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SPECTROSCOPIC BINARY ORBITS
FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 228: TEN STARS WITH *HIPPARCOS* ASTROMETRIC ORBITS

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Hipparcos managed to derive astrometric orbits, from its own observations alone, for just 45 stars; they had not had orbits determined for them previously. Only 17 of them are potentially observable with the writer's radial-velocity instrument, *Coravel*, in Cambridge. Of the 17, eight have now had spectroscopic orbits published for them (seven of them by the writer, with collaborators in two cases). This paper presents orbits for the remaining nine, and for one southern star observed at Haute-Provence. The *Hipparcos* periods, ranging from about 200 days to three years, are tolerably well confirmed here. The other elements that are common to the astrometric and spectroscopic orbits are not very accurately determined in the former set. In particular, the eccentricity differs significantly (2σ) from zero in only five of the ten cases, and even in those there seems to be an unexpected relationship between the longitudes of periastron determined by the two methods: four of the five discrepancies are much nearer to 180° than to zero.

Introduction

The *Hipparcos* satellite provided accurate astrometric data for some 118 000 stars. It noticed irregular motion in a considerable number of cases, but only in 45 instances[1] was it able to offer complete sets of astrometric orbital elements. After the writer noticed that a few of the spectroscopic binaries in which he had an interest were among those 45 stars, it occurred to him to place on his observing programme all the remaining ones that he would be likely to find observable, apart from one (HD 160346) whose orbit was otherwise known[2]. The restrictions to northern declinations and to spectral types not much earlier than mid-F proved to restrict the number of potentially observable stars from 45 to 17. Among the 17, the orbits of eight have already been published by the writer, either in this *Magazine* or elsewhere (bibliographical references are given in Table I, below). The other nine orbits are presented here. In addition, one is given here for a southern star, HR 4657 (δ ~ −10°), unobservable from Cambridge but sufficiently observed in the past when the author had access to the Haute-Provence (OHP) *Coravel.* Basic data on the stars are listed in Table II.

TABLE I

Orbits already published by the writer for stars with Hipparcos orbits

HD no.	*Hip. no.*	*Reference*	
110743	62124	*JA&A*, **22**, 187, 2001	(Paper JAA 24)
112914	63406	*The Observatory*, **122**, 309, 2002	(Paper 167)
113449	63742	*The Observatory*, **130**, 125, 2010	(Paper 212)
116127	65135	*The Observatory*, **127**, 379, 2007	(Paper 197)
128642	70857	*The Observatory*, **130**, 75, 2010	(Paper 211)
150710	81726	*ApJS*, **147**, 103, 2003 (with A. A. Suchkov)	
193216	99965	*The Observatory*, **122**, 14, 2002	(Paper 162)
213429 (HR 8581)	11170	*A&AS*, **75**, 167, 1988 (with A. Duquennoy, M. Mayor, W. I. Beavers & J. J. Eitter)	

TABLE II

Basic data for the ten stars discussed in this paper

HD no.	*Hip. no.*	*V*	*(B−V)*	α_{2000}			δ_{2000}		*Constell^{n}.*	*Type*	*π*	M_V
		m	*m*	*h*	*m*	*s*	°	′			*″.001*	*m*
32850	23786	7·73	0·81	5	06	42	14	27	Ori	G9 V	42·24	+5·9
106516	59750	6·11	0·46	12	15	11	−10	19	Vir	F9 V	44·74	+4·4
110314	61880	8·29	0·63	12	40	50	40	31	CVn	G2 V	13·66	+4·6
137687	75389	7·33	0·82	15	24	18	60	33	Dra	G9	18·51	+3·7
138369	76031	7·42	0·64	15	31	43	0	53	Ser	G0	19·67	+3·9
156558	84179	8·41	0·67	17	12	30	69	18	Dra	K0	17·89	+4·7
178593	93995	7·48	0·47	19	08	16	25	22	Vul	F8	16·30	+3·5
183536	95769	8·19	0·53	19	28	42	34	37	Cyg	G5	16·04	+4·2
188307	97837	7·70	0·57	19	52	53	41	05	Cyg	F8	18·76	+4·1
193554	100259	8·26	0·63	20	20	04	23	38	Vul	G5	21·63	+4·9

HD 32850

This star has a large proper motion of about 0″·37 annually, that was recognized already nearly 100 years ago in Cincinnati[3] on the basis of catalogue positions going back nearly 100 years before *that* — to the one of 1823 by Weisse[4]. The implied proximity of the object is probably responsible for the rich literature that had built up on it, even before *Hipparcos* demonstrated its parallax to be as much as 42 arc-milliseconds, corresponding to a distance of about 24 pc. Although it did not feature in the Gliese[5] or Woolley[6] catalogues, it was proposed as a 'nearby star' by Halliwell[7] on the basis of its 'photometric parallax', which he estimated at 43 ± 5 milliseconds — its proper motion certified it as a main-sequence object, quite apart from its having been actually classified as K0 V by Nassau & MacRae[8]. (It is G5 in the *Henry Draper Catalogue*; Bidelman[9] reported that Kuiper had called it G8, and Gray *et al.*[10] have relatively recently given it as G9 V.) Still in pre-*Hipparcos* times, Clark, Laureijs & Wardell[11] noted (merely *en passant* — their actual interest was in an interstellar cloud behind it), that HD 32850 has a 'spectroscopic distance' of 24 pc.

There are some radial velocities of HD 32850 in the literature, but none that is very helpful in determining the orbit. Beavers & Eitter[12] gave one measurement, made with the Ames photoelectric spectrometer in 1976. Fouts & Sandage[13] reported that they had made three observations at Mount Wilson, but they gave only a mean value (+23·5 km s^{-1}) and no dates; in any case their observations, though obtained with the 100-inch telescope, have standard errors of more than 6 km s^{-1} and so would not be of utility for present purposes. White, Gabor & Hillenbrand[14] gave two velocities, with dates; they gave in addition upper limits to the rotational velocity, of which the lower was 10 km s^{-1}. Other published estimates of the $v \sin i$ of HD 32850 are well below 10 — Fuhrmann[15] gave one of 2·5 ± 1·0 km s^{-1}, and Nordström *et al.*[16] (who noted a mean (only) of five radial velocities, whose mutual discrepancies confirmed the star as a spectroscopic binary) gave one of 4 km s^{-1}.

The star was placed on the observing programme of the Cambridge *Coravel* at the end of 2002 and has been observed 45 times. The mean rotational velocity was found to be 1·3 km s^{-1}, with a formal standard error of only 0·2 km s^{-1}; owing to the disregard of non-rotational sources of line-broadening, however, the decimal in rotational velocities determined with the *Coravel* is never considered significant. Eleven of the 45 individual values were zero, so it is evident that the distribution of those values was truncated there, since negative values are of course not permitted; the mean is accordingly biassed in the positive direction, and it would fairly represent the result to specify it as 1 ± 1 km s^{-1}.

The radial velocities derived from the 45 traces are shown in Table III, after those of Beavers & Eitter and of White *et al.*, which have all been increased by 0·8 km s^{-1} in an effort to place them more nearly on the Cambridge zero-point. They have, however, not been utilized in the solution of the orbit, although they are plotted in Fig. 1, from which it will be seen that the Beavers & Eitter one is 'wild'. The orbital elements are presented, together with those of the other stars treated in this paper, near the end of the paper, in Table XIII. The mass function is quite small and does not demand a companion more massive than about 0·3 $M_{\odot}$. Fuhrmann[15] deduced from the size of the astrometric orbit (about 0″·01) and the distance of the system that the secondary object must have a mass of 0·4 ± 0·1 $M_{\odot}$. He said that if that object is a red dwarf then a ΔV of four or five magnitudes must be expected and "This should immediately be detectable with modern imaging techniques" — though it seems like a tall order to resolve a system with a separation of perhaps 0″·03 and a $5^{m} \Delta V$. Just because Fuhrmann discusses the possible nature of the undetected companion, *Simbad* treats the companion to a separate identity (albeit at the same sky position) and web page, with Fuhrmann's paper as the whole bibliography.

The only quantity that is at all accurately determined among those of the astrometric orbit is the period, which is 1·4 days shorter than the spectroscopic value and has a standard error of 2·4 days, almost 100 times the analogous spectroscopic quantity. The astrometric e and ω have s.d.s of 0·24 and 81°, respectively, and the inclination too, at 29 ± 36 degrees, is almost indeterminate. (In fairness to *Hipparcos*, we must admit that the determination of orbits is no more than an incidental bonus in relation to the satellite's principal objective, and moreover *it* was dealing simultaneously with more than 100 000 stars, whereas *our* result arises from a considerable number of special observations deliberately obtained individually on HD 32850. The true and realistic underlying costs per star, however, are nevertheless still probably higher in the astrometric case.)

