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SPECTROSCOPIC BINARY ORBITS
FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 198: 48 PISCUM, 16 AURIGAE, 5 HERCULIS, AND β SCUTI

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The first three objects are (at least for the purposes of this paper) single-lined binaries in which the observed star is a late-type giant; β Sct appears to most instruments to be an analogous object, but spectra at short wavelengths show faintly an additional component of early type, making the system a composite-spectrum one. The orbital periods are 621, 434, 1222, and 833 days, while the eccentricities are 0.32, 0.12, 0.29, and 0.32, respectively. The secondary star in 48 Psc appears to be marginally detected in radial-velocity traces near nodal passage; the mass function of 16 Aur is large enough to suggest that the secondary star might be detectable, and there is possible photometric evidence of an eclipse.

Introduction

The (rather tenuous) connection between the stars treated in this paper is that they all possess constellation designations! More than 30 systems with constellation designations (not counting variable-star ones) have already featured in this series of papers, and here are four more. It is somewhat of an ironic comment on

the present state of astronomical research that much interest is centred on the faintest and most elusive objects, while so many bright stars, even ones visible to the naked eye, are known to be binaries and yet nobody has bothered to determine their orbits. That said, it should be recorded that the derivation of orbits for the first three stars discussed here was reported¹ at an AAS meeting nearly 20 years ago; only an abstract, with no orbital elements or other details, was published, but incomplete sets of preliminary elements had been presented for two of the stars, 16 Aur and 5 Her, at another conference² (IAU Colloquium 88, in Schenectady) some years previously. An orbit that was acknowledged by its author to be provisional was published³ as long ago as 1936 for one of the three, 16 Aur, and proves to be very near the one derived below. β Scuti was recognized as a spectroscopic binary in the 19th Century, and a determination of its orbit was made 80 years ago. It is hardly surprising that we are in a position now to present an improved one; some of the earlier elements differ from the new ones by 10–40 standard deviations of the latter.

In a paper presented to the above-mentioned Colloquium in 1984, Beavers² gave a progress report on the observing programme undertaken with the photo-electric radial-velocity spectrometer⁴ at the Fick Observatory at Ames, Iowa; he referred to the interest in bright late-type giant stars which exhibit radial-velocity variations in what were then regarded as long periods, and gave some preliminary orbital elements for certain of them, including 16 Aur and 5 Her among the objects of immediate interest here. Only the elements P , γ , K , and e were given, but not T or ω . At an AAS meeting in 1988, Beavers & Eitter¹ evidently reported orbital elements for no fewer than 18 spectroscopic binaries (many of them newly discovered by them) whose primaries are late-type giants. It is to be supposed that the orbits must by then have been much less preliminary than they had been four years previously, but the paper was reported¹ only as an abstract containing no information beyond the identities of the stars concerned. Already at that time the paper's senior author had left Ames and was no longer working in the field of astronomy. When several years had passed and it had become evident that the paper that had been presented to the AAS had not been worked up for publication in full, the present writer looked at the list of binaries to see whether any of them could usefully be added to his observing programme. The majority were in the southern celestial hemisphere and were inaccessible to the Cambridge telescope; two were already on the programme; but a few, including the three treated here, were adopted. The initial observations of all three of them were all made within a 24-hour interval in 1993 February. The observations upon which Beavers & Eitter depended, at least those made up to a certain point, had already been published⁵ by those authors and provided a flying start to the campaign. The three stars have been systematically followed ever since. The fourth star discussed here, β Scuti, whose orbit was determined by Young⁶ in 1927 on the basis of 17 spectra obtained with the DAO 72-inch reflector, was placed on the writer's observing programme in response to interest shown in it by devotees of stellar winds.

48 Piscium (HR 106, HD 2436)

About 4° following and 1° north of Algenib (γ Pegasi, the lower left-hand star of the Great Square as seen from moderate northern latitudes) is the sixth-magnitude star 48 Psc. Its magnitude and colours have been measured by Rybka⁷ at $V = 6^m \cdot 06$, $(B - V) = 1^m \cdot 58$, $(U - B) = 2^m \cdot 00$. Such extreme redness could easily characterize an early-M giant, but the accepted type of 48 Psc (as given, for example, in the *Bright Star Catalogue*⁸) is K5 III. It seems, however, as if no actual MK

classification is to be found in the literature; the *Bright Star Catalogue* type may represent the Mount Wilson⁹ type of K5 with a luminosity class assigned to it to correspond with the spectroscopically estimated⁹ absolute magnitude. The *HD*¹⁰ type is K2. In the second¹¹ of the large papers from Mount Wilson on spectroscopic absolute magnitudes, the ‘estimated’ type is given as K5 and the ‘measured’ type as K1; the distinction is that ‘estimation’ was performed in the classic manner, by direct visual comparison of the spectrum with suitable standards, whereas ‘measurement’ involved the quantitative comparison of the strength of the hydrogen lines $H\gamma$ and $H\delta$ with specified nearby iron lines. Analogous comparison of luminosity-sensitive pairs of lines produced a value of $+0^m.5$ for the absolute magnitude; in a later paper⁹ that value was revised to $+0^m.1$. The *Hipparcos* parallax of only $0''.00293 \pm 0''.00072$ corresponds to a distance modulus of about $7^m.7 \pm 0^m.6$ and thereby to an absolute magnitude as bright as -1 or -2 . The *Hipparcos* data could advantageously be re-reduced with account taken of the orbital motion of the photocentre, which probably has an amplitude of about 0.5 AU.

Little interest has been shown in 48 Psc in recent years. Its infrared magnitudes have been measured by Kidger & Martin-Luis¹², who also gave results for V ($6^m.06$) and $(B - V)$ ($1^m.61$), and the apparent angular diameter, as modelled by a conventionally limb-darkened disc, has been given¹³ as 1.99 ± 0.022 milliseconds of arc.

Adams *et al.*¹⁴ were the first to measure a radial velocity for 48 Psc, no doubt from the same plates as they used¹¹ for classification and luminosity estimation; they gave a mean of -1.5 km s⁻¹ with a ‘probable error’ of 0.6 km s⁻¹. Nearly 50 years later Abt¹⁵ very helpfully published the individual velocities and dates, which show that the plates were taken in 1916–1918. Adams *et al.* were unlucky not to discover the velocity variations: their four plates were all taken within a small range of phase though not all in the same cycle. Young¹⁶ published a mean velocity of -11.1 with a ‘probable error’ of 2.6 km s⁻¹ from four plates taken at $66 \text{ \AA mm}^{-1}$ at $H\gamma$ with the 74-inch David Dunlap Observatory (DDO) reflector. An asterisk against the entry for 48 Psc in Young’s paper draws attention to the fact that it was one of “a number of stars which showed a somewhat larger range than the agreement of the lines would lead one to expect”, and the ensuing number, 19, specifies the range of the four velocities. It will be very useful if someone does the same for the DDO as Abt has done for Mount Wilson, by providing the individual data for velocities that were published only as means. In the text of his paper, Young mentions that “the detection of the binary character of those stars with small range, less than 20 km, is uncertain and doubtless some of these have been included as of constant velocity.” (The perception of what constitutes a “small range” has evidently undergone considerable revision since the development of photoelectric measurement of velocities!) Adding to the data from Mount Wilson and the DDO, four radial-velocity measures¹⁷ were made by the French objective-prism observers led by Fehrenbach. They have not been included in the discussion here; such measurements are never reliable enough for the purposes of orbit determination, and in fact only two of them would fall within the boundaries of the diagram (Fig. 2) of the orbit.

One might think that the discrepancy between the Mount Wilson and DDO means, coupled with the range of the DDO velocities, would have sufficed to identify 48 Psc as a binary, but in the event it was left to Beavers so to identify it, in the progress report² that he gave in 1984. The large listing⁵ of Ames velocities by Beavers & Eitter includes 23 measurements of the star. Those measurements, together with those of Adams *et al.*^{14,15}, are listed at the head of Table I. Some of the Ames observations are noted⁵ as being of quality ‘B’ and are here identified

TABLE I

Radial-velocity observations of 48 Piscium

Except as noted, the sources of the observations are as follows:
 1976–1983 — published by Beavers & Eitter⁵ (weighted $1/20$ in orbital solution);
 1987–1998 — Haute-Provence Coravel (wt. $1/2$); 1999–2006 — Cambridge Coravel

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O–C) km s^{-1}
1914 Oct. 28·21*	20433·21	–0·7	$\overline{36}\cdot406$	–0·1
1915 Jan. 2·12*	20499·12	–1·8	$\overline{36}\cdot512$	–0·9
1916 Sept. 17·38*	21123·38	+1·8	$\overline{35}\cdot517$	+2·7
Nov. 13·27*	180·27	–2·2	·608	+0·1
1976 Sept. 22·30	43043·30	–8·8:	0·792	+0·2
Dec. 15·09	127·09	–17·7:	·927	+0·9
22·07	134·07	–20·2	·938	–0·9
1977 Sept 10·39	43396·39	–1·4:	1·360	–0·5
1978 July 27·43	43716·43	–15·2:	1·875	–0·5
Aug. 5·40	725·40	–17·3:	·890	–1·5
23·36	743·36	–19·1:	·919	–1·1
Sept. 5·30	756·30	–20·1:	·940	–0·7
Oct. 5·27	786·27	21·8	·988	–1·1
Nov. 8·23	820·23	–15·9	2·043	+2·0
Dec. 10·07	852·07	–12·2:	·094	+0·9
1980 Aug. 23·36	44474·36	–14·5:	3·095	–1·6
Sept. 7·32	489·32	–10·7	·119	0·0
23·29	505·29	–8·9:	·145	–0·2
Nov. 25·10	568·10	–3·6	·246	–0·3
26·09	569·09	–3·6	·248	–0·3
1982 Jan. 8·03	44977·03	–15·7	3·904	+1·2
Oct. 22·23	45264·23	–1·9	4·366	–1·0
Nov. 17·15	290·15	–0·4	·408	+0·2
Dec. 17·06	320·06	–2·8:	·456	–2·2
1983 Aug. 25·38	45571·38	–11·6	4·861	+1·9
Sept. 9·31	586·31	–16·7	·885	–1·3
23·30	600·30	–19·4	·907	–2·3
1987 Nov. 20·86†	47119·86	–0·7	7·353	+0·3
1988 Nov. 26·86†	47491·86	–19·8	7·951	+0·2
1993 Feb. 11·76	49029·76	–0·9	10·426	–0·3
July 8·11	176·11	–3·3	·662	+0·3
Nov. 4·19‡	295·19	–13·2	·853	–0·2
Dec. 24·82	345·82	–18·8	·935	+0·3
25·91	346·91	–18·7	·937	+0·5
1994 Jan. 1·80	49353·80	–19·4	10·948	+0·4
Feb. 19·76	402·76	–19·1	11·026	+0·1
July 31·12	564·12	–2·2	·286	0·0
Dec. 10·83	696·83	–0·5	·500	+0·3
28·80	714·80	–0·9	·529	+0·2
1995 Jan. 4·80	49721·80	–1·0	11·540	+0·2
9·78	726·78	–0·9	·548	+0·4
June 3·11	871·11	–8·8	·780	–0·5
Dec. 31·81	50082·81	–10·6	12·121	0·0

TABLE I (*continued*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity km s⁻¹</i>	<i>Phase</i>	<i>(O-C) km s⁻¹</i>
1996 Nov. 15·89 [§]	50402·89	-3·0	12·636	-0·1
Dec. 25·88	442·88	-4·7	·700	+0·1
1997 Jan. 24·80	50472·80	-6·6	12·748	+0·2
Feb. 10·75 [§]	489·75	-7·8	·776	+0·3
July 21·10	650·10	-18·7	13·034	-0·1
Sept. 9·99	700·99	-11·5	·116	-0·4
Dec. 20·83	802·83	-2·8	·280	-0·5
1998 July 11·12	51005·12	-2·4	13·605	-0·2
24·09	018·09	-2·9	·626	-0·2
1999 July 10·48 [¶]	51369·48	-5·5	14·191	+0·2
Nov. 3·25 [¶]	485·25	-1·2	·378	-0·4
Dec. 19·86	531·86	-0·6	·453	0·0
28·84	540·84	-1·0	·467	-0·4
2000 Jan. 17·73	51560·73	-0·6:	14·499	+0·2
July 19·12	744·12	-9·6	·794	-0·5
Aug. 29·11	785·11	-13·6	·860	-0·1
Sept. 21·05	808·05	-16·3	·897	+0·1
Oct. 13·05	830·05	-18·8	·933	+0·1
Nov. 3·99	851·99	-20·6	·968	0·0
16·99	864·99	-20·6	·989	+0·1
Dec. 27·89	905·89	-16·9	15·055	-0·1
2001 Jan. 13·80	51922·80	-14·0	15·082	+0·2
27·74	936·74	-11·9	·104	+0·2
Feb. 9·75	949·75	-10·0	·125	+0·2
July 24·12	52114·12	-0·8	·390	-0·1
Aug. 2·09	123·09	-0·6	·404	0·0
14·08	135·08	-0·6	·424	0·0
Sept. 30·06	182·06	-0·8	·499	0·0
Nov. 5·01	218·01	-1·2	·557	+0·2
Dec. 20·85	263·85	-2·3	·631	+0·5
29·76	272·76	-2·8	·645	+0·3
2002 July 27·11	52482·11	-20·9	15·982	-0·2
Aug. 29·10	515·10	-18·7	16·035	-0·2
Sept. 27·09	544·09	-14·6	·082	-0·4
Oct. 21·97	568·97	-10·5	·122	0·0
Nov. 21·92	599·92	-6·6	·172	+0·2
Dec. 4·91	612·91	-5·8	·193	-0·2
17·89	625·89	-4·4	·213	+0·2
2003 Jan. 11·83	52650·83	-3·0	16·254	+0·1
Feb. 17·77	687·77	-1·6	·313	0·0
Aug. 17·12	868·12	-2·5	·603	-0·3
Sept. 23·05	905·05	-3·7	·663	-0·1
Oct. 18·01	930·01	-5·2	·703	-0·3
Nov. 12·95	955·95	-6·4	·745	+0·2
Dec. 15·88	988·88	-9·3	·798	0·0
2004 Jan. 27·73	53031·73	-13·8	16·867	+0·2
Feb. 25·76	060·76	-17·8	·913	-0·2
Aug. 20·11	237·11	-5·5	17·197	-0·1
Sept. 14·08	262·08	-3·7	·237	-0·1
Oct. 19·02	297·02	-2·1	·293	-0·1
Nov. 13·99	322·99	-1·5	·335	-0·3
Dec. 5·80	344·80	-0·6	·370	+0·2

