whole problem: the angular separation is now very small, so the angular motion must be correspondingly rapid. Within a very few years a final decision between the various orbits should become possible, especially if improved processing of speckle-interferometry measures removes the ambiguity in sign of the position angles.

4. Spectroscopy

When it became clear that there was little prospect that HD 88021/2 could be observed at a time when there would be a large difference in radial velocity between the components, we were obliged to abandon the hope of determining a mass ratio by the spectroscopic method put forward in Paper 1 (Griffin 1986). Nevertheless, it remained worth while to observe the spectrum of the system in order to determine the spectral types of the components, and to that end we took a spectrogram with the coudé spectrograph of the Mount Wilson 100-inch reflector on 1984 March 23. Details of the equipment and procedures are given in Paper 1; suffice it to say here that the spectrogram is on IIa-O emulsion, covers the nominal wavelength range 3650-4650 Å, and has a reciprocal dispersion of 10 Å $mm^{-1}$and a trailed width of 1.7mm.A small part of the spectrogram is illustrated in Fig. 3. The Figure also shows the corresponding regions of the spectra of other stars which we have identified as being spectroscopically similar to the individual components of the binary.

By the methods, at once naïve and refined, developed in Paper 1 we discovered that the most accurate match for the late-type component, HD 88021, is provided by the spectrum of β Gem (K0 III). When appropriate fractions of the spectrum of β Gem are subtracted from that of HD 88021/2, the spectrum of HD 88022 which is thus uncovered bears the unmistakeable hallmarks (Conti 1970) of a metallic-lined A star: in relation to the general metallic-line spectral type, the Ca $_{\rm II}$ K line is too weak and the Balmer lines are too strong, *i.e.* both are too early in type. The subtraction process for the wavelength region 3850–4050 Å is depicted in Fig. 4, in which the metallic-line star *ε* Ser, which has been classified (Cowley *et al.*, 1969) as A2m, is compared with HD 88022. Fig. 5 shows the spectrum of HD 88022 over the whole wavelength range (3650–4650 Å) for which we have recovered it.

In HD 88022 the Balmer-line profiles and the weakness of the Ca II K line match those in *ε* Ser well, though the other metallic lines are systematically less enhanced than they are in the spectrum of *ε* Ser. We therefore propose the classification of A2m for the spectrum of HD 88022. Comparisons with other spectra similarly classified prompt us to comment that *ε* Ser shows a particularly late metallicline type. The fact that HD 88022 should prove to be metallic-lined causes little surprise, since we have already remarked (Paper 1) on the rather high frequency of Am secondaries in composite systems—an observation based on preliminary investigations of some of the systems on our composite-star programme. Of course, not all the secondaries of those stars have sufficiently narrow-lined spectra for the condition to be instantly recognizable.

A by-product of the subtraction procedure is the ratio of fluxes of the K-and A-type components, which is conveniently expressed in the sense K/A and is of interest for comparison with the flux ratios computed for single stars of known spectral types. The comparison is performed automatically: lists of fluxes measured in 50-Å bands by Willstrop (1965), and necessarily restricted to the wavelength interval 4000–4650 Å which is common to our own work and Willstrop's, in sample K giants and A dwarfs

Table 3. Relative fluxes of *ε* Phe (K0 III) and ι Cen (A2 V) in 50-Å bands, compared with the ratios between HD 88021 and HD 88022. The ε Phe/ι Cen ratios have all been multiplied by the empirical factor 1.34, which represents the relative visual luminosity of HD 88021 in comparison with HD 88022.

λ (Å)	From Willstrop (1965) ε Phe	ι Cen	Ratio	HD 88021/2 (observed)
3650	---	---	---	0.63
3700	---	---	---	0.37
3750	---	---	---	0.30
3800	---	---	---	0.16
3850	---	---	---	0.21
3900	---	---	---	0.19
3950	---	---	---	0.30
4000	196	842	0.31	0.29
4050	193	704	0.37	0.40
4100	193	637	0.41	0.41
4150	183	763	0.32	0.33
4200	205	736	0.37	0.38
4250	207	717	0.39	0.41
4300	226	523	0.58	0.60
4350	252	599	0.56	0.53
4400	271	665	0.55	0.55
4450	298	650	0.62	0.65
4500	317	624	0.68	0.68
4550	325	606	0.72	0.70
4600	340	597	0.76	0.74
4650				

are fed into a computer, which then selects pairs of K and A stars whose flux ratios are most nearly similar to the observed flux ratios in HD 88021/2. Since no two Am stars seem to be identical it is doubtful whether Willstrop's list contains an adequate variety of standard stars; but at least the computer was able to confirm our classification of early K giant and early A dwarf. The observed fluxes, and the corresponding ratios between a suitable pair of stars selected from Willstrop's list, are shown in Table 3.

In order to match the observed flux ratios in Table 3, it has been necessary to multiply those calculated from Willstrop's (1965) data by the constant factor 1.34, which is tantamount to adopting that factor as representing the difference in luminosity between the two stars in the *V* band. Thus we expect the components of ADS 7662 to differ by that factor, which is just over $0^{m}.3$ in magnitude terms, in the sense that the late-type component (HD 88021) is the brighter.

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Errata in Paper 1. We apologize for having omitted the reference to Willstrop (1965) in the bibliography of Paper 1; it is given in the bibliography of the present paper. A few errors unfortunately crept into Paper 1 after we had seen the proofs. The first line on p. 206 should be restored to the foot of p. 207, and the word 'respectively' should be deleted from the fourth line up from the foot of p. 218. The half-tone plate (Fig. 3) appears to have suffered abrasion in the printing process and hardly does justice to the pristine cosmetic quality of the Mount Wilson spectrograms.

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