TABLE III

Radial-velocity observations of HD 32850

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
1976 Dec. 17·22*	43129·22	+33·3	$\overline{46}$·697	+13·9
2002 Apr. 19 †	52383	18·4	$\overline{1}$·662	−2·4
Oct. 31 †	578	22·2	0·609	−0·7
Dec. 11·09	619·09	15·3	·809	+0·3
2003 Jan. 10·04	52649·04	16·3	0·954	0·0
Feb. 19·90	689·90	34·1	1·153	+0·1
Mar. 16·87	714·87	33·6	·274	−0·1
Apr. 2·85	731·85	31·6	·357	0·0
Sept. 29·16	911·16	34·3	2·228	0·0
Oct. 12·16	924·16	33·5	·291	+0·2
Nov. 3·16	946·16	30·5	·398	+0·1
13·13	956·13	28·8	·447	0·0
Dec. 6·02	979·02	24·7	·558	−0·2
16·08	989·08	23·0	·607	0·0
2004 Jan. 9·02	53013·02	18·4	2·723	+0·1
15·03	019·03	17·7	·752	+0·6
Feb. 9·00	044·00	13·3	·874	−0·3
22·91	057·91	15·3	·941	−0·1
29·92	064·92	18·3	·975	+0·1
Mar. 13·86	077·86	25·7	3·038	−0·1
29·85	093·85	32·4	·116	−0·3
Sept. 21·15	269·15	17·5	·968	0·0
26·21	274·21	20·5	·992	+0·4
Oct. 6·15	284·15	26·1	4·040	0·0
2005 Jan. 4·98	53374·98	27·7	4·482	+0·1
13·02	383·02	26·0	·521	−0·3
Feb. 8·90	409·90	21·0	·651	−0·3
Apr. 3·84	463·84	13·8	·914	−0·3
Nov. 14·11	688·11	21·8	6·003	+0·3
18·04	692·04	24·1	·022	+0·2
25·09	699·09	27·8	·057	−0·2
30·10	704·10	30·2	·081	−0·1
2006 Nov. 26·15	54065·15	14·2	7·835	−0·1
2007 Feb. 6·87	54137·87	34·9	8·189	+0·4
Oct. 18·20	391·20	29·8	9·420	+0·1
Nov. 12·11	416·11	25·4	·541	−0·1
2008 Feb. 10·97	54506·97	18·6	9·982	−0·4
Oct. 28·24	767·24	33·9	11·247	−0·2
Nov. 19·07	789·07	31·9	·353	+0·2
2009 Oct. 12·20	55116·20	15·5	12·943	0·0
2010 Oct. 7·22	55476·22	19·8	14·692	+0·2
Nov. 24·10	524·10	14·7	·925	+0·2
Dec. 12·11	542·11	+22·6	15·012	0·0

TABLE III (*concluded*)

Date (UT)		MJD	Velocity km s⁻¹	Phase	(O – C) km s⁻¹
2011 Jan.	14·96	55575·96	+34·4	15·177	0·0
Feb.	12·92	604·92	32·6	·317	−0·1
Apr.	8·84	659·84	23·9	·584	0·0
Nov.	18·10	883·10	20·7	16·669	+0·1
Dec.	10·07	905·07	+16·0	·776	−0·2

*Observation by Beavers & Eitter[12]; wt. 0.
†Observation by White *et al.*[14]; weight 0.

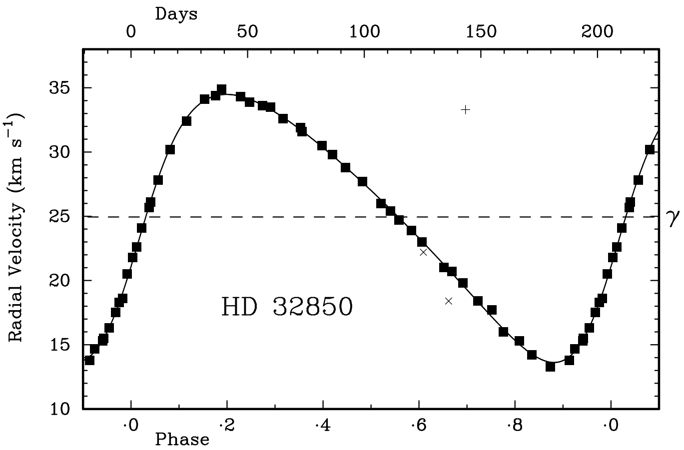

FIG. 1

The observed radial velocities of HD 32850 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. (In later captions, that would be rendered simply as 'Orbit of HD 32850'.) Observations made with the Cambridge *Coravel* are plotted as filled squares. The two crosses represent the velocities published by White *et al.*[14] and the plus plots the one by Beavers & Eitter[12]; they were not included in the solution of the orbit.

HD 106516 (HR 4657)

Attention was drawn to this star by its large space motion, expressed by its unusually large proper motion, directed almost exactly southwards, of just over one second of arc annually. That proper motion was known[17] at least as early as the 19th Century, in which it featured in some of the Cincinnati publications, under the identity Lalande[18] 22954, or in the cited case Lalande 22954–68, implying that it is a double star, although it is actually a very wide one. (Lalande 22968 is the star (HD 106596) shown in Lalande's catalogue as being 28^s following and 52″ south of the star we now know as HR 4657. That was at epoch 1800, however; so great is the proper motion of HR 4657 that the 'companion' has been left far behind and is now about 2½ minutes *north* of the star of present interest, as well as still being nearly half a minute of time following.) The *Bright Star Catalogue*[19] notes a 13^{m} companion at a distance of 73″; it does not seem to feature in other published catalogues, but the *Aladin* picture raised by *Vizier* shows what seems to be a suitable candidate for it, a rather faint star that from the point of view of HR 4657 passed by about 40″ due east some years ago and now is considerably to the north as well as east. It is only too obviously just an optical companion and nothing really to do with HR 4657.

Being marked out so conspicuously by its proper motion as a 'high-velocity' star, HR 4657 has been the subject of very many investigations; its *Simbad* bibliography runs to more than 300 entries, of which only the briefest synopsis can be attempted here. Even before the (1950) nominal starting date of that bibliography, the star featured in several papers from Mount Wilson. As long ago as 1917 Adams & Joy[20], in an early listing of results of the then-newly-developed scheme of 'spectroscopic parallaxes', found its absolute magnitude to be $+4^{m}\cdot7$; normal spectral classification (by comparison with a set of standard spectra of different types), which they called the 'estimated' type, gave a result of F3, but the 'measured' type (explicit comparison of the strengths of certain Balmer lines with nearby metallic lines) gave F4. Both methods gave types that were too early, no doubt because all the metallic lines in the spectrum of HR 4657 are considerably weaker than in most other comparable stars because of metal deficiency that is associated with the high space velocity — HR 4657 is an interloper that has strayed into our vicinity from a halo population. The F3 'estimated' type held fast in successive papers, by Adams *et al.*[21] in 1921, Adams & Joy[22] in 1923, and Adams *et al.*[23] in 1935, but the 'measured' type slipped to F6 in 1921, perhaps as the importance of *relative* line intensities was more clearly recognized as being more informative than absolute ones. After that, 'measured' types seem to have been abandoned. The absolute magnitude was shown as $+3^{m}\cdot7$ in 1921 and $+3^{m}\cdot5$ in 1935; the (revised[24]) *Hipparcos* value is $4^{m}\cdot36$, with an uncertainty of only $0^{m}\cdot05$. The spectral classification, from several different sources, remained at F6 V or thereabouts for a long time after the MK system[25] was devised, but has subsequently slipped considerably further: the latest one, by Gray *et al.*[26], which evidently owes something to Keenan's efforts at refinement of the MK system, is F9 V Fe–1 CH–0·7.

In its 'measurements' listing, *Simbad* records, among the plethora of papers on HR 4657, nine giving its photometry, ten giving MK spectral types, six giving radial velocities, and no fewer than 30 giving [Fe/H] values. *Simbad* is not too careful, however, about duplicating its references, and in fact 12 of the 30 [Fe/H] entries are out-and-out duplicates; not all of the remainder are genuine, mutually independent, determinations, though that is no fault of *Simbad*'s. There is a good consensus that [Fe/H] is down by 0·7 — deficiency by a factor of five — in HR 4657.

The *Bright Star Catalogue*[19] has a note on HR 4657 at the back of the volume, saying baldly, 'Arcturus group'; it is hardly necessary to record that that assertion came from Eggen[27], but he proposed it only once, so he probably realized later that it was not so. The 'group parallax' required for membership was 0″·0275, whereas the actual[24] value is 0″·0447, definitely discrediting Eggen's assertion.

The radial velocity of HR 4657 was first measured at Mount Wilson more than 100 years ago. A mean value of +5·9 km s^{-1} from five plates, with a 'probable error' of 1·5 km s^{-1}, was published by Adams & Joy[22] in 1923. Fifty years later Abt[28] compiled an individual listing of many Mount Wilson velocities that had originally been published only as means; for HR 4657 he found not five but *eight* velocities recorded, ranging in date from 1910 to 1914, so in principle all of them should have been available to Adams & Joy to incorporate into their mean. When one allows for the correction* made to the velocities by Abt, one can identify the Adams & Joy mean with the last five out of the eight velocities that Abt listed, although the 'probable error' does not quite match. The three that were omitted are evidently the first three, which were taken on almost-consecutive nights in 1910; those three are very accordant with one another but differ by some 10 km s^{-1} from the mean of the other five. Taken together, the eight velocities show that the star is a spectroscopic binary, but that is not clear from the five upon which Adams & Joy must have relied.

A mean of +10·8 ± 2·23 ('p.e.') was given by Przybylski & Kennedy[30] from four velocities obtained at Mount Stromlo Observatory, but the individual values and dates are not available.

Next, Abt & Levy[31] measured velocities from nine plates taken at 63 Å mm^{-1} with a Cassegrain spectrograph on one of the 36-inch reflectors that used to grace Kitt Peak. They gave a mean of +6·8 km s^{-1}, with an r.m.s. scatter of the individual values of 2·9 km s^{-1}; only 13 of the 62 stars that were similarly observed and not identified as binaries had less scatter, so the binary nature of the star was by no means discovered, although the actual purpose of the observations was to assess the frequency of spectroscopic binaries among high-velocity main-sequence stars. Later, Abt & Willmarth[32], using a CCD at 10 Å mm^{-1} with the coudé-feed telescope of the Kitt Peak 84-inch reflector, obtained 15 more measurements of HR 4657. Again, they wanted to investigate the binary frequency among high-velocity field dwarfs. Among the 45 stars on their programme, they found five binaries. Three of them had already been identified as such, but Abt & Willmarth reported two additional ones.

Not long previously, Morbey & Griffin[33] had drawn attention to twelve particular papers from much the same source, papers that presented spectroscopic orbits that appeared implausible. They[33] actually *demonstrated* that, of the 27 first-time orbits presented in two of the specified papers, 24 were not supported by the data upon which they were based and in 21 cases the evidence did not show that the stars concerned were binaries at all. The basic procedure that underlay the misconceptions was the searching of sparse data strings for short periods, whereby it was possible to find periods that would arrange the data in such an order that the residuals (which were really just observational errors) appeared to run systematically with phase. Having imagined that they must have stemmed the flow of such papers, those authors[33] were disappointed at the appearance of the work by Abt & Willmarth[32], where both of the two new orbits exhibited exactly the same character, and for exactly the same reason, as before†. The two orbits were those of HR 4657 and HD 110987. The former *did* exhibit a variation in velocity: plotted directly against time, Abt & Willmarth's

*+0·5 km s^{-1} in this case; dependent on spectral type and specified in Table 3 in the *Introduction* to the *Radial Velocity Catalogue*[29].