TABLE I (*concluded*)

Date (UT)		<i>MJD</i>	<i>Velocity</i> <i>km s⁻¹</i>	<i>Phase</i>	(<i>O</i> − <i>C</i>) <i>km s⁻¹</i>
2005 July	18·11	53569·11	−6·0	17·731	0·0
Aug.	7·12	589·12	−7·5	·764	0·0
Sept.	8·07	621·07	−10·3	·815	+0·1
	24·03	637·03	−12·0	·841	+0·1
Oct.	26·00	669·00	−16·2	·892	−0·2
2006 Jan.	28·76	53763·76	−17·8	18·045	0·0
July	24·10	940·10	−1·0	·328	+0·3
Sept.	9·08	987·08	−0·4	·404	+0·2
Oct.	3·10	54011·10	−0·7	·443	−0·1
Nov.	2·03	041·03	−0·5	·491	+0·2
Dec.	3·91	072·91	−1·6	·542	−0·4
	28·85	097·85	−1·8	·582	0·0

*Published Mount Wilson measurement^{11,15}; weight 0.†OHP observation¹⁹, provided through the *CDS*, wt. $\frac{1}{2}$.‡Observed with ESO *Coravel*.§Observed with Cambridge *Coravel*.¶Observed with DAO 48-inch telescope; weight $\frac{1}{2}$.

with a colon and given half-weight in comparison with the majority, which have quality ‘A’. Following them in Table I are the writer’s own observations, consisting of 20 obtained with the Haute-Provence (OHP) *Coravel* and 55 with the Cambridge one, plus two obtained with the DAO spectrometer and one with the ESO *Coravel*. The OHP and ESO velocities, and also the Mount Wilson ones, have been accorded an adjustment of $+0·8 \text{ km s}^{-1}$ to take account of the expected discrepancies in zero-points. The Cambridge observations, which in the cases of hotter stars routinely need a negative correction, are in distinct need of a positive one amounting to $0·2 \text{ km s}^{-1}$ for this very red star, and such a correction has been applied. Ames velocities, which have usually been found to need an adjustment of $+0·8 \text{ km s}^{-1}$ to place them on the Cambridge zero-point, appear here to need a change of $+1·5 \text{ km s}^{-1}$, the standard deviation of that mean offset being $0·25 \text{ km s}^{-1}$. By way of a compromise in partial deference to past experience, therefore, they have been altered by $+1·2 \text{ km s}^{-1}$. All the entries in the table already include the specified adjustments.

In papers that are not retrieved by *Simbad* for 48 Psc, the *Coravel* observers de Medeiros & Mayor¹⁸ included the star in a listing (their Table 6) of “Double-lined spectroscopic binary systems SB2 with an evolved component”, and de Medeiros, Udry & Mayor¹⁹ gave a mean velocity of $-11·53 \pm 9·54 \text{ km s}^{-1}$ (from *two* observations) and a $v \sin i$ of $< 1·7 \text{ km s}^{-1}$. Spurred on by the assertion of its SB2 character, the writer made careful observations of 48 Psc at the nodal passage of 2000 November, when any secondary should have been clearly visible in radial-velocity traces as an entity more or less separate from the primary dip. One such trace is shown in Fig. 1. There seemed to be just enough of a depression near the expected place to warrant saying that the secondary is probably detected, with a Δm of 3–4 magnitudes and a mass ratio not very far from unity, although for practical purposes the system could hardly be said to be double-lined. There are analogous or worse difficulties over many of the other stars in the two papers, which are by no means self-consistent. For example, all seven of the stars in ref. 19 Table 3, entitled “Rotation and radial velocity for 6 [*sic*] apparently single evolved

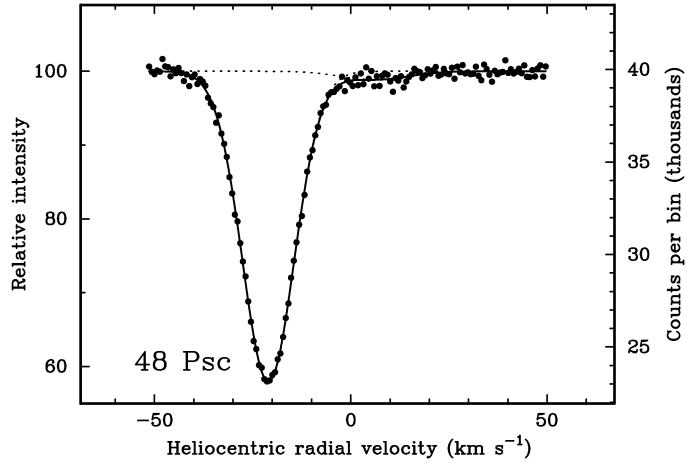


FIG. 1

Radial-velocity trace of 48 Piscium, obtained with the Cambridge *Coravel* on 2000 November 3, showing an indication of a very shallow second dip. The observation was made very close to the more favourable node, at which the difference in radial velocity between the obvious component and any secondary would be a maximum. Analogous indications are seen in other traces obtained near the node. They are, however, so marginal that the author has not deigned to treat them as measuring the radial velocity of a companion star. The γ -velocity is -7.4 km s^{-1} , from which the velocity of the primary differs in this observation by about -13 km s^{-1} , so an equally massive secondary could be expected to show a dip at about $+6$.

stars”, appear also in ref. 18 Table 6, whose heading is quoted above, as SB2 systems. One of the supposedly SB2 stars in that Table 6, HD 169985, features also in Table 7, on the very next page of the same paper, in a listing of “Evolved stars with no CORAVEL dip”.

In the solution of the orbit of 48 Psc, the Mount Wilson observations have not been utilized, but the Ames ones have been included with a weight of 0.05. The OHP, ESO, and DAO spectrometer measurements have been half-weighted. The solution is illustrated by Fig. 2; the elements are as follows:

$$\begin{array}{ll}
 P = 621.39 \pm 0.13 \text{ days} & (T)_{15} = \text{MJD } 51871.9 \pm 1.0 \\
 \gamma = -7.44 \pm 0.03 \text{ km s}^{-1} & a_1 \sin i = 81.5 \pm 0.4 \text{ Gm} \\
 K = 10.09 \pm 0.04 \text{ km s}^{-1} & f(m) = 0.0561 \pm 0.0008 M_{\odot} \\
 e = 0.325 \pm 0.004 & \\
 \omega = 192.7 \pm 0.7 \text{ degrees} & \text{R.m.s. residual (wt. 1)} = 0.21 \text{ km s}^{-1}
 \end{array}$$

For comparison, it should be recorded that Beavers² listed the period as 620 days and K as 9 km s^{-1} ; he did not give any of the other elements.

The mass function requires the minimum mass of the secondary star to be $0.75 M_{\odot}$ if the primary mass is supposed to be $2 M_{\odot}$, or almost $1 M_{\odot}$ if the primary were $3 M_{\odot}$. If the secondary is indeed detected in radial-velocity traces (Fig. 1), then it cannot be a white dwarf but must be a tolerably late-type, probably F, star.

16 Aurigae (HR 1726, HD 34334)

16 Aur is a $4^{1/2}$ -magnitude star, to be found nearly $3/4$ of the way from Capella towards β Aur. Its Galactic latitude is about -2° ; although the Milky Way appears

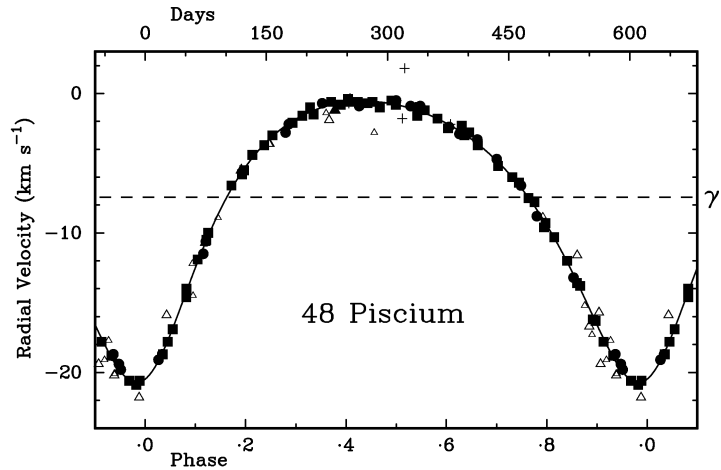


FIG. 2

The observed radial velocities of 48 Piscium plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The filled symbols are the ones that carry the principal weight in the orbital solution — squares represent data from the Cambridge *Coravel*, circles are for OHP observations and one ESO observation, and triangles are for the DAO spectrometer. Measurements published by Beavers & Eitter⁵ from the Fick Observatory spectrometer⁴ at Ames, Iowa, and weighted 0.05 in the solution are represented by open triangles; Mount Wilson velocities are plotted as pluses. Where certain velocities have been accorded smaller weights than normal for their source, they are shown with smaller symbols and their entries in the corresponding table (Table I) are followed by colons.

thin in that direction ($l \sim 173^\circ$, almost exactly towards the anti-centre) 16 Aur is in the middle of a small cluster of 5^m–6^m stars that is so striking as to have impelled Melotte²⁰ to catalogue it as Mel 31. Within a radius of 1° from 16 are 14 (= KW) Aur, 17 (= AR) Aur, the fifth-magnitude but un-numbered IQ Aur, and 18 and 19 Aur. It is nothing more than a chance grouping of stars, as is demonstrated by their disparate radial velocities, proper motions, and parallaxes. At the cost of digression from the main point, however, it may be remarked that the two stars AR and IQ Aur do appear to be a physical pair; that seems to have been first pointed out by Bidelman to Hoffleit in time for the information to be incorporated in the notes to the third edition (1964) of the *Bright Star Catalogue*, and it has been discussed by Sargent & Eggen²¹. The note in the current (fourth) edition⁸ of the *Catalogue* goes on to assert that AR Aur (HR 1728) is a member of the Aur OB1 Association, which is not so but has been subscribed to by such authorities as Batten *et al.*²² and Nordström & Johansen²³. Aur OB1 is²⁴ actually about ten times as far away as AR and IQ Aur.

As well as being a spectroscopic binary, 16 Aur is a visual binary, there being a companion of about the eleventh magnitude about $4''$ away from the principal star. The companion was discovered by (Otto) Struve²⁵ at Poulkova in 1846 and carries his 'discovery number' OΣ 103; it features in Burnham's double-star catalogue²⁶ as BDS 2623 and in Aitken's²⁷ as ADS 3872. There has been no clear relative motion, so the companion must share very accurately the large proper motion ($0''.164$ annually) of the primary; the pair has accordingly travelled together some $25''$ across the sky since the discovery of the companion, leaving no doubt as to the physical association of the components.

The broad-band magnitudes of 16 Aur have been measured by a number of observers^{28–32}, with results close to $V = 4^m.54$, $(B - V) = 1^m.26$, $(U - B) = 1^m.27$. The V values show a range of $0^m.04$, possibly raising a suspicion of slight variability. Indeed, Johansen³³, who was not observing 16 Aur with a view to determining its own magnitude but was using it as a comparison star in a photometric investigation of AR Aur, noted that it appeared slightly ($0^m.02$) faint on two particular dates, and was perceptive enough to point out that such a decline might be attributable to an eclipse if the orbital period of 434.8 days found for 16 Aur by Christie³ were only half a day in error.

Spectroscopic estimates were made of 16 Aur's luminosity as early as the 1920s at the DAO by Young & Harper³⁴, who gave independent assessments of $M_V = +0^m.2$ and $+0^m.6$, respectively, and at the Norman Lockyer Observatory by Rimmer³⁵, who obtained $+1^m.1$. Adams *et al.*⁹ at Mount Wilson later listed it as $+0^m.4$. Wilson³⁶ found $M_V = +0^m.6$ by his K -line method. The star's parallax of $0''.01392 \pm 0''.00139$, as determined by *Hipparcos*, corresponds to a distance modulus of $4^m.28 \pm 0^m.22$ and so to an absolute magnitude of $+0^m.26$ with the same uncertainty, largely corroborating the efforts of the early spectroscopists.

The MK type was first given by Roman³⁷, as K3 III. Keenan, who was greatly exercised over spectral classifications in the 1980s, included 16 Aur in several successive catalogues giving revisions of the MK standards for late-type stars. In 1983 he³⁸ gave the type as K2.5 IIIb CN – 0.5. Certainly it is a fact that CN is extraordinarily weak: in the quantitative measurements made by Griffin & Redman³⁹ almost half a century ago, 16 Aur had the smallest 'CN ratio' of all among 49 stars classified then as K3 III. But in 1985 Keenan & Yorka⁴⁰ dropped the reference to CN and instead called 16 Aur K2.5 IIIb Fe – 1. Confusingly, in a 1987 paper on the recognition of 'SMR' stars, Keenan, Yorka & Wilson⁴¹ showed low-resolution intensity plots of the blue-violet region of the spectra of four stars that range from the SMR μ Leo through the mild-SMR κ Lyr and the normal HR 6793 to the metal-weak 16 Aur, whose type is given as [K]2.5 III CN – 1 — and indeed the tracings show that the CN band in 16 Aur is dramatically weaker than it is in the other three stars. All the same, in 1988 Keenan & Yorka⁴² had again dropped any reference to CN in favour of Fe, and had adjusted both the temperature and the luminosity classes, to K2 III Fe – 1; but in the following year the *Perkins Catalogue*⁴³ put it at K2.5 III Fe – 1, so the earlier temperature class was restored. After the results of the *Hipparcos* mission were published, Keenan was naturally concerned to make sure that the MK luminosity classifications accorded with the parallaxes (an exercise which actually resulted in surprisingly modest alterations and went far towards validating all his previous labours on classification), and in a paper⁴⁴ with Barnbaum he presented a further listing of MK standards, but 16 Aur is not included. At the time of his death, Keenan had been working on a much larger catalogue which has not been published, but he had sent the first nine hours of right ascension (corresponding to the part of the sky covered in the printed version of the previous one⁴⁴) to the present author in manuscript; there, he reverted to the type K2.5 IIIb CN – 0.5 for 16 Aur — exactly the same as it had been five revisions previously! The catalogue, with its brief introductory text, and extended as far as 14 hours RA which is as far as Keenan got with it (the associated notes still go only to 9 hours), is accessible at the time of this writing at a web site identified in a footnote on the second page of ref. 44.