†Abt & Willmarth's paper was actually published just *before* the one by Morbey & Griffin. The latter work, however, was appreciably delayed in publication, first owing to the difficulty of the *ApJ* editor (Abt!) in finding anyone willing to referee it, and then (at the invitation of the authors) to allow time for Abt to write his own paper[34] by way of a palliative and to publish it adjacently. The Abt & Willmarth paper was submitted to the *Astrophysical Journal* on 1986 July 7, whereas the Morbey & Griffin one had been submitted on 1985 October 30, and its content would have been known immediately on that date by Abt in his capacity as editor of that *Journal*. The present writer wishes, however, to emphasize that the editorial handling of ref. 33 was absolutely dispassionate and professional and was in no way responsible for any delay.

15 measurements show a clear trend indicative of an orbit whose period is longer than the total duration (509 days) of the observations. Such an orbit can in fact be computed from them; it is not a good approximation to the true one (not surprisingly, since the data do not cover a full cycle), but it fits them with an r.m.s. residual of only 0·61 km s^{-1}. Abt & Willmarth, however, produced an orbit with a period of 23·10 ± 0·01 days, with a phase distribution *worse* than that of the incomplete-cycle one (there is only one data point in one half of the cycle) and a much larger r.m.s. residual* of 1·4 km s^{-1}, so there seemed to be no incentive to prefer it to the obvious one. It would have been instructive if the other HR 4657 radial velocities of which they had knowledge (those made by Abt & Levy[31], and the Mount Wilson ones published by Abt[28]) had been plotted on the same graph. The other false orbit in Abt & Willmarth's paper, that of HD 110897 (HR 4845, 10 CVn), shows only observational 'noise'; the twelve radial velocities are organized into an 'orbit' with a period of 5·924 days (about one-hundredth of their total time span and one-eighth of the mean interval between them). A note on the matter is relegated to the *Appendix* to this paper, since it is not of direct relevance here.

Eventually an orbit that was in principle the correct one was published from the Harvard–Smithsonian Center for Astrophysics on the basis of radial velocities obtained with their digital spectrometers[35]. Overlapping groups of authors[36,37] had two bites at the same cherry. First, Latham *et al.*[36] produced in 1992 an orbit from 33 observations. Then in 2001 Carney *et al.*[37] superseded it by adding just six more (two of which were obtained on the same night); they also re-reduced the previously published observations, the effect being to mitigate the worst residuals in the first effort.

The declination of HR 4657 (about −10°) puts it out of reach of the Cambridge telescope, but the writer was able, during the time that he was able to use the Geneva Observatory's *Coravel* radial-velocity spectrometer at Haute-Provence, to make 24 measurements with that instrument, and also two each at ESO and the DAO, where he enjoyed guest-investigator privileges from time to time. At the time his observations were begun, the only orbit published for HR 4657 was the one[32] that was obviously mistaken. All the radial velocities available for HR 4657 are listed in chronological order in Table IV. In the solution of the orbit, the writer's observations and those (revised and supplemented[37]) from the CfA (the two made on the same night have been averaged and treated as one) have been given unit weight, apart from one OHP measure and one ESO one, which have unusual residuals and are rejected on statistical grounds. The velocities given by Abt & Willmarth[32] have been weighted 0·2. Those previously given by Abt & Levy[31] merit a very small weight and make no appreciable difference to the orbit, and have been zero-weighted. The early Mount Wilson measures[22,28], though also meriting only the small weight of 0·04, increase the time base so greatly that they nearly halve the standard error of the period, and have been retained in the solution. To try to maintain the radial-velocity zero-point generally adopted in this series of papers[38], the *Coravel* measurements in Table IV have received the usual adjustment of +0·8 km s^{-1}; then, to bring the mean residuals of the other series close to zero, empirical corrections of +1·8, +1·5, and +1·0 km s^{-1} have been made to the Mount Wilson, Abt & Willmarth, and CfA observations, respectively. The final orbit is illustrated in Fig. 2, and the elements are given in Table XIII towards the end of this paper, together with those previously published by Latham *et al.*[36] and Carney *et al.*[37].

*According to Abt & Willmarth; the 'orbit' comes out with slightly different elements in a solution by the present writer, and the r.m.s. residual is then 1·01 km s^{-1}.

TABLE IV

Radial-velocity observations of HR 4657

Except as noted, the sources of the observations are as follows:
1910–14 — Mount Wilson[22,28] *(weight 0·04); 1965/6 — Abt & Levy*[31] *(weight 0)*
1983–88 — Carney et al.[37] *(weight 1); 1989–97 — OHP (this paper) (weight 1)*

Date (UT)	*MJD*	*Velocity* km s^{-1}	*Phase*	*(O – C)* km s^{-1}
1910 May 18·19	18809·19	−3·1	0·904	−1·3
20·17	811·17	−2·4	·907	−0·6
21·21	812·21	−2·6	·908	−0·7
1912 May 30·19	19552·19	+4·7	1·785	+1·7
1913 Mar. 28·38	19854·38	+6·5	2·144	+4·7
1914 Feb. 8·50	20171·50	+12·8	2·520	+0·5
Mar. 15·43	206·43	+12·8	·561	+1·1
May 11·23	263·23	+4·2	·629	−5·7
1965 Jan. 18·47	38778·47	+3·9	24·586	−7·2
Apr. 17·40	867·40	+8·7	·691	+1·3
18·34	868·34	+8·2	·692	+0·8
19·44	869·44	+8·4	·694	+1·1
20·30	870·30	+6·7	·695	−0·6
May 9·24	889·24	+10·7	·717	+4·4
1966 Apr. 2·40	39217·40	+0·5	25·106	+0·4
June 2·24	278·24	+8·7	·179	+5·2
3·14	279·14	+5·4	·180	+1·9
1983 Dec. 27·44	45695·44	+2·8	32·789	−0·1
1984 Jan. 18·30	45717·30	+1·6	32·815	0·0
1985 Jan. 2·47*	46067·47	+4·4	33·230	−1·6
3·41*	068·41	+4·5	·231	−1·6
4·41*	069·41	+6·3	·232	+0·2
Feb. 11·41*	107·41	+9·0	·277	+0·8
Mar. 7·32	131·32	+9·4	·306	+0·1
30·24	154·24	+9·8	·333	−0·5
May 6·29*	191·29	+11·7	·377	+0·2
8·15	193·15	+12·1	·379	+0·6
June 20·26*	236·26	+12·1	·430	−0·3
21·24*	237·24	+12·3	·431	−0·1
Dec. 7·46	406·46	+10·4	·632	+0·6
18·51*	417·51	+7·3	·645	−2·0
22·43	421·43	+8·9	·650	−0·2
26·48	425·48	+9·2	·655	+0·3
29·42	428·42	+8·7	·658	−0·1
1986 Jan. 11·44*	46441·44	+8·3	33·673	+0·1
18·37	448·37	+7·4	·682	−0·4
23·31	453·31	+7·4	·688	−0·2
29·34	459·34	+7·8	·695	+0·5
Mar. 15·34*	504·34	+4·6	·748	−0·2
16·30*	505·30	+4·3	·749	−0·5
20·32	509·32	+4·2	·754	−0·3
Apr. 11·32*	531·32	+3·3	·780	0·0
May 4·11	554·11	+2·7	·807	+0·7
18·09	568·09	+1·0	·824	−0·2
23·24*	573·24	+1·8	·830	+0·8
24·24*	574·24	+3·6	·831	+2·7
26·18*	576·18	+2·6	·833	+1·8

TABLE IV (*continued*)

Date (UT)			*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
1986	June	17·08	46598·08	−0·4	33·859	−0·1
	Dec.	6·42	770·42	−1·2	34·064	+0·3
		21·47	785·47	−1·3	·081	−0·4
1987	Jan.	5·42	46800·42	−0·5	34·099	−0·3
	Feb.	8·30	834·30	+0·7	·139	−0·9
	Mar.	9·27	863·27	+2·9	·174	−0·3
	Apr.	5·30	890·30	+5·5	·206	+0·7
		11·17	896·17	+4·6	·213	−0·6
	May	3·10	918·10	+6·3	·239	−0·2
		16·13	931·13	+6·5	·254	−0·7
	June	6·05	952·05	+8·0	·279	−0·3
	Dec.	7·47	47136·47	+12·5	·498	0·0
1988	Jan.	3·49	47163·49	+12·7	34·530	+0·5
		27·32	187·32	+12·8	·558	+1·0
	Feb.	11·38	202·38	+11·3	·576	−0·1
		24·41	215·41	+10·9	·591	−0·1
		27·43	218·43	+12·0	·595	+1·1
	Mar.	7·23	227·23	+10·3	·605	−0·3
	Nov.	5·23†R	470·23	+0·2	·894	+1·7
1989	Feb.	23·25‡	47580·25	−1·8	35·024	+0·6
	Apr.	30·88	646·88	+0·7	·103	+0·7
1990	Jan.	27·20	47918·20	+12·8	35·425	+0·5
	Feb.	12·30‡R	934·30	+14·0	·444	+1·5
	Mar.	13·38§	963·38	+12·1	·478	−0·5
1991	Jan.	27·24	48283·24	−0·9	35·858	−0·7
	Feb.	2·15	289·15	−0·6	·865	−0·1
	Dec.	17·26	607·26	+8·0	36·242	+1·4
1992	Jan.	16·26	48637·26	+8·5	36·277	+0·3
	Feb.	27·44§	679·44	+9·7	·328	−0·4
	Apr.	21·90	733·90	+12·1	·392	+0·3
	June	25·85	798·85	+13·1	·469	+0·5
	Nov.	16·44¶	942·44	+9·9	·639	+0·4
	Dec.	18·20	974·20	+8·4	·677	+0·4
1993	Feb.	12·10	49030·10	+4·6	36·743	−0·5
	Mar.	19·08	065·08	+3·7	·785	+0·6
	Dec.	25·26	346·26	+1·0	37·118	+0·4
1994	Feb.	18·19	49401·19	+4·0	37·183	+0·3
	Apr.	29·95	471·95	+8·2	·267	+0·4
	Dec.	11·20	697·20	+12·0	·534	−0·2
		29·26	715·26	+10·7	·556	−1·1
1995	Jan.	7·21	49724·21	+11·0	37·567	−0·6
	May	30·91	867·91	+5·2	·737	−0·2
1996	Mar.	29·98	50171·98	−0·9	38·098	−0·6
	Dec.	16·25	433·25	+11·8	·407	−0·3
1997	Jan.	26·15	50474·15	+12·0	38·456	−0·6
	Apr.	24·97	562·97	+11·2	·561	−0·5
	Dec.	14·46¶2	796·46	+0·9	·838	+0·3
		24·17	806·17	−0·8	·850	−0·9
		29·46¶	811·46	−0·4	·856	−0·3

TABLE IV (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
1998 Jan. 30·34¶	50843·34	−1·0	38·894	+0·5
Mar. 4·29¶	876·29	−2·5	·933	−0·1

*Abt & Willmarth[32]; wt. 0·2.
†Observed with OHP *Coravel*.
‡Observed with ESO *Coravel*.
§Observed with DAO 48-inch.
¶Carney *et al.*[37].
RRejected.
2 Mean of two measurements.