In an earlier instance of equally bewildering changes of classification (that of ζ Cyg, Paper 105⁴⁵ in this series), the situation was so bad that, on reading through the completed paper, its author feared that it read like an attack on Keenan!

Instead of submitting it for publication, therefore, he posted it straight to Keenan with a suitably apologetic covering letter saying that no doubt he (Keenan) could explain everything and inviting him to do so, becoming a co-author of the paper in the process; very sportingly, Keenan accepted, and indeed his explanations did clear the air substantially, to the benefit of everyone. But alas, the same expedient is no longer open to us! During the time that Keenan was evidently wrestling with the problem of classifying 16 Aur, Abt⁴⁶ joined the fray with a type of K3·5 III.

16 Aur featured in most of the early Cambridge programmes of narrow-band photoelectric spectrophotometry, beginning with the work already cited³⁹. The results can be summarized by saying that the various narrow-band indices were quite normal for the spectral type, apart from the weakness of CN³⁹. Subsequent investigations^{47–50} made elsewhere of its chemical abundances agree in finding the star to have a modest metal deficiency of something like a factor of two compared with the Sun.

By virtue of its being brighter than 5^m·5, 16 Aur was included in the Lick programme of systematic measurements of the radial velocities of the bright stars. The first two observations were made in 1905 and 1908; the third, in 1910, exhibited a very large discrepancy which prompted an immediate announcement⁵¹ of the star's variable velocity. The complete results of the programme, with a total of five measurements of 16 Aur, was published by Campbell & Moore⁵² in 1928. In the meantime five velocities had been published by Küstner⁵³ from plates taken with the 12-inch refractor at Bonn; they were all taken within an interval of three weeks in 1913. Two more measurements were provided from the DAO by Harper⁵⁴. In 1936 Christie, working at Mount Wilson, included 16 Aur in a paper entitled *The Provisional Elements of 16 Spectroscopic Binaries*. He did not tabulate his data, but noted that the orbit of 16 Aur had been under investigation since 1933 and that he had five velocities from Lick, 18 from his own observatory, and two from the DAO. There is a graph of the orbital velocity curve, with the data plotted on it; it appears to be one of the best among the 16. (It may be noted that it is captioned 'Boss 1258' — a designation⁵⁵ not used for 16 Aur elsewhere in the paper — and the ordinates are labelled with reversed sign.) The elements were not derived mathematically but simply by comparison of the velocities (plotted *modulo* the apparent orbital period) with a set of standard curves; one result is that eccentricities are given only to 0·1 and longitudes of periastron to 10°.

In Abt's listing¹⁵ of the individual dates and velocities for measurements made at Mount Wilson but previously published (if at all) only as mean values, there are but two entries for 16 Aur, dating from 1924 and 1926 and no doubt representing measures of the plates used by Adams *et al.*⁹ in their work on spectroscopic luminosities. The other 16 plates whose existence is implied by Christie's paper were evidently not to be found in the Mount Wilson records at the time that Abt compiled his catalogue. It is a curious fact that most plates used by Christie seem to have disappeared without trace: it has been noted previously that three plates were thus lost in the case⁵⁶ of HR 4668 and no fewer than 109 in the case⁵⁷ of HR 6363. For HR 6046 it looks from Christie's *tabulation* as if there were 11 Mount Wilson plates (all of which are now lost), but his *diagram* of the orbit appears to show 16, so it seems that Christie had already lost sight of some of the plates even before he had compiled his own table!

In his 1984 progress report² on work being performed with the Ames spectrometer⁴, Beavers presented a tabulation which gave preliminary values for P , K , and e for 16 Aur; more precisely specified values, with standard errors, are noted on a graph of the orbit. The tabulation also showed that he had at his disposal 30

TABLE II

*Radial-velocity observations of 16 Aurigae**Except as noted, the sources of the observations are as follows:**1905–1910 — Lick⁵², weighted $1/40$ in orbital solution;**1913 — Bonn⁵³; 1921, 1923 — DAO⁵⁴; 1924, 1926 — Mt. Wilson¹⁵, all wt. 0;**1977–1984 — published by Beavers & Eitter⁵; weight $1/20$;**1989–1998 — Haute-Provence Coravel (wt. $1/2$); 1999–2007 — Cambridge Coravel*

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity km s⁻¹</i>	<i>Phase</i>	<i>(O–C) km s⁻¹</i>
1905 Oct. 17·40	17135·40	–40·6	$\overline{60}$ ·324	+0·1
1908 Feb. 14·20	17985·20	–40·2	$\overline{58}$ ·282	+1·2
1910 Jan. 19·28	18690·28	–14·8	$\overline{57}$ ·906	–0·5
Mar. 2·19	732·19	–20·8	$\overline{56}$ ·002	+1·6
Oct. 21·41	965·41	–27·6	·539	+1·6
1913 Feb. 25·81	19823·81	–29·8	$\overline{54}$ ·516	+1·0
Mar. 1·80	827·80	–31·3	·526	–1·1
9·77	835·77	–26·3:	·544	+2·6
11·77	837·77	–30·5:	·549	–1·9
15·78	841·78	–23·5	·558	+4·4
1921 Jan. 11·29	22700·29	–39·0	$\overline{47}$ ·142	–2·2
1923 Oct. 12·48	23704·48	–35·8	$\overline{45}$ ·455	–1·0
1924 Jan. 21·26	23805·26	–16·8	$\overline{45}$ ·687	+1·9
1926 Feb. 28·14	24574·14	–36·8	$\overline{43}$ ·458	–2·1
1977 Jan. 6·17	43149·17	–40·3	0·242	+0·9
1978 Jan. 2·21	43510·21	–32·3	1·074	–1·8
23·11	531·11	–35·6	·122	–0·4
Oct. 23·39	804·39	–14·5	·751	+0·5
Nov. 14·32	826·32	–12·3	·802	+0·9
Dec. 10·25	852·25	–12·8:	·862	+0·1
1979 Mar. 15·03	43947·03	–31·1	2·080	0·0
Dec. 15·26	44222·26	–13·7:	·714	+3·3
1980 Oct. 5·34	44517·34	–37·9	3·394	+0·3
Nov. 25·30	568·30	–31·5	·511	–0·3
Dec. 19·21	592·21	–27·5	·566	–0·2
1981 Jan. 10·14	44614·14	–24·1:	3·616	–0·5
Dec. 20·22	958·22	–37·3	4·409	+0·1
1982 Jan. 14·19	44983·19	–32·8	4·467	+1·3
26·17	995·17	–32·0	·494	+0·4
Feb. 2·16	45002·16	–30·8	·510	+0·5
21·09	021·09	–28·0	·554	+0·2
Mar. 6·05	034·05	–27·0	·584	–1·0
Nov. 7·39	280·39	–36·8	5·151	+0·7
17·31	290·31	–38·7	·174	+0·2
Dec. 9·26	312·26	–41·5	·224	–0·6
22·22	325·22	–43·1:	·254	–1·7
1983 Jan. 18·16	45352·16	–40·6:	5·316	+0·3

TABLE II (*continued*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity</i> <i>km s⁻¹</i>	<i>Phase</i>	<i>(O - C)</i> <i>km s⁻¹</i>
1984 Jan. 6·20	45705·20	-36·1	6·130	-0·2
Feb. 7·11	737·11	-39·0	·203	+1·3
1989 Jan. 8·91*	47534·91	-39·7	10·344	+0·5
Oct. 24·01*	823·01	-23·7	11·008	-0·7
1993 Feb. 10·91	49028·91	-13·7	13·785	0·0
17·96	035·96	-13·2	·801	0·0
Mar. 17·88	063·88	-12·9	·866	+0·1
Dec. 26·96	347·96	-30·5	14·520	+0·1
1994 Jan. 8·06	49360·06	-28·7	14·548	-0·1
May 1·81	473·81	-13·1	·810	-0·1
Aug. 4·15	568·15	-24·9	15·027	+0·3
Dec. 11·10	697·10	-41·0	·324	-0·3
29·06	715·06	-39·5	·366	-0·1
1995 Dec. 27·05	50078·05	-40·0	16·202	+0·2
1996 Mar. 29·88	50171·88	-37·3	16·418	-0·3
Nov. 16·16†	403·16	-18·0	·950	-0·6
28·04†	415·04	-19·8	·978	+0·1
Dec. 2·10†	419·10	-20·7	·987	+0·1
15·13	432·13	-24·1	17·017	0·0
22·04	439·04	-25·8	·033	+0·1
1997 Jan. 23·97	50471·97	-33·6	17·109	+0·4
Mar. 2·93‡	509·93	-39·5	·196	+0·5
28·88‡	535·88	-41·1	·256	+0·3
Apr. 9·85‡	547·85	-41·0	·284	+0·4
27·83	565·83	-40·4	·325	+0·3
July 20·12	649·12	-31·2	·517	-0·4
Dec. 22·08	804·08	-13·2	·874	-0·1
1998 July 31·14	51025·14	-38·5	18·383	+0·2
1999 Apr. 13·20‡	51281·20	-19·3	18·973	+0·1
Dec. 29·02	541·02	-26·8	19·571	+0·1
2000 Jan. 9·00	51552·00	-24·9	19·597	+0·2
20·01	563·01	-23·3	·622	-0·1
Feb. 25·92	599·92	-17·3	·707	+0·2
Mar. 4·92	607·92	-16·2	·725	+0·2
21·88	624·88	-14·5	·764	-0·1
Apr. 5·84	639·84	-12·9	·799	+0·4
21·86	655·86	-12·9	·836	-0·2
Sept. 21·17	808·17	-39·8	20·187	-0·2
Oct. 17·24	834·24	-41·4	·247	-0·1
Nov. 4·14	852·14	-41·5	·288	-0·2
22·19	870·19	-40·6	·329	0·0
Dec. 9·12	887·12	-39·4	·368	-0·1
2001 Jan. 6·97	51915·97	-36·2	20·435	-0·2
25·94	934·94	-33·2	·479	+0·2
Apr. 28·83	52027·83	-18·5	·693	-0·1
Oct. 4·16	186·16	-28·8	21·057	-0·2
12·19	194·19	-30·6	·076	+0·1
Nov. 5·04	218·04	-36·0	·131	-0·1
Dec. 15·09	258·09	-41·2	·223	-0·3

TABLE II (concluded)

Date (UT)	MJD	Velocity km s ⁻¹	Phase	(O-C) km s ⁻¹
2002 Feb. 6·95	52311·95	-40·0	21·347	+0·1
Mar. 27·89	360·89	-34·7	·460	-0·1
Sept. 28·21	545·21	-13·3	·884	+0·1
Oct. 19·20	566·20	-15·9	·933	+0·1
2003 Jan. 10·08	52649·08	-35·3	22·123	0·0
Mar. 16·89	714·89	-41·3	·275	+0·1
Sept. 29·16	911·16	-16·7	·727	-0·4
Nov. 17·10	960·10	-12·8	·840	-0·1
2004 Jan. 17·04	53021·04	-20·1	22·980	0·0
Mar. 29·89	093·89	-37·5	23·148	-0·2
Sept. 16·14	264·14	-29·0	·540	+0·2
Dec. 18·09	357·09	-14·9	·754	0·0
2005 Apr. 3·87	53463·87	-22·4	24·000	-0·2
Sept. 29·20	642·20	-37·2	·411	+0·1
2006 Feb. 20·95	53786·95	-15·3	24·744	+0·1
Apr. 10·86	835·86	-12·9	·857	-0·1
Sept. 21·16	999·16	-40·7	25·233	+0·4
2007 Mar. 21·86	54180·86	-21·2	25·652	-0·1
31·87	190·87	-19·6	·675	-0·1

*OHP observation¹⁸, provided through the CDS, wt. 0.
† Observed with Cambridge *Coravel* in preliminary form (wt. 1/4).
‡ Observed with DAO 48-inch telescope (wt. 1/2).

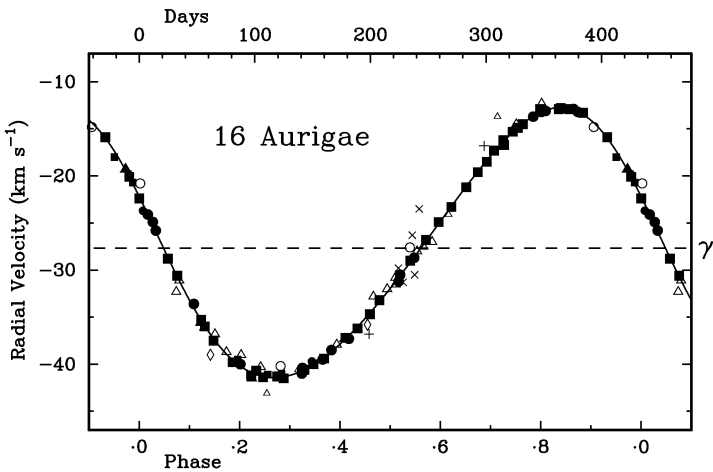


FIG. 3

The observed radial velocities of 16 Aurigae plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The same symbols are used as in Fig. 2 for the corresponding data sources. Additional sources featured here are Lick⁵² (open circles; weight 0·025), and the DAO (open diamonds; two measures by Harper⁵⁴) and Bonn (crosses; six measures by Küstner⁵³) (both zero-weighted).

radial velocities, including the five published⁵² from Lick, so he must have had 25 of his own. Exactly that number of Ames velocities of the star were subsequently published⁵; they are included in Table II, together with the measurements from Lick⁵², Bonn⁵³, the DAO⁵⁴, and Mount Wilson¹⁵. Also in Table II are two measurements made by de Medeiros & Mayor¹⁸ with the OHP *Coravel* in 1989. Starting in 1993, the present writer has made 64 observations of 16 Aur — 18 with the OHP *Coravel* and 45 with the Cambridge one, plus one with the DAO spectrometer — to add to the table. All the published observations, as well as the OHP ones, have been adjusted by $+0.8 \text{ km s}^{-1}$; in addition, the early Bonn, Mount Wilson, and DAO ones have received the corrections assessed in Table 3 of the *Introduction* to the *Radial Velocity Catalogue*⁵⁸. In the solution of the orbit, the Cambridge *Coravel* observations have been accorded unit weight, except that the six made in 1996/7, when the spectrometer was in a preliminary form, have been weighted $1/4$. The single DAO and 18 OHP ones have been half-weighted. The few published measurements from Bonn, Mount Wilson, the DAO, and de Medeiros & Mayor have not been used in the solution. The Lick velocities have been weighted 0.025 , and the Ames ones 0.05 , apart from five which are noted⁵ as quality B: their velocities are followed by a colon in Table II and their weighting has been halved. In some ways it is a bit unfortunate to be obliged to attribute such derisory weightings to velocities that by earlier standards were excellent. Those velocities, however, greatly increase the time base of the data and thereby contribute significantly to the precision with which the orbital period is determined (in the present case approximately doubling it); that precision would, however, reach illusory heights if the early data were charitably accorded weightings above what their actual variances warrant. The elements found here for the orbit are shown in Table III; those given by Christie³ and by Beavers² are listed for comparison. The velocity curve and the data are illustrated in Fig. 3.