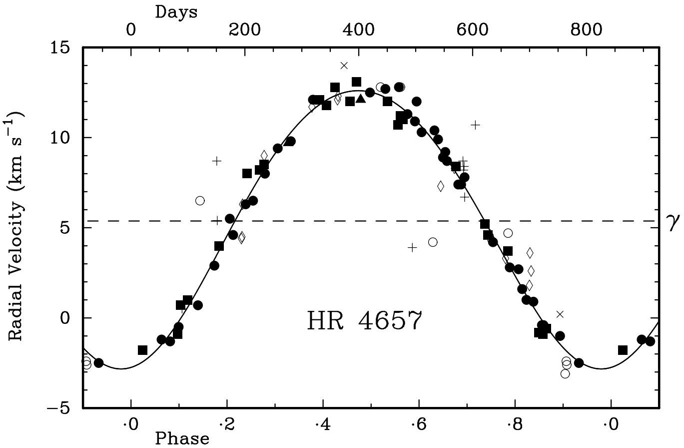

FIG. 2

The observed radial velocities of HR 4657 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The orbit largely depends on full-weight radial velocities from two sources — those from CfA by Carney *et al.*[37] (filled circles) and the writer's measurements with the OHP and ESO *Coravel*s (filled squares, except for two rejected ones plotted with crosses). Also used with full weight in the orbit are the writer's two observations from the DAO, shown as filled triangles. Weighted 0·2 are the velocities of Abt & Willmarth[32] (open diamonds), from which *those* authors derived a period of 23·10 days; previous measurements by Abt & Levy[31] are plotted as plusses but zero-weighted. The open circles represent velocities measured photographically at Mount Wilson[22,28] about 100 years ago; they have been given weight 0·04 in the solution of the orbit.

The velocity curve looks very like a sine wave, but the two principal data sets separately give very similar values for the longitude of periastron and, although the individual values for the eccentricity are in none too good agreement, the jointly determined value is more than four times its standard deviation and can be accepted as certainly non-zero. In any case there is no reason to think that a strictly circular orbit would be likely at the two-year period of HR 4657.

The astrometric period, at 853 days, is ten days (a little more than its standard error) longer than the spectroscopically determined one. The eccentricity is in good agreement, and is so small that ω is necessarily rather uncertain. The inclination is of useful precision, 73·9 ± 2·4 degrees, making $\sin i$ about 0·96 with an uncertainty a little over 1%. The mass function obtained in the spectroscopic orbit demands for the secondary object a minimum mass of about 0·45 $M_{\odot}$; the astrometrically estimated value of $\sin^3 i$ raises the probable actual mass of the secondary to near 0·5 $M_{\odot}$, corresponding to that of a main-sequence star of type about M0, which would be nearly five magnitudes fainter than the primary. It is satisfactory that a_0, the semi-major axis of the astrometric orbit, is 0·65 times the parallax, while the spectroscopic value of $a_1 \sin i$ is 0·60 AU, and half the difference is explained by the departure of $\sin i$ from unity. Since the mass ratio is likely to be somewhat over 2:1, the maximum angular separation could be expected to be over three times a_0, *viz.*, about 0″·10. The system would be worth an observation by speckle (or other) interferometry if there were an instrument for which the Δm expectation does not appear too daunting. A speckle effort by Jao *et al.*[39] at CTIO failed, probably because the Δm was too great.

HD 110314

HD 110314 is within the field of the North Galactic Pole as defined by Yoss & Griffin[40] ($b > 75°$), but did not feature in their comprehensive photometric and radial-velocity survey of the late-type stars in that field because the *HD* type, at G0, was just too early to fall within their definition of 'late type'. All the same, its velocity is readily measurable with radial-velocity spectrometers employing a late-type mask. The first effort to classify it on the MK system[25] was by Upgren[41], who obtained objective-prism spectra of the field at the very low dispersion of 580 Å mm^{-1} at Hγ, gave it an identity of 41° 130, and considered its type to be G6 but did not venture a luminosity class (as for most of the other stars he *did*). Sturch & Helfer[42] took a particular interest in the stars whose luminosities were left unclassified by Upgren, and found that many of them (marginally including HD 110314) had $(U-B)$ colour indices that were 'too red' in relation to $(R-I)$. They reported that spectrograms showed that many of such stars were giants, and their proper motions showed that they were members of the halo population. It is a fact that HD 110314 has a large proper motion (nearly 0″·2 annually); indeed it features in Luyten's '*Two-Tenths*' (*LTT*) *Catalogue*[43] — and *Simbad* even uses the designation 'LTT 13601' in preference to any other as the main heading for its bibliography, no matter under what identification one calls for it. It would seem, however, that excess redness in $(U-B)$ might well suggest excess line-blanketing of the spectrum — the reverse of what might be expected of halo stars. Indeed, Olsen[44], who made a shot at divining spectral types for stars having 'interesting Strömgren indices' (just from those indices themselves, not actual spectra) proposed for HD 110314 a type 'dG1 sl', where the 'sl' stood for 'strong-line'; but of course lines that would be of normal strength for a star of the type that Upgren proposed, G6, *would* look strong in a star whose type was actually G1. Sturch & Sharpless[45] found the type to be G2 IV from a slit spectrogram at 63 Å mm^{-1}, and Schild[46], from one at 87 Å mm^{-1}, considered it to be G2 V. The parallax[24] of 0″·0137 supports Schild, showing the absolute magnitude to be 4·6 ± 0·13.

The only radial velocities to be found in the literature seem to be one of +5 km s^{-1} (no date given) by Sturch & Sharpless[45], and a mean of +5·8 ± 4·5 km s^{-1} from two measurements, also without dates given, by Nordström *et al.*[16]. Both *Simbad* and the Abt & Biggs catalogue[47] promise four velocities (albeit with an improbable mean) in a 1918 *JRAS Canada* publication, but they are not to be found there. Thus any orbit has to depend on the writer's 40 observations alone, which have all been made with the Cambridge *Coravel*, starting in 2002 when the systematic programme of radial-velocity observations of stars with *Hipparcos* orbits was begun. The velocities are set out in Table V;

the relatively early type of the star would probably warrant a correction of about –0·5 km s^{-1} to all the measurements to put them on the scale normally adopted in this series of papers, but no such correction has been applied. The velocity curve (Fig. 3) is not as uniformly covered in phase as the writer likes his orbits to be; that is because the orbit has a period rather close to the integral number of 4 years, and has been seen round only two and a bit times, so the seasonal gaps have not been completely filled in. The elements have been included in Table XIII below, with those of all the other stars treated in this paper.

TABLE V

Cambridge radial-velocity observations of HD 110314

Date (UT)	*MJD*	*Velocity* *km s^{-1}*	*Phase*	*(O–C)* *km s^{-1}*
2002 Aug. 12·86	52498·86	+12·0	0·620	–0·6
Dec. 9·21	617·21	+10·3	·699	–0·2
2003 Jan. 11·22	52650·22	+9·6	0·720	–0·2
Mar. 15·08	713·08	+8·3	·762	+0·1
Apr. 6·99	735·99	+8·0	·777	+0·5
May 7·89	766·89	+6·4	·798	–0·1
June 14·92	804·92	+5·0	·823	–0·1
2004 Jan. 15·23	53019·23	–5·8	0·965	+0·3
Feb. 9·17	044·17	–6·6	·982	–0·4
Mar. 2·15	066·15	–5·9	·997	–0·4
30·07	094·07	–3·2	1·015	+0·3
Apr. 14·01	109·01	–1·9	·025	+0·2
May 4·99	129·99	+0·3	·039	+0·2
21·94	146·94	+2·3	·050	+0·3
June 4·97	160·97	+3·5	·059	+0·1
16·98	172·98	+4·1	·067	–0·5
28·90	184·90	+5·6	·075	0·0
July 16·89	202·89	+6·7	·087	–0·4
Dec. 27·26	366·26	+14·1	·196	+0·1
2005 Jan. 11·24	53381·24	+14·4	1·206	+0·2
Mar. 12·14	441·14	+15·1	·245	+0·1
May 8·99	498·99	+15·5	·284	+0·1
July 17·90	568·90	+15·5	·330	–0·1
2006 Jan. 27·27	53762·27	+15·1	1·459	+0·1
Mar. 1·09	795·09	+15·2	·480	+0·4
Apr. 4·05	829·05	+14·3	·503	–0·2
May 11·01	866·01	+13·7	·528	–0·5
June 5·95	891·95	+14·0	·545	0·0
July 3·92	919·92	+14·0	·563	+0·3
2007 Nov. 24·26	54428·26	–0·9	1·901	0·0
Dec. 11·26	445·26	–1·9	·912	0·0
2008 Jan. 6·26	54471·26	–3·2	1·929	+0·3
Feb. 2·19	498·19	–5·0	·947	0·0
May 2·94	588·94	–4·5	2·007	0·0
2009 Jan. 14·23	54845·23	+13·5	2·178	+0·1
Dec. 21·28	55186·28	+15·1	·404	–0·3
2010 Jan. 31·21	55227·21	+15·4	2·431	+0·1
2011 Jan. 19·24	55580·24	+12·2	2·665	+0·7
May 11·05	692·05	+9·1	·740	0·0
Dec. 5·26	900·26	+0·7	·878	–0·4

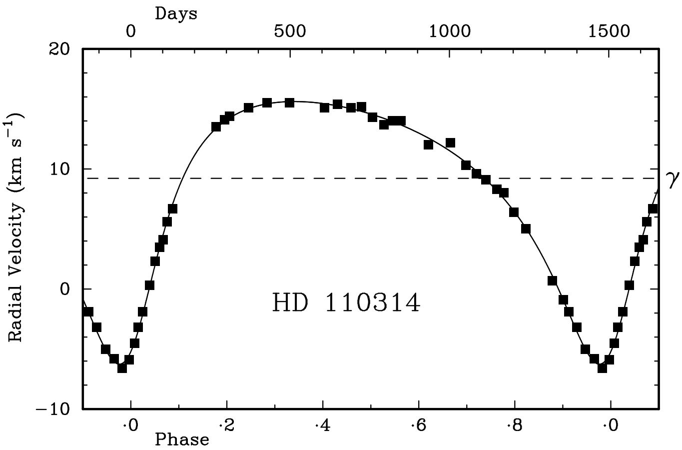

FIG. 3

As Fig. 1, but for HD 110314. All the measurements in this case come from the Cambridge *Coravel*, whose data are always plotted as filled squares.

The mass function is large enough to be very significant: if the solar-type primary has indeed the same mass as the Sun, then the mass of the secondary has to be at least 0·77 $M_\odot$, which is appropriate to a K0 main-sequence star that would be only about $1^m \cdot 5$ fainter than the primary. Such an object, whose spectrum would match the mask in the *Coravel* instrument (which was designed from the spectrum of Arcturus, type K2 III) considerably better than the primary's, should give in radial-velocity traces a second dip that is something like ⅓ as deep as that given by the primary. In other words, the trace should look obviously double-lined; at $8^m \cdot 3$ the system is by no means faint for observation with the *Coravel*, and a 3:1 ratio of dip depths should be apparent even without specially prolonged integrations. No such duplicity has been noticed, however, and the orbital velocity curve near the γ-velocity crossings shows no sign of the inflections that characterize incipiently double-lined systems. The difficulty is exacerbated by the astrometric finding of an orbital inclination that is not very near 90°: it is given as 123 ± 6 degrees. Inserting the corresponding value of $\sin^3 i$ into the expression for the mass function, one finds that, for the central value of i, the mass of the secondary is raised almost to that of the primary; at 1σ up ($i \sim 129°$) the secondary becomes actually *more* massive than the primary, while for 1σ down the effect is a little less dramatic. In any case it is clear that the secondary simply cannot be another main-sequence star.

Possible solutions to the conundrum are (*a*) that the secondary is a massive white dwarf — but a white dwarf at the system's distance of about 70 pc could be expected to have featured (but hasn't) in existing ultraviolet sky surveys — and (*b*) the companion object is itself double. If the companion's mass of close to 1 $M_\odot$ were split into equal halves it could represent a pair of M0 V stars that would jointly have an absolute magnitude of 8 or so; they would be about four magnitudes fainter than the primary in the *B* photometric band in which the *Coravel* operates, and would match the mask worse than the primary does, so they would be effectively invisible to the *Coravel*.

The astrometric major semi-axis of the photocentre of the system is 1·57 times the parallax; both quantities have uncertainties of nearly 6%, so the joint uncertainty is about 8%. Multiplying by the central value of $\sin i$ gives $a_0 \sin i \sim 1{\cdot}31 \times \pi$ (the parallax), which agrees very well with the spectroscopic $a_1 \sin i$ value of the primary's orbit, which is 1·35 AU with an uncertainty of less than 1%. The comparison of the sizes of the astrometric and spectroscopic orbits demonstrates that the photocentre coincides with the primary component within observational uncertainty. The agreement reinforces the conclusion that the secondary must be relatively very faint, although there is no escaping the fact, that necessarily follows from the mass function, that that object has a mass at least comparable with that of the primary.

The relative orbit of the components must measure about 3 AU, which at the distance of the system subtends up to 0″·04. Therefore HD 110314 could be expected to be resolvable by speckle interferometry on a large telescope, provided that the Δm were not prohibitive; a measure of that quantity (the Δm) would be very informative, particularly if it could be determined in different wavelength bands.

HD 137687

Most of the binary stars that are near enough to us to have *Hipparcos* orbits can have large proper motions without needing extravagant transverse velocities to do so, and so are mostly to be found also in the Luyten, and/or Lowell, and often even the old Cincinnati catalogues; the three stars already treated above are cases in point, and HD 137687 is another. It features already in the great Cincinnati catalogue[48], that was issued in four parts in 1915–18 (while cis-Atlantic personnel were otherwise engaged!). The annual proper motion is shown there (the star being identified as Groombridge[49] 2234 and as Ci 18 2062) as 0″·401; the *Hipparcos* value is 0″·400. *Simbad* elects to use, as the main heading for the bibliography of HD 137687, its number, G 239–53 (with annual proper motion 0″·35), in one[50] instalment of the comparatively imprecise Lowell proper-motion surveys; it might equally well have chosen G 224–67 (0″·37) or G 225–9 (0″·47) in another[51], but 'HD 137687' might have been a better choice.

Despite its brightness ($7^{m}{\cdot}3$), HD 137687 has been surprisingly neglected in the literature. There were two pre-*Hipparcos* efforts[52,53] (no doubt galvanized by the high proper motion) to measure its parallax, under the respective identifications GC[54] 20737 and BD[55] +61° 1501, but (like most parallaxes at their epoch) their uncertainties were of the same order as the quantities themselves. The same cannot be said for the *Hipparcos* one, whose (revised[24]) value is 18·51 ± 0·40 arc-milliseconds, corresponding to a distance of 54 ± 1 pc and a distance modulus of 3·66 ± 0·05 magnitudes. Apart from the *HD* type of G5, there seems to be only a pre-MK classification[9], by Kuiper, of G9. As far as radial velocities are concerned, one velocity, of –97·21 ± 0·23 km s^{-1} has been published[56], but with no date, and unhelpfully attributed only to "an unpublished bibliographic catalogue". Nordström *et al.*[16] report having three measurements, with a mean of –92·5 ± 5·6 km s^{-1}, but they are not given individually. They do show, however, that the star has a high radial velocity to go with its large transverse motion: with a proper motion about 22 times the parallax, it moves about 22 AU a year — a transverse velocity of just over 100 km s^{-1}.

Alone among all the *Hipparcos*-orbit stars observed by the writer, HD 137687 has proved to be double-lined. Fig. 4 illustrates a radial-velocity trace, taken right at a node when the velocity separation of the components is almost as great as

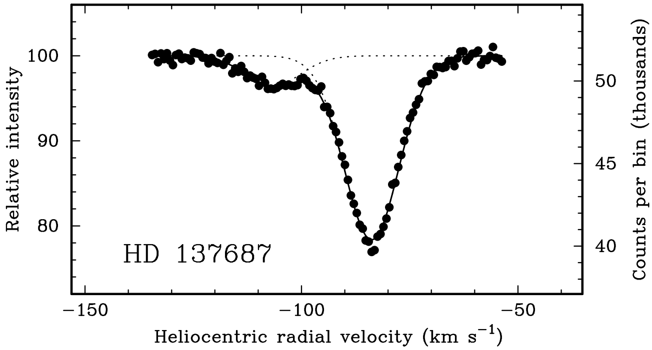

FIG. 4

Radial-velocity trace of HD 137687, obtained with the Cambridge *Coravel* on 2004 May 17 very close to a nodal passage, illustrating the very unequal double lines.

it can ever be (the opposite node actually offers a separation slightly greater, by nearly 1 km s^{-1}). The two dips are seen to be very unequal; their depths have a ratio of 1:0·14, and neither demonstrates any perceptible rotational velocity. The Cambridge *Coravel* has furnished the only data available for the determination of the orbit; they are listed in Table VI and consist of 41 measurements, of which four are not useable (taken when the two dips were mutually superimposed and the traces could not reliably be reduced as double-lined). The orbit is shown in Fig. 5 and the elements will be found in Table XIII below.

The *Hipparcos* period, at 399 ± 6 days, is 9 days longer than the relatively much more accurate spectroscopic one. The eccentricity, found by *Hipparcos* as 0·20 ± 0·16, agrees within its uncertainty with the 0·099 ± 0·004 derived here. When the eccentricity is hardly more than its standard error, ω is virtually indeterminate, but in fact the *Hipparcos* value is quite similar to the spectroscopic one (14° difference). The spectroscopic orbit furnishes accurate values of $m_{1,2} \sin^3 i$, of 0·290 ± 0·009 and 0·228 ± 0·004 $M_\odot$; there is an opportunity to estimate the orbital inclination if we could reliably assign masses to the components. It transpires that that is not too easy a thing to do, because whereas one might at first sight suppose that HD 137687 is a straightforward main-sequence pair, that turns out not to be the case. In such an unequal system, the colour index (in this case 0^{m}·80, from *Tycho*, in the apparent absence of any ground-based measurement) must largely reflect the colour of the primary. The V magnitude and distance modulus yield an accurate value for the absolute magnitude, which is 3^{m}·67 — which would suggest a primary with a type of about F8, whose colour index would be nowhere near as red as is actually observed. Also noticeable is the depth of the primary's 'dip' in Fig. 4: although it is diluted by the continuum of the secondary, it is significantly more than the 21% depth that the *Coravel* gives from daylight, which presumably has the solar (G2 V) spectrum. We could also pay some regard to Kuiper's classification of the object as G9. It seems inescapable that the primary of HD 137687 must be a star well into the G types, above the main sequence, must have begun its evolution and is therefore implicitly old, and is accompanied by a star whose temperature type is not much later and which we might be tolerably safe in supposing to be on the main sequence.