TABLE III
Orbital elements for 16 Aurigae

<i>Element</i>	<i>Christie</i> ³	<i>Beavers</i> ²	<i>This paper</i>
<i>P</i> (days)	434.8	441.5 ± 0.1	434.16 ± 0.03
<i>T</i> (MJD)	18689.5	—	51727.2 ± 1.4
γ (km s ⁻¹)	-27.5	-26.4 ± 0.4	-27.65 ± 0.03
<i>K</i> (km s ⁻¹)	14.8	14.2 ± 0.6	14.35 ± 0.04
<i>e</i>	0.1	0.12 ± 0.04	0.1189 ± 0.0026
ω (degrees)	40	—	70.1 ± 1.2
<i>a</i> ₁ sin <i>i</i> (Gm)	—	—	85.09 ± 0.21
<i>f</i> (<i>m</i>) (<i>M</i> _☉)	—	0.13	0.1305 ± 0.0010
R.m.s. residual (wt 1) (km s ⁻¹)	—	1.8	0.18

The orbit, whose period is more than a year, is seen now to be established with an uncertainty of less than an hour. Agreement between the new elements and the previous ones, as far as those went, is seen to be good (the values of *T* refer of course to quite different epochs!), apart from the period found by Beavers. Since Christie³ specifically remarked, “The period is well defined by the early Lick observations”, and he thought it appropriate to give it to a tenth of a day and proves to have been right to have done so, *why*, one may ask, would Beavers have made an error of a week although he recorded that he too utilized the Lick measures and indeed claimed a standard error of only 0.1 day for the period? The answer is actually not far to seek, since we have available to us what is presum-

ably the exact data set that Beavers used, encompassing 25 of his own observations plus the five from Lick, so we are able to experiment with his data. He could be expected to have known about the old Mount Wilson observations too, since he used analogous ones from the same source¹⁵ in his orbit of 5 Her, but he does not mention them. If he had started by solving the orbit from his own observations alone, he would have obtained a preliminary period of 435 ± 1.0 days, which he could then have used as the starting value for a solution that incorporated the Lick velocities and would then have obtained 434.12 ± 0.07 days. But what evidently happened was that he omitted the preliminary step and started the solution of the whole data set at (probably) $P = 440$ days, thinking that that would be ‘near enough’, and the solution pulled in to the period that he found of 441.5 days (actually it produces $P = 441.48 \pm 0.12$ days) which corresponds to an error of 1 in the cycle count between the Lick and Ames epochs. That is still a plausible-looking solution if one is not comparing it with the correct one, although the r.m.s. error found for the (A-quality) Ames observations is raised from 0.9 to 1.7 km s^{-1} (Beavers noted it as 1.8 , but he may not have down-weighted the B-quality velocities). In the ‘wrong’ solution the two old Mount Wilson velocities give residuals of 16.0 and 4.6 km s^{-1} whereas in the ‘right’ one they are only 2.1 and 1.8 km s^{-1} , so it seems likely that Beavers disregarded them. This is not the first time that an error has been found^{59–61} in the cycle count between sets of data taken at well-separated epochs.

It is of interest to review Johansen’s suggestion³³ that a slight apparent dimming of 16 Aur on two nights might have been due to an eclipse. The dates concerned are 1966 January 23 and 29. There was a conjunction on 1966 January 29.3, with an uncertainty of a little more than a day; at that conjunction (phase 0.47) the primary star is at the far side of its orbit, so the event would be of the nature of a transit. The mass function is substantial: it requires a minimum mass of about 1.05 , 1.3 , and $1.55 M_{\odot}$ for the secondary if the primary mass is taken as 2, 3, or $4 M_{\odot}$, respectively. If a transit really takes place, then $\sin i \sim 1$ and the secondary has virtually the minimum mass required by the mass function. If a transit of the secondary were indeed responsible for the apparent dimming by about $0^{\text{m}}.02$, then that object must have covered about 2% of the surface area of the primary. Tabular values of the radii of mid-K giant stars run to about $20 R_{\odot}$; if that is true for 16 Aur, it would take an occulting body with a radius of about $3 R_{\odot}$ to cover 2% of it — too big, if we suppose the secondary to be a main-sequence star of little more than one solar mass. We could of course posit that the secondary is beginning its evolution and has recently swollen to the requisite size, but that is rather an artificial and *ad hoc* hypothesis. We could also consult the *Catalogue of Apparent Diameters and Absolute Radii of Stars*⁶² for an individual assessment of the diameter of the 16 Aur primary. We find there an angular diameter of $0''.00400$, on no less (but no more recent!) an authority than Hertzsprung’s⁶³; his actual listing, based simply on the brightness and colour of the star, shows an angular radius of $0''.0020$. The *Catalogue*⁶² interprets it as corresponding to a linear radius of $16.5 R_{\odot}$, but the present writer has difficulty in agreeing. The *Hipparcos* parallax is $0''.01392$ with a standard error just one-tenth as large, so the distance is about 72 pc. At that distance, $0''.002$ represents (0.002×72) AU, *i.e.*, 0.144 AU or about $31 R_{\odot}$ (still with an uncertainty of 10% stemming from the parallax plus whatever amount we might assign to Hertzsprung’s number), exacerbating the difficulty over the size needed for the secondary to cover 2% of it. It might be concluded that Johansen’s suggestion — which was responsible for 16 Aur’s inclusion in the *New Catalogue of Suspected Variable Stars*⁶⁴, where it is no. 1909 — is an

interesting one, that the timing of the apparent fade is absolutely right, but its significance remains doubtful because the secondary object seems unlikely to be large enough to obscure enough of the primary to have caused the apparent fading.

It would be of interest to follow this matter up by careful photometric observations at the times of conjunction, which are now accurately known: they are at phases $\cdot 047$ and $\cdot 575$, occurring $20\cdot 5$ and $249\cdot 6$ days, respectively, after periastron passages, whose dates are represented by the expression $T + nP$ where T and P are taken from the table (Table III) of orbital elements and n is any integer. Events could last up to 10–15 days (depending on the mass ratio) if the orbital inclination is sufficiently close to 90° to make them almost central. The putative apastron event at phase $\cdot 575$ would be an eclipse of the secondary, which is most unlikely to be cooler than the primary and whose surface brightness is probably therefore higher, so any eclipse then might well be deeper than the transit event that may have been observed by Johansen, particularly at short wavelengths (B or U).

The *Hipparcos* catalogue includes a (surprisingly short) section⁶⁵ giving astrometric orbits; there are 235 of them, of which only 45 are independent, the others utilizing some information derived from already-known spectroscopic orbits. 16 Aur features in the listing, in the latter category: P , e , and ω were adopted from Christie³, and T , a_0 , i , and Ω were derived from the satellite's measurements. It seems hardly worthwhile to cite the values of those quantities here, because Pourbaix & Boffin⁶⁶ subsequently rejected them, finding that the orbit did not survive their statistical tests. All the same, it seems reasonable to expect that, since 16 Aur is a single-lined system with an $a_1 \sin i$ of more than half an AU, it should exhibit an astrometric orbit with an angular semi-axis of more than half the annual parallax — as indeed the *Hipparcos* orbit gave for it ($0''\cdot 00724$).

5 *Herculis* (HR 5966, HD 143666)

5 Her is a late-G giant star to be found on the extreme western margin of Hercules, closely following the triangle of stars β , γ , and κ Ser that marks the head of Serpens. (It can be on the western margin without being 1 Her: 1 (= χ), 2, and 4 Her are in a peninsula of Hercules that, north of Corona Borealis, extends further to the west than the boundary at the declination ($+18^\circ$) of 5 Her, while the former 3 Her (HR 5963) is well within the present boundary of CrB.)

The *UBV* magnitudes of 5 Her have been measured by Roman⁶⁷, Argue²⁹, and Johnson *et al.*³⁰, with results close — in fact identical in the cases of V and $(U-B)$ — to $V = 5^m\cdot 12$, $(B-V) = 0^m\cdot 99$, $(U-B) = 0^m\cdot 74$. The *HD* type is G5, but in their early assessment of spectroscopic parallaxes Adams *et al.*¹¹ gave G7 as both the 'estimated' and the 'measured' type (see the section on 48 Psc for explanation), and maintained that classification in their later paper⁹. In both papers the absolute magnitude is given as $+0^m\cdot 7$. At much the same time (1921) as the earlier paper¹¹, Rimmer⁶⁸ determined an M_V of $+0^m\cdot 9$, and Young & Harper³⁴ each independently found it to be $+1^m\cdot 0$. The *Hipparcos* parallax of $0''\cdot 01058 \pm 0''\cdot 00085$ yields a distance modulus of $4^m\cdot 88 \pm 0^m\cdot 18$ and thereby an absolute magnitude of $+0^m\cdot 24$ — a little brighter than any of the early spectroscopic estimates. The *Hipparcos* number stems from an 'acceleration solution'; in view of the fact that 5 Her actually made almost a complete orbital circuit while it was under observation by *Hipparcos*, it is clear that a continuous acceleration must be, at best, a very rough representation of the actual photocentric motion, and one must expect that a re-reduction that takes into account the orbital parameters would lead to a more reliable result.

The MK type was first given by Roman^{37,67} as Ko III, but Harlan⁶⁹ regarded it as G8 III. Keenan^{38,40} initially gave the more refined classification of G8 IIIb Fe – 0.5, but then⁴³ truncated it to plain G8 IIIb. Fig. 1 of ref. 44 shows that the luminosity derived from its parallax places it right on the boundary between luminosity classes III and IIIb; in fact the Keenan luminosity class is aligned better with the estimates of the spectroscopic-parallax pioneers^{11,68,34,9} than with the *Hipparcos* measurement, but the difference is not great. The slight metal deficiency that Keenan noted^{38,40} for a time in his classifications is supported by deductions both from narrow-band photometric indices^{47,48,70–73} and from actual spectra^{50,71}, which all give results of $[\text{Fe}/\text{H}] \sim -0.25$. Noticeable also is the fact that they concur in giving values of M_V close to $+1^{\text{m}}.0$, in agreement with Keenan⁴³ as well as with the early values, and distinctly fainter than is indicated by the *Hipparcos* parallax. By coincidence, in one of the narrow-band papers, that of Gottlieb & Bell⁴⁸, 5 Her is the subject of a ‘worked example’ that demonstrates the procedure used by those authors to interpret the narrow-band indices derived by Spinrad & Taylor⁷⁴ from spectral scans at 15-Å resolution. Spectroscopy⁷¹ of the 26708-Å region found that the Li I line that is present in some stars at that wavelength was undetectably weak in 5 Her.

Radial velocities of 5 Her were published from no fewer than three observatories in the 1920s. Plaskett *et al.*⁷⁵ listed six measurements of the star (under the alias Boss⁵⁵ 4075) made at the DAO in 1919 and 1920 with a prism spectrograph giving about 30 Å mm^{–1} at H γ ; they range between -18.2 and -13.9 km s^{–1} in a non-systematic fashion. Adams *et al.*¹⁴ gave a mean value of -16.9 from three plates taken at Mount Wilson, with a ‘probable error’ of only 0.2 km s^{–1}. Abt⁷⁶ comes to the rescue once again with the individual times and velocities, which show that the dispersion used was 36 Å mm^{–1} at H γ , thereby identifying also the telescope as the 60-inch; it is seen that two of the plates were taken on the same evening, so their results have been averaged and treated here as a single observation. Then the Lick compendium⁵² of velocities of practically all stars brighter than 5^m.5, derived from spectra taken at 11 Å mm^{–1} at H γ with the 36-inch refractor, includes five velocities for 5 Her. Four are near -21 km s^{–1}, but the third plate, which is well removed in time from the others, disagrees by an amount that is definitely significant in relation to the normal accuracy of Lick measures on stars with good lines. That fact was evidently noticed, because the plate was re-measured by another person — the two measures gave -14.5 and -15.8 km s^{–1} — but there is no comment that the velocity is or may be variable, probably owing to commendable caution in view of there being only the one discrepancy.

Events then ran parallel with those relating to 16 Aur: at the Schenectady Colloquium² in 1984 Beavers presented, and in the *Proceedings* published, a partial set of preliminary orbital elements. It was based on 33 observations that included the five from Lick⁵² and three from Mount Wilson^{14,76}, so it would seem that he had 25 of his own measurements; 24 was the number subsequently published in his big paper⁵ with Eitter. Three other velocities were reported by de Medeiros & Mayor¹⁸ and were later made available from the *Centre de Données Stellaires*. Meanwhile the present writer began observing the star in 1993 and has followed it ever since, accumulating 89 new measurements, of which two came from the DAO spectrometer, 19 from the OHP *Coravel*, and 68 from the Cambridge one.