TABLE VI

Cambridge radial-velocity observations of HD 137687

Date (UT)		*MJD*	*Velocity*		*Phase*	*(O − C)*	
			Prim. *km s^{-1}*	*Sec.* *km s^{-1}*		*Prim.* *km s^{-1}*	*Sec.* *km s^{-1}*
2002	Aug. 13·01	52499·01	−96·7		0·621	—	—
	Sept. 12·86	529·86	−101·0	−81·8	·700	0·0	+0·5
	26·81	543·81	−102·3	−80·3	·736	−0·1	+0·4
	Oct. 18·75	565·75	−103·2	−80·1	·792	0·0	−0·7
	Nov. 14·75	592·75	−102·9	−80·7	·861	−0·3	−0·5
	Dec. 9·22	617·22	−100·0	−83·5	·924	+0·1	−0·1
2003	Jan. 16·24	52655·24	−93·0		1·021	—	—
	Feb. 15·21	685·21	−87·8	−100·5	·098	−0·4	−1·0
	Mar. 15·17	713·17	−83·9	−103·9	·170	0·0	+0·1
	Apr. 8·09	737·09	−82·5	−105·3	·231	+0·1	+0·3
	May 6·04	765·04	−82·9	−104·6	·303	+0·2	+0·4
	26·05	785·05	−84·5	−103·3	·354	0·0	−0·1
	June 11·00	801·00	−86·0	−102·2	·395	0·0	−0·9
	July 12·96	832·96	−90·5		·477	—	—
	Aug. 13·93	864·93	−92·7		·559	—	—
	Sept. 14·81	896·81	−98·2	−84·8	·641	+0·2	+0·7
	Oct. 11·83	923·83	−101·5	−82·2	·710	−0·1	−0·4
	Dec. 15·27	988·27	−102·3	−81·0	·876	−0·1	−0·3
	27·28	53000·28	−101·0	−82·7	·906	0·0	−0·5
2004	Jan. 15·27	53019·27	−97·7	−85·0	1·955	+0·4	+0·9
	Feb. 9·27	044·27	−93·4	−92·2	2·019	−0·1	−0·2
	26·26	061·26	−89·8	−97·4	·063	+0·1	−1·1
	Apr. 20·07	115·07	−82·7	−103·9	·201	+0·3	+1·2
	May 17·06	142·06	−82·7	−105·5	·270	0·0	0·0
	June 5·04	161·04	−83·5	−104·2	·319	0·0	+0·3
	12·99	168·99	−84·1	−104·8	·339	−0·1	−1·0
	25·91	181·91	−85·2	−102·9	·372	−0·1	−0·5
	July 16·93	202·93	−87·7	−99·1	·426	−0·3	+0·5
2005	Jan. 13·29	53383·29	−101·7	−80·1	2·889	+0·1	+1·2
	Mar. 25·16	454·16	−89·5	−95·3	3·070	−0·2	+1·8
	Apr. 19·10	479·10	−85·2	−102·6	·134	+0·2	−0·5
	May 31·01	521·01	−82·6	−105·7	·242	0·0	−0·1
2006	Mar. 1·22	53795·22	−98·5	−84·4	3·945	+0·3	+0·6
	June 4·01	890·01	−83·4	−105·5	4·188	−0·1	−0·8
	Nov. 3·78	54042·78	−95·0	−91·0	·580	+0·3	−1·5
2007	Feb. 4·25	54135·25	−103·4	−79·6	4·817	−0·1	−0·2
	15·22	146·22	−102·8	−80·2	·845	+0·2	−0·5
	Apr. 5·17	195·17	−97·4	−86·7	·971	−0·4	+0·6
	May 31·06	251·06	−86·3	−99·1	5·114	+0·1	+1·6
	Oct. 15·80	388·80	−89·6	−98·0	·467	−0·2	−1·0
2009	May 30·04	54981·04	−95·6	−88·6	6·986	+0·3	+0·2

If that is so, without worrying too much about fine details we might deem that the companion, which gives a dip ⅐ as deep as the primary's (⅛ of the total dip area), also contributes about ⅛ of the total light, or in magnitude terms is about $2^{\mathrm{m}}{\cdot}25$ fainter than the system as a whole. That places it at $M_V \sim 5^{\mathrm{m}}{\cdot}9$, corresponding to the luminosity of a star of type K0 V. Then we have merely to subtract its contribution from the light of the system as a whole to retrieve the properties (M_V, $(B-V)$) that must pertain to the primary, whose mass we

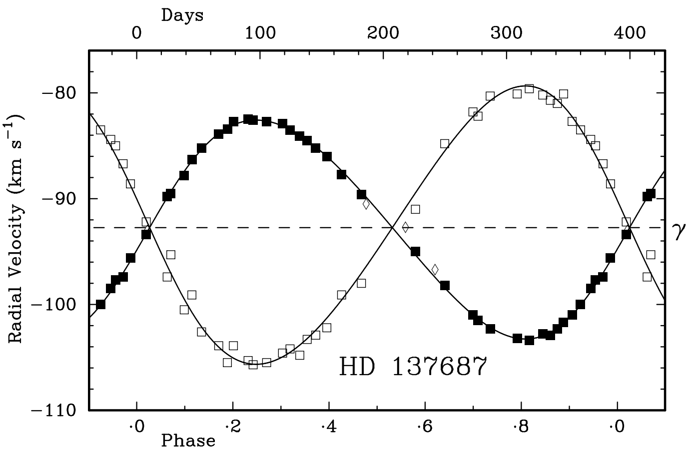

FIG. 5

Orbit of HD 137687. The filled symbols represent the primary, open ones the secondary. Open diamonds indicate observations that were reduced as single-lined and not used in the solution of the orbit.

also know from the orbital elements to be 1·27 times as great. The result of the photometric exercise is as follows:

Star		M_V	$(B-V)$	M_B
		m	*m*	*m*
Model	G5 IV	3·8	0·78	4·58
	K0 V	5·9	0·89	6·79
	G5 IV + K0 V	3·65	0·80	4·45
HD 137687 (observed)		3·67	0·82	4·49

The luminosity and colour index attributed to the primary star in the table above correspond to the spectral type G5 IV; the colour index is just midway between the received values for luminosity classes III and V, and the luminosity is rather more than halfway down between those classes. According to its putative mass, derived *via* the spectroscopic mass ratio from the mass to be attributed to the K0 V star with which the secondary component is identified, the primary should have a mass very near to 1 $M_{\odot}$ and should have spent most of its time on the main sequence as a star of solar type. Dr. R. E. M. Griffin kindly informs me that the evolutionary track of a 1-$M_{\odot}$ star does indeed pass very close to the (M_V, $(B-V)$) position indicated for the primary star. That being accepted, the masses given by the spectroscopic orbit then lead to the equation $\sin^3 i \sim 0{\cdot}29$, from which $\sin i \sim 0{\cdot}66$, $i \sim 41^{\circ}{\cdot}5$. An error of 10% on the conjectural input masses would be reflected as a change of only about $1^{\circ}{\cdot}7$ in the inclination. The value deduced here for i is well within the uncertainty of the one given by the *Hipparcos* orbit, 46 ± 8 degrees.

The semi-axis of the relative orbit of the stars is given in linear terms by $((a_1 + a_2)\sin i)/\sin i$, all of which quantities can be substituted numerically; the expression yields a distance of 1·27 AU, which would subtend in the sky an angle of 1·27 times the parallax or about 23 milliseconds of arc, if not foreshortened by projection. Although we know that the Δm is not much more than two magnitudes, HD 137687 does not appear to be an object that would easily be resolved on the sky. The radii of the orbits of the individual stars around their common centre of gravity will be in the inverse ratio of their masses, and so should be about 10 and 13 arc-milliseconds for the primary and secondary, respectively. The photocentre of the system is expected, from the 7:1 relative brightnesses of the components, to lie about ⅛ of the way from the primary to the secondary, *viz.*, about 3 milliseconds from the primary in the direction towards the centroid of the system. It should therefore have a radius of about 7 milliseconds; the actually observed value, by *Hipparcos*, is 7·7 milliseconds, with an uncertainty of about 10%.

HD 138369

This star, at $7^{m}\cdot4$, is of nearly the same magnitude as the previous one but not so favourably situated in the sky for observation from Cambridge, being less than 1° north of the celestial equator. It has even less in the way of literature. In fact, apart from a mean radial velocity of $-1\cdot5 \pm 1\cdot5$ km s^{-1} given by Nordström *et al.*[16], who recognized it as variable, the only papers to be mentioned here are two efforts to resolve the star by speckle interferometry. The first, by Mason *et al.*[57] at McDonald, was unsuccessful (it is quite difficult to find the object in the relevant table, in which it (HIP 76031) is bizarrely sandwiched between HIP 112562 and 112784!). The second, by Tokovinin, Mason & Hartkopf[58], on the *SOAR* 4·1-m telescope on Cerro Pachon in Chile (near the *Gemini South* telescope), was apparently successful. They obtained observations on two nights in the same observing run, finding a secondary with a Δm of only 1·0–1·2 magnitudes at a separation of 0″·039. There appeared to be change of 20° in position angle between the nights, in an elapsed time of only two days. A note in the paper reads, "New pair. Motion detected? Measurements could be affected by vibrations. The resolved pair may correspond with the 1·7-year astrometric orbit."

There are no radial velocities to be incorporated in the orbit to supplement the Cambridge ones, which (as for most of the stars treated here) began in 2002. There are 41 of them, listed in Table VII, and they yield the orbit whose elements appear in Table XIII and which is illustrated in Fig. 6. There are some unusually bad residuals in the orbit, making the r.m.s. residual larger than is normal for stars of HD 138369's magnitude. But the star is of quite an early type (there is no MK classification, indeed no advance on the *HD*'s G0, but the distance modulus derived from the parallax leads to $M_V \sim 3^{m}\cdot88 \pm 0^{m}\cdot10$, suggesting a type near F8, though the colour index suggests G2). Anyway, the depth of the 'dip' in the *Coravel* traces is only half as great as is given by late-K giants. The declination, too, is unhelpful, especially in combination with a need early in the calendar year to observe at dawn low in the south-east, where shortcomings in the support system of the 36-inch mirror can be noticeable in the star images.

There is nothing in Fig. 6 to suggest that the system is double-lined; if it really has a secondary only about one magnitude fainter than the primary it ought to be obvious both in the traces and in the 'dragging' of the measured velocities towards the γ-velocity. The amplitude of the radial-velocity orbit is far too large for the observations all to be understood as measuring blends of two components. It should be mentioned that there *was* an occasion early in the observing campaign (2003 June 20) when the remark appears in the handwritten observing notes, "Big slope, or bl[ended] to R[ed]"; but there are instrumental and other accidental circumstances that can cause traces to slope, and the reductions allow for (in effect, remove) the slope in determining the

TABLE VII

Cambridge radial-velocity observations of HD 138369

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
2002 Aug. 14·86	52500·86	+14·5	0·899	+0·6
2003 Feb. 18·20	52688·20	+0·2	1·201	+1·1
Mar. 19·09	717·09	−1·7	·248	−0·4
Apr. 19·08	748·08	−2·0	·298	−0·7
May 20·08	779·08	−1·3	·348	−0·3
June 20·94	810·94	−0·5	·400	0·0
Aug. 2·88	853·88	+1·3	·469	+0·9
6·88	857·88	+1·0	·475	+0·5
2004 Feb. 26·20	53061·20	+8·8	1·804	−0·5
Mar. 31·13	095·13	+12·0	·858	+0·1
Apr. 23·10	118·10	+14·3	·895	+0·5
May 7·07	132·07	+14·6	·918	−0·1
31·01	156·01	+15·3	·957	−0·1
June 25·93	181·93	+13·7	·999	+0·4
July 30·87	216·87	+7·2	2·055	+0·3
Aug. 7·88	224·88	+5·0	·068	−0·5
2005 Jan. 9·27	53379·27	−0·1	2·317	+1·1
Mar. 23·19	452·19	−0·3	·435	−0·2
May 21·97	511·97	+1·1	·531	−0·4
June 22·94	543·94	+1·7	·583	−0·8
July 16·92	567·92	+3·2	·622	−0·2
Aug. 15·86	597·86	+4·1	·670	−0·5
2006 Jan. 29·28	53764·28	+14·6	2·939	−0·7
Mar. 1·19	795·19	+13·8	·989	−0·3
Apr. 4·11	829·11	+8·4	3·043	+0·2
May 6·08	861·08	+3·1	·095	0·0
30·01	885·01	+0·1	·134	−0·8
June 21·95	907·95	−1·2	·171	−0·8
July 18·92	934·92	−1·3	·214	−0·2
2007 May 23·04	54243·04	+5·3	3·712	−0·6
June 4·99	255·99	+6·6	·733	0·0
19·97	270·97	+7·6	·757	+0·2
July 7·96	288·96	+8·8	·786	+0·2
29·89	310·89	+10·2	·821	+0·1
2008 Feb. 2·24	54498·24	+2·3	4·124	+1·0
May 3·05	589·05	−1·7	·270	−0·3
2009 Apr. 29·10	54950·10	+11·9	4·853	+0·2
May 20·03	971·03	+13·3	·887	−0·1
2010 Mar. 23·16	55278·16	−1·1	5·383	−0·4
May 12·05	328·05	+1·0	·464	+0·7
June 3·03	350·03	+1·7	·499	+0·8

velocity from the trace. It is, however, a fact that on that occasion the velocity of HD 138369 was about 5 km s^{-1} from the γ-velocity, and any companion could be expected to be rather more than double that distance away from the primary dip, on the red side. Accordingly, on 2003 August 6, a special observation was made in which a much wider region of velocity space was scanned, so that there could be no doubt as to where the 'continuum' of the trace lay; it was quickly concluded that there was *no* secondary. No analogous remark or action

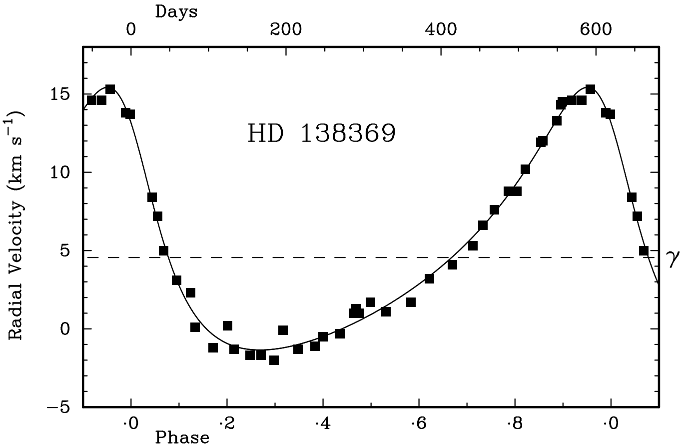

FIG. 6
Orbit of HD 138369.

is recorded since then. We note, however, that duplicity with a small *Δm* could explain why the system appears redder than might be expected from its absolute magnitude, as the information in the immediately preceding paragraph might suggest that it does.

The *Hipparcos* orbital period of 616 ± 21 days is well confirmed by the 619·3 ± 1·4 found here. The *Hipparcos* eccentricity, at 0·27 ± 0·22, is almost indeterminate, so it is hard to know how the ω can have an uncertainty of 'only' 22° (though it differs from the Cambridge value by 160°). The astrometric a_0 value is 0·86 times the parallax and so indicates an orbital radius of 0·86 AU; the spectroscopic $a_1 \sin i$ is only 0·44 AU, but the two values (whose ratio is 0·51) can be reconciled by the astrometrically determined inclination, which is 145 ± 9 degrees, allowing values of $\sin i$ from 0·44 to 0·69 even without straying more than 1σ from the mean.

If the ratio of 0·51 of the sizes of the spectroscopic and astrometric orbits is taken as an estimate of $\sin i$, that value can be inserted in the expression for the mass function, which then becomes

$$m_2^3/(m_1 + m_2)^2 \simeq 0{\cdot}22\ M_\odot.$$

Then if m_1 is taken as 1 $M_\odot$, m_2 has to be about 0·94, suggesting that the *Δm* of the system should be even smaller than Tokovinin *et al.*[58] reported. But there is a glaring lack of self-consistency in that calculation, because near-equal duplicity would reduce the size of the photocentric orbit nearly to zero and thereby undermine the very data that led to that proposition in the first place! Even if we were to accept the value just adopted for $\sin i$ and the result of the calculation of m_2 from the mass function, the m_2 mass does not necessarily signify a star comparable with the primary — it could well be a binary pair of M-type stars with a relatively negligible total luminosity. But if the system consists of two main-sequence stars with a *Δm* of little more than one magnitude, and therefore masses that are not very different from one another, as Tokovinin *et al.*'s observations seem to indicate, the photocentre will be shifted by about a quarter of the radius of the relative orbit from the primary towards the secondary, so the photocentric orbit should have only about *half* the radius of the primary's orbit. In summary, therefore, all that can be said is that at present there is conflicting (or misunderstood, or not correctly synthesized) evidence concerning the HD 138369 system.

HD 156558

This star, at nearly 70° declination, is only about 5° from the pole of the ecliptic, in the north-preceding direction; the fact that it is to the north gives it the unusual property that its right ascension *regresses* as time goes on. The parallax leads to an absolute magnitude of about $4^{m}\cdot 7$, so in the absence of a good spectral classification we may consider the star to be of solar type. There is almost no literature on it: the *Simbad* bibliography consists exclusively of just five catalogues. Not in the bibliography, but retrieved by Abt & Biggs[47] and in the *Simbad* 'measurements' section, there is just one report of radial-velocity measurements — three of them, with a mean of $-55\cdot 3$ km s^{-1} with a 'probable error' of $0\cdot 5$ km s^{-1}, by (R. E.) Wilson & Joy[59]; the individual values, which are in good mutual accord and so give no evidence of the binary nature of the star, were later published by Abt[60], and have been transcribed to the head of Table VIII here. The rest of the table consists of the writer's 59 observations made with the Cambridge *Coravel*, starting in 2002. The orbit, which depends on those alone, is shown in Fig. 7 and its elements appear in Table XIII below.

The spectroscopic period of HD 156558, 891 days, is well within the uncertainty of the *Hipparcos* period of 883 ± 26 days. The modest eccentricity is also within the wide limits of the *Hipparcos* value of $0\cdot 12 \pm 0\cdot 16$; and when the error on the eccentricity is greater than the quantity itself, ω is obviously

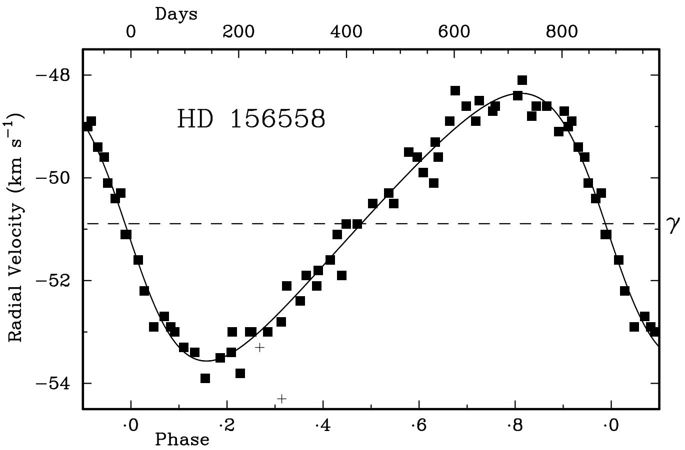

FIG. 7

Orbit of HD 156558. The two plusses (there ought to be three, but one is off the bottom of the plot) indicate Mount Wilson photographic velocities published by Wilson & Joy[59,60]. They were not used in the solution of the orbit.