All of the available velocities are listed in Table IV. The Lick⁵², Mount Wilson^{14,76}, and DAO⁷⁵ ones, and those made at OHP, have all been increased by 0.8 km s^{–1}, as usual. The additional corrections recommended⁵⁸ by the *Radial Velocity Catalogue* for Mount Wilson and the DAO have not been applied in this

TABLE IV
Radial-velocity observations of 5 Herculis

Except as noted, the sources of the observations are as follows:
1976–1983 — published by Beavers & Eitter⁵, weighted $1/16$ in orbital solution;
1986–1998 — Haute-Provence Coravel; 1999–2007 — Cambridge Coravel

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O–C) km s^{-1}
1918 Apr. 17.47*	21700.47	–21.3	17.078	+0.9
Aug. 7.23*	812.23	–20.3	.169	+0.5
1919 May 19.36†	22097.36	–15.9	17.403	+1.1
Aug. 8.18*	178.18	–17.4	.469	–1.1
12.18†	182.18	–16.6	.472	–0.4
1920 Feb. 11.58‡	22365.58	–16.4	17.622	–1.2
24.56‡	378.56	–17.4	.633	–2.2
Apr. 11.45‡	425.45	–13.1	.671	+2.0
May 7.36‡	451.36	–15.7	.692	–0.7
15.30‡	459.30	–14.6	.699	+0.4
25.25‡	469.25	–14.4	.707	+0.6
1922 May 7.46*	23181.46	–20.3	16.290	–1.7
1924 May 17.44*	23922.44	–19.0	16.896	–1.5
1976 May 19.28	42917.28	–17.0	0.438	–0.4
June 1.28	930.28	–17.1:	.449	–0.6
20.22	949.22	–16.6	.464	–0.3
July 6.18	965.18	–15.1:	.477	+1.1
1977 Mar. 22.38	43224.38	–13.3	0.689	+1.7
Apr. 27.29	260.29	–15.3	.719	–0.2
July 2.21	326.21	–15.6::	.773	–0.3
6.17	330.17	–15.8:	.776	–0.5
1978 May 16.25	43644.25	–21.6	1.033	+0.4
June 9.20	668.20	–20.0	.052	+2.2
18.18	677.18	–22.4	.060	–0.2
July 15.18	704.18	–22.8	.082	–0.7
Aug. 11.11	731.11	–21.1	.104	+0.8
1979 Mar. 15.42	43947.42	–18.9	1.281	–0.1
May 21.24	44014.24	–15.7	.336	+2.2
24.20	017.20	–17.6	.338	+0.3
June 22.17	046.17	–17.4	.362	+0.1
1982 May 7.25	45096.25	–20.7	2.221	–0.9
June 2.21	122.21	–20.3	.242	–0.9
8.18	128.18	–20.1	.247	–0.8
23.17	143.17	–20.8	.259	–1.7
1983 Apr. 20.32	45444.32	–15.5	2.506	+0.4
May 23.27	477.27	–16.2	.533	–0.5
June 8.25	493.25	–15.9	.546	–0.3
1986 June 4.93 [§]	46585.93	–16.6	3.440	0.0
July 28.87 [§]	639.87	–16.3	.484	–0.2
1987 May 10.10 [§]	46925.10	–15.0	3.717	+0.1

TABLE IV (*continued*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity km s⁻¹</i>	<i>Phase</i>	<i>(O-C) km s⁻¹</i>
1993 Feb. 11·25	49029·25	-16·6	5·439	0·0
Mar. 19·19	065·19	-16·0	·468	+0·3
July 5·96	173·96	-15·4	·557	+0·1
Sept. 12·83	242·83	-14·9	·614	+0·3
Dec. 30·26	351·26	-14·5	·702	+0·5
1994 Feb. 19·19	49402·19	-15·1	5·744	0·0
Apr. 30·10	472·10	-15·8	·801	-0·2
July 30·83	563·83	-16·9	·876	+0·1
1995 Jan. 4·27	49721·27	-21·5	6·005	-0·1
June 5·05	873·05	-21·8	·129	-0·2
Dec. 27·25	50078·25	-18·7	·297	-0·2
1996 Mar. 31·14	50173·14	-17·6	6·375	-0·3
Apr. 25·06	198·06	-17·3	·395	-0·2
Dec. 16·26	433·26	-15·8	·588	-0·4
1997 Jan. 26·25	50474·25	-15·3	6·621	-0·1
Mar. 1·16 [†]	508·16	-15·2	·649	-0·1
Apr. 1·14 [†]	539·14	-15·2	·674	-0·2
May 1·12 [†]	569·12	-15·3	·699	-0·3
June 18·02 [†]	617·02	-15·8	·738	-0·7
July 23·91	652·91	-15·4	·767	-0·1
Sept. 9·83	700·83	-16·1	·807	-0·5
1998 Apr. 29·09	50932·09	-21·1	6·996	0·0
July 8·97	51002·97	-22·1	7·054	+0·1
1999 Apr. 2·47	51270·47	-18·9	7·273	0·0
July 8·30	367·30	-17·3	·352	+0·4
Dec. 29·28	541·28	-16·2	·494	-0·2
2000 Feb. 11·25	51585·25	-15·7	7·530	0·0
Mar. 4·21	607·21	-15·5	·548	+0·1
Apr. 7·14	641·14	-15·7	·576	-0·3
2001 Jan. 14·30	51923·30	-16·1	7·807	-0·5
Mar. 3·23	971·23	-16·7	·846	-0·4
Apr. 29·09	52028·09	-17·4	·893	0·0
June 23·02	083·02	-18·7	·938	+0·3
July 23·93	113·93	-19·6	·963	+0·4
Aug. 20·90	141·90	-20·6	·986	+0·2
Sept. 29·80	181·80	-22·0	8·018	-0·3
Oct. 25·74	207·74	-22·3	·040	-0·2
2002 Jan. 4·30	52278·30	-22·6	8·097	-0·6
Feb. 21·23	326·23	-21·6	·137	-0·2
Mar. 27·13	360·13	-20·8	·164	+0·1
Apr. 20·11	384·11	-20·5	·184	0·0
May 16·06	410·06	-19·9	·205	+0·2
June 11·00	436·00	-19·6	·226	+0·1
July 13·98	468·98	-19·1	·253	+0·1
Aug. 14·90	500·90	-18·6	·280	+0·2
Sept. 10·81	527·81	-18·1	·302	+0·3
Oct. 4·79	551·79	-18·5	·321	-0·4
Nov. 4·72	582·72	-18·2	·346	-0·5

TABLE IV (*concluded*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity</i> <i>km s⁻¹</i>	<i>Phase</i>	<i>(O – C)</i> <i>km s⁻¹</i>
2003 Feb. 18·22	52688·22	–16·5	8·433	+0·2
Apr. 7·13	736·13	–16·4	·472	–0·2
May 8·09	767·09	–15·9	·497	+0·1
June 19·05	809·05	–15·7	·532	0·0
July 20·93	840·93	–15·3	·558	+0·2
Aug. 14·91	865·91	–15·3	·578	+0·1
Sept. 14·84	896·84	–15·1	·604	+0·2
Oct. 14·77	926·77	–15·4	·628	–0·2
2004 Mar. 1·21	53065·21	–15·0	8·741	+0·1
Apr. 6·13	101·13	–15·2	·771	+0·1
May 7·09	132·09	–15·3	·796	+0·2
June 5·06	161·06	–15·7	·820	+0·1
July 5·98	191·98	–16·0	·845	+0·2
Aug. 30·84	247·84	–17·3	·891	+0·1
Sept. 13·82	261·82	–17·7	·902	0·0
Oct. 7·76	285·76	–18·6	·922	–0·2
25·74	303·74	–19·0	·936	–0·1
Dec. 26·30	365·30	–20·8	·987	0·0
2005 Apr. 19·12	53479·12	–22·2	9·080	0·0
May 28·00	518·00	–21·7	·112	+0·1
June 23·00	544·00	–21·1	·133	+0·4
July 16·93	567·93	–20·9	·153	+0·2
Aug. 15·88	597·88	–20·4	·177	+0·3
Sept. 12·84	625·84	–20·2	·200	0·0
Oct. 20·74	663·74	–19·8	·231	–0·2
2006 Mar. 2·22	53796·22	–17·9	9·339	–0·1
Apr. 5·10	830·10	–17·5	·367	0·0
May 11·04	866·04	–17·1	·397	0·0
June 1·03	887·03	–17·0	·414	–0·1
July 2·98	918·98	–16·4	·440	+0·2
Aug. 7·92	954·92	–16·2	·469	+0·1
Sept. 20·80	998·80	–16·1	·505	–0·2
Oct. 26·74	54034·74	–15·8	·535	–0·1
2007 Jan. 13·24	54113·24	–15·5	9·599	–0·2
Feb. 15·26	146·26	–14·9	·626	+0·3
Mar. 22·17	181·17	–15·2	·654	–0·1
Apr. 10·10	200·10	–14·8	·670	+0·3
30·08	220·08	–15·1	·686	–0·1
May 19·06	239·06	–15·0	·702	0·0
June 1·02	252·02	–14·8	·712	+0·2
27·96	278·96	–14·9	·734	+0·2

*Lick observation⁵², weight $1/20$.†Mount Wilson observation^{14,76}, weight 0.‡DAO observation⁷⁵, weight 0.§OHP observation¹⁸, provided through the *CDS*, wt. 1.¶Observed with Cambridge *Coravel* in preliminary form, wt. $1/4$.

||Observed with DAO 48-inch telescope, weight 1.

instance, since they seem to be the reverse of helpful; the effect is only cosmetic anyway, because those data are not used in the orbital solution. Unusually, the Ames velocities prove to be best left alone and not to be increased by $0·8 \text{ km s}^{-1}$, so in this case no adjustment has been made to them. The velocities obtained with the Cambridge *Coravel* have been subjected to an empirical correction of

-0.3 km s^{-1} to bring them into line with the OHP ones, an amount in keeping with the relative offset found previously between the two sources for stars of such a colour as that of 5 Her. As far as weighting is concerned, the *Coravel* measurements have been accorded unit weight, except that the four measures made in Cambridge in 1997, when the instrument was in a preliminary state, were weighted $1/4$ like the corresponding ones for 16 Aur, and the small negative correction made to the later Cambridge data was omitted from those four. The Mount Wilson data^{14,76} were deemed too few, and the DAO ones⁷⁵ too ragged, to be usefully included in the solution of the orbit and were attributed zero weight. The Lick⁵² velocities have been weighted $1/20$ and the Ames⁵ ones $1/16$, the weighting being halved for the three Ames B-quality ones (listed with a colon in Table IV) and divided by 5 for the single C-quality measure (double colon). The orbit obtained on the basis just set out is shown in Fig. 4 and its elements are:

$$\begin{aligned}
 P &= 1222.2 \pm 1.0 \text{ days} & (T)_8 &= \text{MJD } 52159 \pm 6 \\
 \gamma &= -17.85 \pm 0.03 \text{ km s}^{-1} & a_1 \sin i &= 57.5 \pm 0.7 \text{ Gm} \\
 K &= 3.58 \pm 0.04 \text{ km s}^{-1} & f(m) &= 0.00509 \pm 0.00018 M_\odot \\
 e &= 0.294 \pm 0.010 & & \\
 \omega &= 137.2 \pm 2.1 \text{ degrees} & \text{R.m.s. residual (wt. 1)} &= 0.23 \text{ km s}^{-1}
 \end{aligned}$$

The preliminary elements given by Beavers² are $P = 1221.7 \pm 1.9$ days, $\gamma = -18.1 \pm 0.2 \text{ km s}^{-1}$, $K = 3.56 \pm 0.27 \text{ km s}^{-1}$, and $e = 0.15 \pm 0.08$. The mass function is too small to encourage hope that the secondary object will be detectable at all easily; as in the case of 48 Psc, it is more likely to be a lower-main-sequence star than a white dwarf.

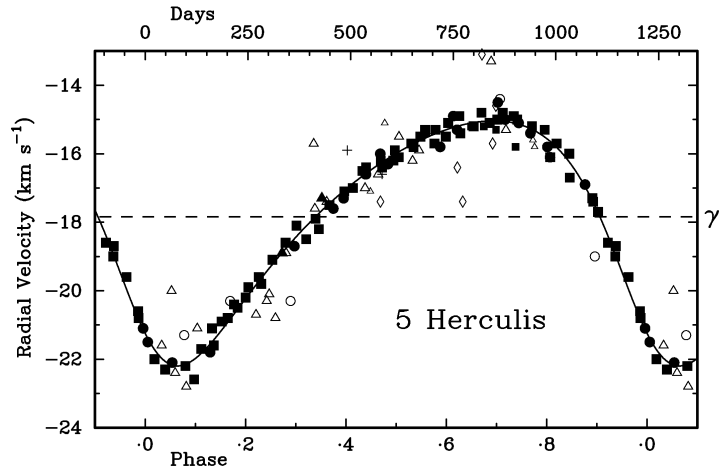


FIG. 4

As Fig. 3, but for 5 Herculis. The assignment of symbols to sources is the same as in Figs. 2 and 3, although not all the weightings are identical (see text for details).

β Scuti (HR 7063, HD 173764)

For a star that is the second-brightest in its constellation there would seem to be no occasion to state whereabouts it is to be found. On the other hand, when

one thinks of the analogous stars in rich constellations such as Gemini or Orion, it seems that only in a very ill-starred constellation could β be as faint as the $4^m \cdot 22$ of β Scuti. Further misgivings are aroused by the fact that the radial-velocity measurements of the star are set out in Campbell & Moore's great compilation⁵² from Lick under the designation 6 Aquilae. Such considerations prompted a small investigation of the relevant matters of nomenclature, with the following results. β Sct is by no means the faintest of its ilk: among the 88 constellations, six are shown in the *Bright Star Catalogue* as not possessing a β at all, and in 17 cases the β is fainter than β Sct; in five of those cases it is fainter than 5^m , and the wooden spoon is adjudicated to β Mic at $6^m \cdot 04$! Moreover, the constellation Scutum has itself had a chequered history. It is not one of the ancient constellations, but was invented by Hevelius⁷⁷ as 'Scutum Sobieskii', named by him after King Jan [John] III Sobieski (1629–1696) of Poland, probably as a mark of gratitude for the King's support after his (Hevelius') observatory burnt down in 1676. It appears in Hevelius' map or *Uranographia*⁷⁷ (a supplement to his work *Prodromus Astronomiae*, published posthumously, by his widow, in 1690) as a shield with John III's coat of arms, mainly a crucifix, emblazoned upon it. The map is confusingly drawn, as had been the convention in early star maps but had mercifully not been followed by Bayer⁷⁸ in early editions of his work, reversed right-to-left, as if one were looking at a globe of the sky from the outside. Bayer, of course, did not attach Greek-letter designations to any of the stars in Scutum because the constellation Scutum had not been devised in his day; as it turned out, neither did he treat any of the relevant stars as meriting such designations as members of adjacent constellations, although two of the seven principal stars of Scutum are shown on his map of Serpens and five on that of Aquila. Flamsteed⁷⁹ assigned some of the stars in the area now defined as Scutum to other constellations, thus accounting for the designation 6 Aql in Campbell & Moore⁵². Flamsteed himself did not number the stars but simply listed their positions in order of right ascension for epoch 1690 in each constellation, and it was Lalande⁸⁰ who actually attached the 'Flamsteed numbers' to them, merely reflecting their serial positions in the catalogue⁷⁹. Lacaille⁸¹ assigned Greek-letter designations, analogous to Bayer's, in the constellations of the southern sky, but he went only as far north as the Tropic of Capricorn. The constellation Scutum Sobieskii was finally restored to the map by Gould⁸², who also assigned the Greek letters, which go only as far as η .

The broad-band magnitudes of β Sct have repeatedly been measured^{30,31,83–88}, with results for V and $(B - V)$ always close to $4^m \cdot 22$ and $1^m \cdot 10$, respectively, while $(U - B)$ values have not been in such good agreement, ranging from $0^m \cdot 79$ to $0^m \cdot 866$. The $(U - B)$ colour is unusually blue in relation to the $(B - V)$ index, a circumstance that could well have indicated the likelihood of the existence of the hot companion before that object was actually detected; the relationship of the two colours is not without parallel, but analogous cases are mostly variable or other pathological stars and/or possess blue companions themselves, like U Sgr. It is hard to understand why Buscombe & Dickens⁸⁹ noted that β Sct exhibits an ultraviolet *deficiency*.

The spectral type, initially listed as H in the *Draper Catalogue*⁹⁰ (in which the star is DC 8373) and then as Go in the *HD*⁹¹, was first given on the MK system by Morgan & Roman⁹² as G5 II, a type repeated by Johnson & Morgan⁹³ and subsequently copied into many papers by others. Vaughan & Zirin⁹⁴, however, listed it as G7 II; they did not appear to be saying that they classified it, but neither did they quote a source for it. The same type was quoted by Brown & Landstreet⁹⁵. Morgan & Keenan⁹⁶ had meanwhile moved slightly in the other direction, re-

classifying it in 1973 as G4 II CN I, a type repeated in 1980 by Keenan & Pitts⁹⁷. Shortly after that, Parsons⁹⁸ recognized the existence of a hot companion to the G star, in UV data collected by the *TD1*⁹⁹ satellite; by comparing the flux distribution with tabulated¹⁰⁰ quantities, he considered the type of the companion to be B8 or B9, about four magnitudes fainter than the cool primary, and estimated the interstellar reddening of the system to be $0^m \cdot 12$. In worrying about types and publishing successive catalogues of standards in the 1980s, Keenan first³⁸ gave the elaborate classification G5 II CN $0 \cdot 5$ Fe I H δ I — just in time for it to be incorporated in the *Bright Star Catalogue* — but afterwards he was satisfied with plain G4 IIa, which persisted throughout the next three listings^{40,42,43}. Hunsch & Reimers¹⁰¹, relying on a photometric synthesis over a wide wavelength range rather than actual spectroscopy, put forward types of G8 II + AoV, with an $E(B-V)$ of $0^m \cdot 18$. Seemingly analogous flux-fitting by Parsons & Ake¹⁰², however, yielded a combination of cG4 + B9 with a Δm of $3^m \cdot 3$ and an $E(B-V)$ of $0^m \cdot 20$, and *IUE* spectra indicated a type of B9.2 for the hot component. Bersier¹⁰³ interpreted Geneva photometry¹⁰⁴ as indicating a reddening of $0^m \cdot 174$. Comparatively recently, Ginestet, Carquillat & Jaschek¹⁰⁵ have classified the primary from infrared spectra as G6 Ib.

The luminosity of β Sct was recognized early on to be above that of a normal giant. Young & Harper³⁴, who classified the spectrum as G6 and made independent estimates of its luminosity, gave absolute magnitudes of $-1 \cdot 0$ and $-0 \cdot 4$, respectively, while Rimmer³⁵ gave it as $-2 \cdot 7$. Rimmer's work^{68,35} on spectroscopic parallaxes, based on observations made with only a 12-inch refractor at the Norman Lockyer Observatory, has been largely overlooked in comparison with the efforts made with much larger telescopes and more manpower at Mount Wilson and the DAO, but it is at least as reliable and there is a lot of it. A Mount Wilson estimate⁹, made a decade later than the DAO and Norman Lockyer ones, gave an M_V of $-1^m \cdot 9$ and a type of cG7. Wilson & Bappu included β Sct in the first demonstration¹⁰⁶ of *K*-line luminosity dependence, and derived for it an M_V of $-4^m \cdot 3$, which they compared with the $-1^m \cdot 9$ from the Mount Wilson spectroscopic parallax just cited⁹ and with a 'Yerkes' value of $-2^m \cdot 0$ which presumably represents an interpretation of the MK luminosity classification. In a quickly ensuing discussion of "Some theoretical aspects of H and K emission in late-type stars", in which the β Sct M_V is given as $-4^m \cdot 4$, Hoyle & Wilson¹⁰⁷ asserted that "The use of the Yerkes magnitudes at luminosity classes I and II introduces quite large errors, which are obvious in many cases", of which they gave β Sct as an example. Robust reinforcement of the same idea comes a few lines later in their paper, with "The implication is that much of the error in our estimation ... has been artificially introduced by the use of incorrect visual magnitudes."

That may prove to be an over-statement of their case, although the last word has still not been said about the real luminosity of β Sct. In Wilson's later work³⁶ on *K*-line luminosities, he moderated the value for β Sct to $-3^m \cdot 9$; much later, Wallerstein, Machado-Pelaez & Gonzalez¹⁰⁸, and then Parsons¹⁰⁹, proposed recalibrations of the relationship between line-width and M_V , but at least in the case of β Sct the nett result seems to have been to exacerbate the discrepancy, Parsons finding M_V s of $-4^m \cdot 4$ and $-4^m \cdot 8$ from the supposedly improved relationship. From another angle, Egret, Keenan & Heck¹¹⁰ re-calibrated the correspondence between MK ('Yerkes') luminosity classes and absolute magnitudes and found that a mean value of $M_V = -2^m \cdot 59$ suited class II stars throughout the range of types from G1 to K3. With β Sct now assigned to Class IIa, its Yerkes absolute magnitude could be said to chime exactly with the value of about -3 inferred

from the *Hipparcos* parallax. As recently as 1983, van Altena & Sawada¹¹¹ published a ground-based trigonometrical parallax of $0''.024$ for β Sct, and listed the absolute magnitude that followed from it as $+1^m.12 \pm 0^m.66$. *Hipparcos*, however, found a parallax of $0''.00473 \pm 0''.00079$, which corresponds to an absolute distance modulus of $6^m.63 \pm 0^m.37$ and thereby yields $M_V \sim -2^m.4$, with the same uncertainty. Allowance for the interstellar absorption implied by the reddening approaching $0^m.2$ that seems to be very generally agreed raises the luminosity to $-3^m.0$. A recent effort by Parsons, Franz & Wasserman¹¹², however, to determine an astrometric orbit with the *Hubble* telescope's 'fine-guidance sensor' gave only a result that was admitted to be "marginal", owing (it seems) to the orbit being even smaller than expected in angular size, so a further increase in the estimated luminosity of β Sct seems quite likely. The *Hipparcos* authors made use of the known spectroscopic orbital elements in the determination of the parallax from the raw positional data, and they inferred values of the angular semi-axis and the inclination of the orbit and also the position angle of the node. The star was one of only 235 — just 0.2% of the whole number of stars surveyed by *Hipparcos* — for which orbital parameters were derived, even with help from spectroscopy, as mentioned above in connection with 16 Aur. However, in a recent discussion of *Hipparcos* data on stars with spectroscopic orbit determinations, Jancart *et al.*¹¹³ found that the β Sct astrometric orbit failed their tests of consistency.

On the other side — *their* side — of the discrepancy noted by Hoyle & Wilson, an exaggeration of the luminosity by the *K*-line width may have arisen through broadening of the line by the star's axial rotation. The rotation is just too small for it to have been detectable in the appearance of the spectrum at the reciprocal dispersion ($10 \text{ \AA mm}^{-1}$) employed by Wilson, but could nevertheless have contributed a little towards the measured width of the *K*-line reversal. In early papers^{114,115} on stellar rotational velocities, only upper limits of 15 and 25 km s^{-1} , respectively, could be set for β Sct. A naïve attribution to rotation of the whole of the excess line-width above the minimum found amongst a large assortment of late-type stars — the present writer's rather cavalier *modus operandi* in the utilization of radial-velocity traces — yields a projected rotation of 9 km s^{-1} , which at least gives a fair impression of the amount by which intrinsic line-broadening, as contrasted with true luminosity effects, would affect measures of the *K*-line width. A luminosity-dependent calibration of line-widths in terms of rotational velocities, as used at Geneva in the reduction of radial-velocity traces, produces a $v \sin i$ estimate¹⁸ of $7.8 \pm 1.0 \text{ km s}^{-1}$, not far from the 'naïve' one. Pasquini *et al.*¹¹⁶ quote what is almost certainly the same result as 8 km s^{-1} . A more sophisticated treatment, however, involving the disentangling in Fourier space of line profiles observed at very high resolution, led Gray & Toner¹¹⁷ to apportion the broadening seen in β Sct to rotation of $5.2 \pm 0.4 \text{ km s}^{-1}$ and 'radial-tangential macroturbulence' of $9.1 \pm 0.1 \text{ km s}^{-1}$.

Quite soon after Wilson & Bappu¹⁰⁶ demonstrated the correlation between the *K*-line width and stellar luminosity, Kraft, Preston & Wolff¹¹⁸ investigated whether the same thing was true of the $H\alpha$ absorption line, which like the *K*-line emission must be formed very high in the stellar atmosphere. A practical advantage of $H\alpha$ would be that it is far more easily observed and should be useable for much more distant stars, being in a part of the spectrum where interstellar absorption is less severe, and not requiring exposures many times longer than suffice for the continuum as is the case at *K*. They did indeed find $H\alpha$ to be luminosity-sensitive in the hoped-for fashion, but it seems that the scatter about the mean trend was greater than for the *K* line. Their paper includes a nice reproduction of the $H\alpha$ region of

a $6.7\text{-}\text{\AA}\text{ mm}^{-1}$ Palomar spectrogram of β Sct. A spectrophotometric profile of the line in β Sct (and in many other stars) was published by Eaton¹¹⁹. The line is of course in absorption, so it is surprising to find β Sct included in the listing by The¹²⁰ of “previously known $H\alpha$ -emission stars” in his paper on “a dark region in Aquila and Scutum”; the reference to the source of that information, however, is to a paper¹²¹ listing *K*-line-emission objects.

There are not many papers giving additional information on the spectrum of β Sct. Vaughan & Zirin⁹⁴, in an early excursion into infrared spectroscopy, included the star in a survey of the He I $\lambda 10830\text{-}\text{\AA}$ region in a number of bright stars, and found a strong absorption line (equivalent width $\sim 0.8\text{ }\text{\AA}$) to be present; they considered it to be an indication of a hot chromosphere. Later, Zirin¹²² thought it might indicate a corona rather than a chromosphere. Linsky *et al.*¹²³ published profiles of $10\text{-}\text{\AA}$ regions centred on the *H* and *K* lines; at that time they were unaware of the existence of the early-type component, and it must be said that the *K* line does not appear appreciably filled in by the hot star’s light. Brown & Landstreet⁹⁵ made a search for weak longitudinal magnetic fields in late-type stars but did not see one in β Sct. Luck¹²⁴ made a major investigation of abundances in a set of cyanogen-weak giant stars. It is not clear why β Sct was included, since it was not, and never had been, regarded as CN-weak. Individual abundances were derived for as many as 24 elements, which in general were found to be slightly (~ 0.2 dex) underabundant in β Sct with respect to the Sun; that includes lithium, for which a logarithmic abundance of 0.73 , on the usual scale where $\log N(\text{H}) = 12$, was found from the equivalent width of $23\text{ m}\text{\AA}$ that was measured for the $\lambda 6708\text{-}\text{\AA}$ line. There seems to be some disagreement even as to the presence, let alone the strength, of the lithium line. It is in fact not a straightforward thing to measure unless it is strong, owing to blending with a closely adjacent Fe I line. Mallik¹²⁵ measured it at $50\text{ m}\text{\AA}$ and deduced a $\log N(\text{Li})$ of 0.93 , whereas Lebre *et al.*, in a very recent paper¹²⁶, were unable to detect any Li line at all and considered that $\log N(\text{Li}) < 0.0$. In Luck’s paper¹²⁴ there is a section specifically headed “HR 237 and HR 7063” (the latter star being β Sct); it merely says, however, that another paper discusses those stars extensively, and it is a disappointment to find that the cited paper actually does not mention them.

Hünsch & Reimers¹⁰¹ showed a profile of the Mg II analogues of the *H* and *K* lines at $\lambda\lambda 2802$ and $2795\text{ }\text{\AA}$, demonstrating strong circumstellar (CS) absorption in a massive high-velocity ($\sim 160\text{-km s}^{-1}$) ‘cool’ wind. Their photometric decomposition of the flux from the system into components of G8 II and Ao V, noted above, with $E(B-V) = 0^{\text{m}}.18$ allowed them to propose for the giant component intrinsic colours of $(B-V) = 1^{\text{m}}.01$ and $(U-B) = 0^{\text{m}}.82$. Reimers *et al.*¹²⁷ noted that the CS wind component was always present in the *K* line in their observations of β Sct.

Eggen¹²⁸ at one time assigned β Sct to the ‘Pleiades group’; later, he¹²⁹ included it as a member of the ‘Local Association’, which looks as if it might be the same proposed entity under a different name. The star is noted in the back of the *Bright Star Catalogue*⁸ as being a member of the ‘Scutum OB2’ Association, upon whose existence de Zeeuw *et al.*¹³⁰ have cast serious doubt. Beta Sct has also featured in a number of papers in which it was not of interest in itself but served as a standard of one sort or another. In recent years it has lent its name to a Milky Way field (its Galactic latitude is about -1°) that has become one of the favourites for large CCD surveys such as MACHO¹³¹ and EROS¹³² for microlensing stars, since at that Galactic longitude ($\sim 28^\circ$) we are looking tangentially through a large depth of one of the inner spiral arms of the Galaxy (the ‘Sagittarius–Carina arm’).

The radial velocity of β Sct was measured first in 1899 with the [original] *Mills Spectrograph*¹³³ on the Lick 36-inch refractor. In the following year a change in the velocity was noticed; the fact was promptly announced by Campbell & Wright¹³⁴, and by Campbell¹³⁵, who credited Wright with the discovery. Although the variation was large, the star was not followed systematically; the final compendium⁵² of Lick velocities has a total of 11 measurements of it. One of those that feature in the announcements of variability (that of 1899 June 11) does not appear in the final list. Meanwhile, β Sct had been observed attentively with the then-new 72-inch reflector at the DAO, Victoria, with a one-prism spectrograph giving a reciprocal dispersion of $29 \text{ \AA mm}^{-1}$ at $H\gamma$, and in 1927 Young⁶ published an orbit for the star. It was based on 17 spectrograms, although in order to save part of the substantial computational effort that orbital solutions demanded in pre-computer days he did a certain amount of preliminary averaging and solved for ten 'normal points'. He listed, in addition to his own observations, eleven velocities that the Lick Director, Campbell, had sent to him, plus two that had been made with the Bonn 12-inch refractor and published by Küstner⁵³. At first sight it is difficult to understand why Young did not include the Lick measurements, at least, in the solution, instead of using them (as he mentions) merely to fix the period, especially since Lick observations were generally more accurate than DAO ones. It turns out, however, that in this particular case the Lick velocities were uncharacteristically poor, and it would have been less clear to Young than it is now which ones were worthy of rejection. Re-computing the solution anew from Young's data, we find now that the normal-point solution worked well, inasmuch as it differs negligibly from one computed using all of the observations just as they stand. Young, however, obtained very optimistic values for the uncertainties of the elements, even when allowance is made for his use (widespread at that time) of 'probable errors' rather than standard deviations. He may not have taken into account the fact that, by fitting six elements to only ten points, he greatly diminished the number of degrees of freedom.

Although Young did not get his orbit paper⁶ into print until 1927, he evidently performed the solution very promptly after taking the last plate on 1924 June 20. He made a presentation of his work, reported in abstract in both the *Publications of the AAS*¹³⁶ and in *Popular Astronomy*¹³⁷, at the 32nd meeting of the AAS, held at Dartmouth College in New Hampshire on 1924 August 3–6, at which he gave exactly the elements that appear in his final paper. He also published a brief summary of the work in the *Journal of the Royal Astronomical Society of Canada*¹³⁸.

Four radial-velocity measurements of β Sct, which seem not to have come to Young's attention, were published from the Cape of Good Hope by Lunt¹³⁹ in 1921; nine more were given by Spencer Jones¹⁴⁰ in 1928. They were obtained with a four-prism spectrograph, giving¹⁴¹ a reciprocal dispersion of $19 \text{ \AA mm}^{-1}$ at $H\gamma$, on the *Victoria* 24-inch refractor¹⁴². The last velocities measured at the Cape and Lick were obtained in 1924; there ensued that long interval in the mid-20th Century when almost no interest was shown in the radial velocities of bright stars. One measurement of β Sct was made casually by the writer in collaboration with J. E. Gunn, in an unpremeditated exploratory programme conducted with the then-newly-constructed radial-velocity spectrometer¹⁴³ on the Palomar 200-inch telescope on a night in 1971 when there was a cloud layer that was just short of opaque; as a corollary to that programme, the same stars were re-observed with the original photoelectric spectrometer¹⁴⁴ at Cambridge shortly afterwards, and the two sets of measurements were published¹⁴³. Apart from them, no radial velocities were measured for β Sct between 1924 and 1981/2, when Parsons¹⁴⁵

made seven observations with reticon coude spectrometers on the McDonald 82- and 107-inch reflectors.

Parsons was interested in composite-spectrum binaries and made several measurements each for quite a number of them, with a view to updating existing orbits or initiating data-collection for variable-velocity stars lacking orbits. He gave a number of new orbits, some of which have proved to be wide of the mark, and some revisions of existing orbits, one of which was β Scuti's. How he did that is a mystery: not only are some of the revised elements¹⁴⁵ further than Young's⁶ from the supposedly much more accurate ones derived here (the various sets of elements are listed in Table VI below), but the standard errors given by Parsons¹⁴⁵ are typically nearly three times larger than those that we think that Young ought to have found from his own data alone. A clue is probably given by his noting that he used a total of 39 measurements: they would presumably have been the 11 from Campbell & Moore⁵², two from Küstner⁵³, 17 from Young⁶, two from Griffin & Gunn¹⁴³, and his own seven. In an orbit computed from that *ensemble*, with all the measures (including two obviously 'wild' Lick ones) given equal weights, the standard errors come out nearly as bad as Parsons', although the elements are not the same.

Just one velocity of β Sct, obtained in 1981, was published by Beavers & Eitter⁵ from the Ames spectrometer⁴, and three, taken in 1986/7, were reported by de Medeiros & Mayor¹⁸ from the OHP *Coravel*.

With the routine accessibility of 'space ultraviolet' wavelengths in the 1980s there arose an interest in the chromospheres, coronae, and winds of late-type stars of high luminosity, and in that connection the writer was asked whether he was observing β Sct or knew of an orbit that was an improvement on Young's. The answer was *no*, but the star was forthwith placed on the observing programme; only one observation had been made of it, however, (with the original spectrometer) when it transpired that the interest was of too immediate a nature to admit of a delay while the orbit was re-determined, so the star was deleted again from the programme. Some 3¹/₂ years later the same question was raised again, with the same impatience, by the same party! To forestall any further repetition of such a sequence of events, β Sct was then restored to the observing programme and has been retained there ever since, although no further interest in it has been exhibited from the original quarter. The new observations include 64 made with the Cambridge *Coravel* and 20 with the OHP one, as well as four with the DAO spectrometer¹⁴⁶ and the 1988 'original Cambridge' measurement already mentioned. All of the radial velocities, published and new, are set out in Table V.

As usual, to obtain the best orbit there is a need to harmonize the zero-points and variances of the different data sources. To that end, a zero-point adjustment of +0.8 km s⁻¹ has been made to the measurements from Lick⁵², the Cape^{139,140}, the DAO⁶, Ames⁵, and OHP¹⁸ (including the writer's own), but such an alteration has been withheld from the Bonn⁵³ and McDonald¹⁴⁵ observations on the pragmatic grounds that it would be unhelpful. The Cambridge *Coravel* measurements have been adjusted by -0.4 km s⁻¹, a quite usual amount for them to need for a G-type star. Unit weight has been accorded to the writer's measurements with his own and the OHP *Coravels*, except for four early ones made with the Cambridge instrument when it was in a preliminary state; just as in the case of 5 Her they have been given weight 1/4 and the zero-point correction has not been applied. The velocities obtained with the Ames spectrometer, and by the writer with the Palomar, DAO, and 'original Cambridge' ones, have been weighted 1/4, while the early photographic measures from Lick, the Cape, and the DAO, and

TABLE V

Radial-velocity observations of β Scuti

Except as noted, the sources of the observations are as follows:
 1899–1903 — Lick⁵², weighted $1/40$ in orbital solution;
 1913 — Bonn⁵³, wt. 0; 1918, 1924 — Cape^{139,140}, wt. $1/40$;
 1920–1923 — DAO¹³⁵; 1981/2 — McDonald¹⁴⁵, both wt. $1/40$;
 1986–1998 — Haute-Provence Coravel; 1999–2006 — Cambridge Coravel

Date (UT)	MJD	Velocity km s ⁻¹	Phase	(O – C) km s ⁻¹
1899 May 16·45	14790·45	–16·6	$\overline{32}$ ·772	–0·9
1900 Apr. 18·52	15127·52	–26·7	$\overline{31}$ ·176	+1·3
24·47	133·47	–28·3	·183	+0·2
May 15·44	154·44	–29·0	·208	+0·8
July 19·25	219·25	–32·9	·286	–1·0
1901 Apr. 10·57	15484·57	–23·5	$\overline{31}$ ·605	+2·2
July 8·30	573·30	–24·4	·711	–4·5
1902 Apr. 14·56 ^R	15853·56	–36·8	$\overline{30}$ ·047	–24·6
1903 July 10·35	16305·35	–25·9	$\overline{30}$ ·590	+0·4
1913 Sept. 24·78	20034·78	–14·1	$\overline{25}$ ·065	+1·0
25·78	035·78	–14·8	·066	+0·5
1918 Aug. 7·84	21812·84	–30·6	$\overline{23}$ ·199	–1·2
24·75	829·75	–29·4	·219	+0·9
1920 July 1·33	22506·33	–7·9	$\overline{22}$ ·031	+1·7
19·34	524·34	–10·9	·053	+2·2
28·89*	533·89	–18·4	·064	–3·4
Aug. 11·82*	547·82	–17·6	·081	0·0
Sept. 1·18	568·18	–22·4	·106	–1·3
30·15	597·15	–24·9	·140	+0·2
Nov. 5·09	633·09	–29·5	·183	–1·0
1921 Apr. 7·50	22786·50	–32·0	$\overline{22}$ ·368	0·0
June 16·40	856·40	–30·6	·451	+0·1
Sept. 15·15	947·15	–29·3	·560	–1·8
Nov. 9·07	23002·07	–23·3	·626	+1·4
1922 Feb. 28·56	23113·56	–18·0	$\overline{22}$ ·760	–1·5
May 14·48	188·48	–6·8	·850	+2·2
28·45	202·45	–7·9	·867	–0·4
July 13·36	248·36	–0·7	·922	+2·8
15·26†	250·26	–3·9	·924	–0·5
Sept. 8·19	305·19	–1·0	·990	+3·4
1923 Apr. 9·53	23518·53	–31·5	$\overline{21}$ ·246	–0·3
Sept. 12·23 ^{†R}	674·23	–23·1	·433	+8·0
Oct. 12·11	704·11	–33·8	·469	–3·5
1924 June 20·38‡	23956·38	–13·9	$\overline{21}$ ·772	+1·7
28·75	964·75	–13·4	·782	+1·5
July 29·82	995·82	–9·5	·819	+2·2
Sept. 1·76	24029·76	–7·9	·860	+0·2
22·81	050·81	–4·5	·885	+1·5
23·81	051·81	–5·0	·886	+0·9
26·77	054·77	–7·2	·890	–1·6

TABLE V (*continued*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity km s⁻¹</i>	<i>Phase</i>	<i>(O-C) km s⁻¹</i>
1924 Oct. 10·77	24068·77	-6·8	21·906	-2·4
11·76	069·76	-4·7	·908	-0·4
13·74	071·74	-4·0	·910	+0·1
1971 June 2·41 [§]	41104·41	-32·5	0·351	-0·4
July 29·92 [¶]	161·92	-31·6	·420	-0·3
1981 Mar. 22·49	44685·49	-20·9	4·649	+2·7
May 23·43	747·43	-18·5	·723	+0·7
25·42	749·42	-18·5	·725	+0·5
July 10·26 ^{‡‡}	795·26	-14·9	·780	+0·1
1982 Mar. 7·49	45035·49	-18·8	5·069	-3·1
Sept. 24·08	236·08	-30·7	·309	+1·4
25·10	237·10	-30·9	·311	+1·2
27·11	239·11	-31·4	·313	+0·7
1986 May 26·08	46576·08	-4·7	6·918	-1·0
July 23·99	634·99	-4·1	·988	+0·2
1987 May 9·14	46924·14	-32·1	7·335	+0·1
1988 July 18·92 [¶]	47360·92	-7·9	7·859	+0·2
1992 Feb. 27·57 ^{**}	48679·57	-31·4	9·442	-0·5
Apr. 25·16	737·16	-29·2	·511	0·0
June 21·02	794·02	-26·7	·579	0·0
Aug. 13·93	847·93	-24·1	·644	-0·3
Dec. 20·70	976·70	-13·4	·799	+0·1
1993 Feb. 13·24	49031·24	-7·6	9·864	+0·1
Mar. 25·15	071·15	-3·7	·912	+0·3
July 7·04	175·04	-10·4	10·037	+0·1
Sept. 11·90	241·90	-22·3	·117	+0·2
Nov. 4·00	295·00	-28·6	·181	-0·3
1994 Feb. 16·23	49399·23	-31·7	10·306	+0·4
May 1·16	473·16	-31·8	·394	-0·1
Aug. 2·03	566·03	-29·4	·506	-0·1
Dec. 11·71	697·71	-22·9	·664	-0·2
1995 June 2·05	49870·05	-7·3	10·871	-0·1
1996 Mar. 29·19	50171·19	-31·3	11·232	-0·6
Nov. 21·69 ^{††}	408·69	-28·2	·517	+0·8
Dec. 15·70	432·70	-27·5	·546	+0·5
1997 Jan. 26·24	50474·24	-26·5	11·596	-0·4
Apr. 16·16 ^{††}	554·16	-21·5	·692	-0·4
May 7·15 ^{††}	575·15	-19·9	·717	-0·3
June 17·05 ^{††}	616·05	-15·9	·766	+0·2
Sept. 8·86	699·86	-7·9	·867	-0·4
1998 Apr. 29·12	50932·12	-25·7	12·145	-0·2
July 8·03	51002·03	-30·5	·229	+0·1
1999 Apr. 2·49 ^{**}	51270·49	-27·5	12·551	+0·3
July 9·37 ^{**}	368·37	-22·7	·669	-0·2

TABLE V (*continued*)

<i>Date (UT)</i>	<i>MJD</i>	<i>Velocity</i> <i>km s⁻¹</i>	<i>Phase</i>	<i>(O - C)</i> <i>km s⁻¹</i>
2000 Jan. 30·62	51573·62	-4·2	12·915	-0·4
Apr. 7·17	641·17	-5·4	·996	-0·4
24·13	658·13	-7·7	13·017	-0·2
May 14·10	678·10	-11·5	·041	-0·4
June 7·05	702·05	-16·2	·069	-0·4
18·00	713·00	-18·2	·082	-0·4
July 16·02	741·02	-22·4	·116	0·0
Aug. 14·90	770·90	-25·9	·152	+0·2
Sept. 20·84	807·84	-29·0	·196	+0·2
Oct. 13·77	830·77	-30·4	·224	0·0
Nov. 14·72	862·72	-31·2	·262	+0·3
2001 May 5·16	52034·16	-30·5	13·468	-0·2
June 8·09	068·09	-28·9	·509	+0·3
July 11·04	101·04	-28·0	·548	-0·1
Sept. 22·83	174·83	-24·0	·637	+0·2
Oct. 18·77	200·77	-22·6	·668	-0·1
Nov. 1·74	214·74	-21·1	·685	+0·5
2002 Mar. 27·19	52360·19	-8·5	13·859	-0·3
Apr. 18·15	382·15	-6·1	·885	-0·2
May 16·08	410·08	-3·8	·919	-0·2
June 1·06	426·06	-2·9	·938	0·0
July 4·01	459·01	-3·3	·978	+0·2
Aug. 6·96	492·96	-7·3	14·018	+0·4
Sept. 1·87	518·87	-12·3	·050	+0·3
Oct. 3·80	550·80	-18·4	·088	+0·2
Nov. 4·74	582·74	-23·1	·126	+0·5
2003 Apr. 7·18	52736·18	-32·4	14·310	-0·3
May 1·13	760·13	-32·4	·339	-0·2
June 11·07	801·07	-31·8	·388	0·0
July 13·01	833·01	-31·2	·427	0·0
Aug. 2·94	853·94	-30·6	·452	+0·1
Sept. 13·86	895·86	-29·2	·502	+0·2
Oct. 16·75	928·75	-28·2	·541	0·0
Nov. 15·73	958·73	-27·2	·577	-0·4
2004 Apr. 15·17	53110·17	-16·6	14·759	0·0
June 5·13	161·13	-11·7	·820	-0·1
15·11	171·11	-10·5	·832	+0·1
25·06	181·06	-9·1	·844	+0·4
Aug. 7·94	224·94	-4·7	·897	+0·3
Sept. 5·86	253·86	-3·2	·932	-0·1
Oct. 5·82	283·82	-2·9	·968	+0·1
26·73	304·73	-4·4	·993	+0·2
Nov. 13·71	322·71	-6·9	15·014	+0·2
2005 Mar. 23·21	53452·21	-27·8	15·170	-0·3
May 9·14	499·14	-30·5	·226	0·0
June 23·03	544·03	-31·7	·280	+0·1
July 18·03	569·03	-32·3	·310	-0·2
Aug. 16·95	598·95	-31·9	·346	+0·2
Sept. 25·84	638·84	-31·8	·394	-0·1
Oct. 27·76	670·76	-31·2	·432	-0·1
Nov. 13·71	687·71	-30·8	·452	-0·1

TABLE V (concluded)

Date (UT)	MJD	Velocity km s ⁻¹	Phase	(O-C) km s ⁻¹
2006 Apr. 4.18	53829.18	-25.0	15.622	-0.1
May 3.16	858.16	-23.1	.657	0.0
June 1.13	887.13	-21.4	.692	-0.2
July 4.01	920.01	-18.4	.731	+0.2
Aug. 13.90	960.90	-14.6	.780	+0.4
Sept. 22.83	54000.83	-10.8	.828	+0.1
Nov. 2.72	041.72	-6.8	.877	-0.2
2007 Apr. 5.19	54195.19	-14.6	16.061	-0.1
May 8.12	228.12	-20.5	.101	0.0
June 1.10	252.10	-23.8	.130	+0.2

* Cape observation¹³⁹, weight 1/40.
† Lick observation⁵², weight 1/40.
‡ DAO observation¹³⁵, weight 1/40.
§ Author's Palomar observation¹⁴³, weight 1/4.
¶ 'Original Cambridge' observation, weight 1/4.
|| OHP observation¹⁸, provided through the CDS, wt. 1/4.
** Observed with DAO 48-inch telescope, wt. 1/4.
†† Observed with Cambridge *Coravel* in preliminary form, wt. 1/4.
‡‡ Ames observation⁵, weight 1/4.
^R Rejected observation.

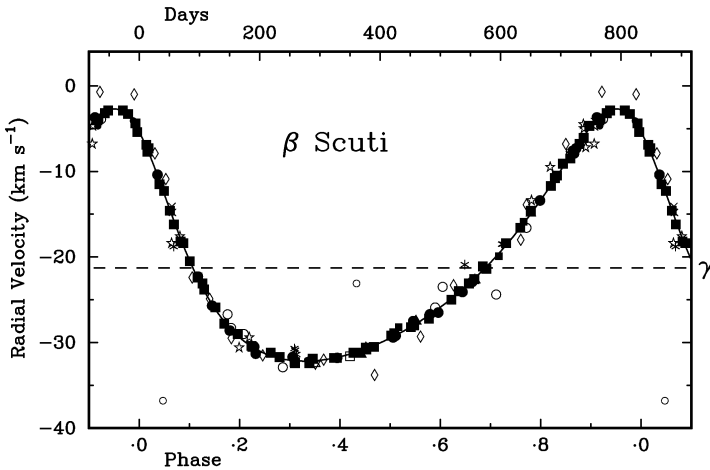


FIG. 5

As Figs 2-4, but for β Scuti. The symbols are identified as before, but in this case there are further additions to the range of sources. Measurements from the Cape Observatory^{139,140} and from McDonald¹⁴⁵ (both weighted 1/40) are plotted as asterisks and as five-pointed open stars, respectively. One measurement made at Palomar¹⁴² and two made with the original radial-velocity spectrometer at Cambridge (both weighted 1/4) are, respectively, shown as a six-point star and as open squares.

the McDonald reticon velocities have all merited weight 1/40. The normally very reliable *Mills Spectrograph* measurements from Lick include two totally 'wild' ones that give residuals of -25 and $+8$ km s⁻¹ and have had to be rejected; there are two others that have uncharacteristically bad residuals but perhaps not quite meriting rejection, and it is also to be recalled that one measurement that featured

in the original announcements of velocity variation did not appear in the final listing of Lick velocities. It is surely significant that that particular datum, together with the one that gives a residual of -25 km s^{-1} and must be of the wrong star or represent some other qualitative mistake, were given in Campbell's letter to Young⁶ only to integer kilometres per second, whereas all the others were given to two decimals. Mr. A. Misch of the Lick Observatory has very kindly sent me scans of the relevant plates; unfortunately, unfamiliarity with the character of the Mills spectrograms leaves me unable to say definitely whether there has been an error in identification. It should be mentioned that the Lick velocities incorporated in Table V are copied from Campbell & Moore⁵², not from the listing by Young⁶ of those sent to him by Campbell, which in some cases differ slightly.

The scene is now set for the derivation of the final orbit, which is illustrated in Fig. 5. The elements are displayed in Table VI, which includes for comparison the elements published by Young⁶, those calculated by the present author from Young's data, and those published by Parsons¹⁴⁵.

TABLE VI
Orbital elements for β Scuti

<i>Element</i>	<i>Young (as published*)</i>	<i>Young (re-calculated†)</i>	<i>Parsons</i>	<i>This paper</i>
<i>P</i> (days)	834 (fixed)	834 (fixed)	832.5 ± 0.7	833.26 ± 0.07
<i>T</i> (MJD)	22480.4 ± 2.3	22481 ± 10	22484.8 ± 24	$51644.4 \pm 1.0^\ddagger$
γ (km s ⁻¹)	-21.9 ± 0.26	-21.96 ± 0.37	-21.5 ± 0.9	-21.30 ± 0.03
<i>K</i> (km s ⁻¹)	16.65 ± 0.41	16.8 ± 0.6	15.8 ± 1.7	14.74 ± 0.04
<i>e</i>	0.35 ± 0.020	0.348 ± 0.029	0.37 ± 0.08	0.3207 ± 0.0026
ω (degrees)	33.9 ± 2.0	34 ± 6	35 ± 13	35.2 ± 0.5
$a_1 \sin i$ (Gm)	178 —	180 ± 7	168 ± 19	160.0 ± 0.5
<i>f</i> (<i>m</i>) ($M_\odot$)	0.33 —	0.337 ± 0.037	0.271 ± 0.091	0.2354 ± 0.0022
R.m.s. residual (wt. 1) (km s ⁻¹)	1.2	1.25	1.7	0.25

*Young's 'probable errors' have been transformed to standard deviations by multiplication by 1.5, and the JD of his *T* is here expressed as an MJD.

†The re-calculation has been performed with the 17 individual measurements, not the ten normal points. The standard errors come out rather smaller when the calculation is done on the normal points, because certain large residuals are fortuitously averaged away.

‡The epoch is 35 cycles later than those quoted in the previous columns. The standard deviation is smallest for the *T* closest to the weighted mean time of all the observations. When computed for the same epoch as the other entries, it is increased owing to the period's uncertainty accumulated over the 35 intervening cycles. The *T* computed for the early epoch is MJD 22480.2 ± 2.6 .

It is seen that Young's orbit⁶ is quite a good approximation to the new one, its principal difference being the larger value for *K*, which is compounded into a 40% over-estimate of the mass function (the expression for which includes the factor K^3). Comment has already been made above on the surprisingly large uncertainties of the revised orbit given by Parsons¹⁴⁵; normally, any increase in the number and time-span of the observations could be expected to reduce the standard deviations of the elements. Inasmuch as Parsons gave only the elements, without any listing of the data, diagram of the orbit, or description of how the solution was derived, the proffered explanation must remain speculative.

The hot secondary star in the β Sct system, though conspicuous in the 'space' ultraviolet, is far from obvious in spectra taken from the ground, as witness its oversight by expert classifiers^{92,93,96,97}. Even after the companion was identified

in satellite spectra⁹⁸ the primary was retained by Keenan^{38,40,42,43} as an MK-standard late-type star, so small is the contribution of the companion to the total luminosity at optical wavelengths.

All the same, Dr. R. E. M. Griffin (private communication) reports that subtraction of the spectrum of 9 Peg (G5 Ib) from that of β Sct in the violet and near-UV leaves a small residue of a spectrum in which the Balmer lines and the K line can easily be discerned (see Fig. 6), and which is matched tolerably well by the spectrum of Vega blurred to mimic a rotational velocity of some 250 km s^{-1} . Unfortunately the S/N ratio of the residue is too low to support a detailed analysis of the secondary component. That is because, in the observed spectrum, the proportion of the flux that is contributed by the primary and has to be subtracted is not far short of 100%, so the residual signal is very small. Also, the spectrum of the primary appears to be that of a high-luminosity mid-G giant for which an exact surrogate is not easy to find (and may not even exist) among the bright stars. 9 Peg is the nearest so far identified but is not a perfect match, and any discrepancies arising from lack of exact correspondence between primary and surrogate naturally get assigned to the residuum and are amplified enormously when the signal is so reduced. Judged, however, simply from its general similarity to the spectrum of Vega, the secondary spectrum appears to be that of a star about type A1 with a projected rotational velocity near 250 km s^{-1} . The extreme disparity in the fluxes from the two components even at wavelengths as short as that of the K line suggests a value of four if not five magnitudes for ΔM_V , which would be consonant with a main-sequence luminosity for the early-type star.

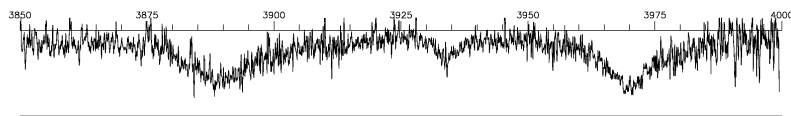


FIG. 6

The result of subtracting the spectrum of 9 Peg (G5 Ib) from that of β Scuti in the wavelength region 3850–4000 Å. The wavelength scale is along the top; the ordinate is photometric intensity, the lower line being the zero level. The three obvious absorption lines, in order of increasing wavelength, are H ζ , Ca II K , and (Ca II H + H ϵ). The profile is noisy because nearly all of the signal in the original spectrum has been subtracted away. (Figure produced and kindly supplied by Dr. R. E. M. Griffin.)

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CORRESPONDENCE

To the Editors of 'The Observatory'

A possible orbital solution for the triple star WDS 18253+4846

Although we are used to thinking of stars as individuals, this is not the norm. The evidence is that most stars that we see in the sky are components of binary or even multiple star systems revolving around a common centre of mass. Some binary systems are sufficiently close to Earth or their mutual distance is large and the stars are well enough separated that we can resolve their images in a telescope and track their motion over a period of time. We call such systems visual binaries.

A relatively large number of visual binaries are included in the *Washington Double Star Catalog* (WDS)¹, but only for a small fraction of them (about 2%) an orbital solution exists². In the case of systems with three or more components, which are in general more important, orbital solutions for all components of the system are calculated only for a few cases.

We present here a short discussion on the orbits of WDS 18253+4846 (HIP 90284 = ADS 11344 = HD 170109), which was discovered to be double (with components A and B) by Struve at Pulkovo in 1843 and designated OΣ 351. However, in 1883 Hussey found that component B was itself a close double, which became HU 66 BC. An orbital solution already exists³ for the pair HU 66 AB, with $P = 300$ years and $a = 0''.392$. Now, using a Sector Grid Search (SGS) method⁴ we have calculated the orbital elements for pair HU 66 BC.

As there are only seven measurements of pair BC in the WDS catalogue and this is not enough for a reliable orbit determination, we calculated an additional 31 relative positions of pair BC using the measurements of pairs AB and AC which were made at the same epoch. This allowed us to calculate orbital elements for pair BC from 38 relative positions. We assigned the appropriate weights to all measurements according to the weighting rules described by Hartkopf *et al.*^{5,6}. In order to make these data consistent, the weights of derived positions are reduced by a factor of two.