TABLE VIII

Radial-velocity observations of HD 156558

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s^{-1}*	*Phase*	*(O – C)* *km s^{-1}*
1936 Apr. 28·49*	28286·49	−55·8	$\overline{27}$·748	−7·3
1942 June 23·36*	30533·36	−53·3	$\overline{24}$·268	−0·3
Aug. 3·20*	574·20	−54·3	·314	−1·7
2002 Aug. 13·01	52499·01	−49·0	0·910	+0·1
Sept. 12·87	529·87	−49·6	·945	+0·2
Oct. 23·79	570·79	−51·1	·991	−0·1
Nov. 14·76	592·76	−51·6	1·016	+0·1
2003 Mar. 19·15	52717·15	−53·9	1·155	−0·3
Apr. 16·12	745·12	−53·5	·186	0·0
May 8·03	767·03	−53·0	·211	+0·4
June 13·05	803·05	−53·0	·251	+0·1
July 12·98	832·98	−53·0	·285	−0·2
Aug. 6·91	857·91	−52·8	·313	−0·2
Sept. 10·90	892·90	−52·4	·352	−0·2
Oct. 11·87	923·87	−52·1	·387	−0·3
14·82	926·82	−51·8	·390	0·0
Nov. 5·74	948·74	−51·6	·415	0·0
Dec. 5·72	978·72	−50·9	·449	+0·3
2004 Mar. 2·24	53066·24	−50·5	1·547	−0·3
Apr. 15·12	110·12	−49·6	·596	+0·1
May 19·08	144·08	−49·3	·634	+0·1
June 15·03	171·03	−48·9	·664	+0·2
Aug. 7·99	224·99	−48·5	·725	+0·2
Sept. 1·92	249·92	−48·7	·753	−0·2
Oct. 18·87	296·87	−48·4	·805	0·0
Nov. 13·79	322·79	−48·8	·835	−0·4
Dec. 11·71	350·71	−48·6	·866	−0·1
2005 Jan. 13·28	53383·28	−48·7	1·902	+0·3
Mar. 12·22	441·22	−50·4	·967	−0·1
May 5·08	495·08	−52·2	2·028	−0·2
23·03	513·03	−52·9	·048	−0·4
June 11·03	532·03	−52·7	·069	+0·2
22·99	543·99	−52·9	·083	+0·2
July 16·99	567·99	−53·3	·110	+0·1
Aug. 6·90	588·90	−53·4	·133	+0·1
Oct. 29·78	672·78	−53·8	·227	−0·5
Nov. 16·72	690·72	−53·0	·247	+0·2
2006 Mar. 1·23	53795·23	−51·9	2·365	+0·2
May 6·12	861·12	−51·9	·438	−0·6
June 4·05	890·05	−50·9	·471	+0·1
July 2·99	918·99	−50·5	·503	+0·1
Aug. 2·01	949·01	−50·3	·537	0·0
Sept. 7·96	985·96	−49·5	·578	+0·4
Oct. 4·90	54012·90	−49·9	·609	−0·3
Nov. 1·81	040·81	−49·6	·640	−0·3
Dec. 2·76	071·76	−48·3	·675	+0·7

TABLE VIII (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2007 Feb. 15·23	54146·23	−48·6	2·758	−0·1
Apr. 6·14	196·14	−48·1	·814	+0·3
May 2·12	222·12	−48·6	·843	−0·2
July 7·04	288·04	−48·9	·917	+0·3
18·98	299·98	−49·4	·931	+0·1
Aug. 6·97	318·97	−50·1	·952	−0·2
30·96	342·96	−50·3	·979	+0·4
Sept. 7·89	350·89	−51·1	·988	−0·2
2008 July 4·04	54651·04	−52·1	3·325	+0·4
Oct. 5·85	744·85	−51·1	·430	+0·3
2009 June 2·07	54984·07	−48·6	3·698	+0·3
2010 May 18·09	55334·09	−53·0	4·091	+0·2
Aug. 30·96	438·96	−53·4	·209	0·0
2011 Sept. 10·90	55814·90	−50·1	4·630	−0·7
Nov. 27·73	892·73	−48·9	·718	−0·2
2012 Apr. 30·10	56047·10	−49·1	4·891	−0·3

*Mt. Wilson photographic observation[59,60]; weight 0.

indeterminate, so it is not to be wondered at that in this case there is a discrepancy of more than 100°. What is at first sight surprising is that the astrometric orbit is as big as it is: at 11·4 arc-milliseconds, with an uncertainty of just over 10%, it is 0·64 times the parallax, making the orbital radius 0·64 AU. In contrast, the $a_1 \sin i$ value given by the orbital elements is only 0·217 ± 0·005 AU. The numbers are readily reconciled by supposing that $\sin i$ must be 0·217/0·64, or about 0·32, corresponding to $i \sim 19°$. In fact the *Hipparcos* value for i is 159 ± 16 degrees, equivalent to 21 ± 16 degrees but specifying a retrograde direction of motion, so although it is far from accurate it does at least agree that the orbit is seen rather face-on, and indeed its actual value is fortuitously close to the one that the spectroscopic elements lead us to expect. The small value indicated for $\sin i$ leads to a secondary mass that is much larger than the minimum that would be required by the mass function taken in isolation, but it is still only about 0·45 $M_\odot$, so the secondary object (if not itself double) should be a star of about type M0, four or five magnitudes fainter than the primary.

About 5′ north-preceding HD 156558 there is a 9^m K-type star, BD +69° 899, whose radial velocity has been measured four times (initially by accident, as the telescope's RA display is none too accurate at high declinations!). The four dates were 2003 Feb. 21·24 and Apr. 16·12, and 2005 Jan. 13·28 and May 23·03, and the velocities measured were +12·2, +12·6, +12·7, and +12·7 km s^{-1}, respectively.

HD 178593

This is another star whose literature consists mainly of entries in catalogues. There is, however, ground-based broad-band photometry by Guetter[61], $V = 7^m{\cdot}48$, $(B-V) = 0^m{\cdot}51$, $(U-B) = -0^m{\cdot}03$. The $(B-V)$ is not in very good accord with the $0^m{\cdot}47$, taken from the *Simbad* header material, entered in Table II.

There seems to be no spectral classification other than the *HD* type of F8, but the colour index might suggest F7, and the distance modulus obtained from the parallax gives the absolute magnitude as $3^{m}\cdot54 \pm 0^{m}\cdot08$, which would correspond with about F6. One radial-velocity measurement is quoted by Bartkevičius & Gudas[56], as $+44\cdot00 \pm 5\cdot00$ km s^{-1}, which would not be helpful for the orbit even if we knew its date. There is also a mean of $+19\cdot6 \pm 0\cdot4$, from two measurements, listed by Nordström *et al.*[16], which again is of no utility in the absence of dates; the spectroscopic-binary nature of the object was not discovered. Speckle interferometry by Mason *et al.*[57] did not reveal any secondary star.

A spectroscopic orbit is obtained here on the basis solely of the 62 radial velocities measured with the Cambridge *Coravel* in 2002–12. They are set out in Table IX, and are noticeably more ragged than the usual run of Cambridge data. That is because the 'dips' in radial-velocity traces are not only of smaller area than most owing to the rather early type of the star, but are significantly smeared out by rotation, whose mean value is 15·6 km s^{-1}, with a formal standard error less than 0·2 km s^{-1}. The imprecision caused by the width and shallowness of the dip was increasingly mitigated as time went on by taking the scan wider and integrating it for longer. A subjective overview of the data in Table IX suggested that the observations of 2002–05 tend to have, on average, considerably larger residuals than those made after 2005, and a trial of *half*-weighting the earlier group not only confirmed that impression but showed that half-weighting was actually not fully sufficient to remove completely the discrepancy between the residuals of the two moieties of the data set. It is, however, as far as the writer felt it was reasonable to go, and it is on that basis (the first 39 observations half-weighted, the last 23 full weight) that the orbit shown in Fig. 8 has been computed. The elements appear in Table XIII.

The *Hipparcos* period of about 897 days differs from the spectroscopically determined 1015 days by more than the former's standard error (specified as 41·0142 days) would lead one to hope. The astrometric eccentricity of about $0\cdot65 \pm 0\cdot11$ is in good agreement with the spectroscopic 0·61, so it is mystifying

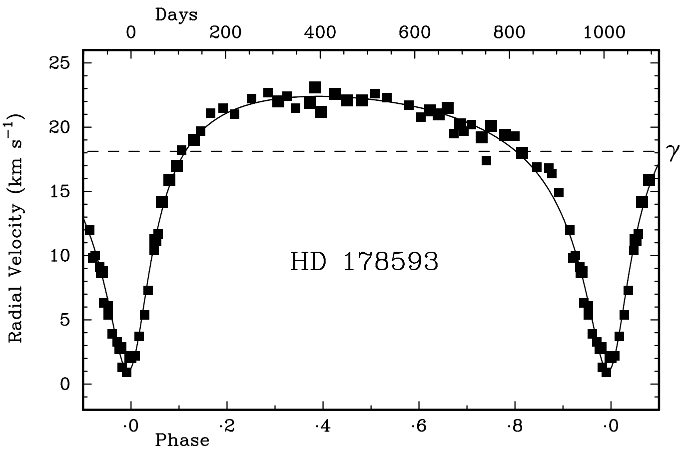

FIG. 8

Orbit of HD 178593. The larger symbols represent the later and more accurate *tranche* of the Cambridge observations.

TABLE IX

Cambridge radial-velocity observations of HD 178593

The observations of 2002–2005 were half-weighted in the solution of the orbit

Date (UT)	*MJD*	*Velocity* *km s^-1*	*Phase*	*(O – C)* *km s^-1*
2002 Aug. 22·99	52508·99	+16·8	0·870	+1·7
Sept. 12·89	529·89	14·9	·891	+1·2
Oct. 12·92	559·92	9·8	·921	−1·1
Nov. 14·71	592·71	6·1	·953	−0·3
2003 Apr. 19·11	52748·11	18·2	1·106	+0·6
May 29·05	788·05	19·7	·145	+0·1
June 19·05	809·05	21·1	·166	+0·8
July 14·99	834·99	21·5	·192	+0·6
Aug. 8·98	859·98	21·0	·216	−0·4
Sept. 13·93	895·93	22·2	·252	+0·4
Oct. 17·88	929·88	22·7	·285	+0·6
Nov. 27·77	970·77	22·4	·325	+0·1
Dec. 15·76	988·76	21·5	·343	−0·8
2004 May 31·07	53156·07	22·6	1·508	+0·5
June 26·01	182·01	22·3	·534	+0·3
Aug. 11·02	228·02	21·7	·579	0·0
Sept. 5·95	253·95	20·8	·604	−0·7
Nov. 13·83	322·83	19·5	·672	−1·3
Dec. 5·74	344·74	19·7	·694	−0·8
21·71	360·71	20·2	·710	0·0
2005 Jan. 22·29	53392·29	17·4	1·741	−2·3
Mar. 23·21	452·21	19·3	·800	+1·1
May 8·09	498·09	16·9	·845	+0·4
June 9·05	530·05	16·4	·876	+1·7
July 17·07	568·07	12·0	·914	+0·4
28·98	579·98	10·0	·926	−0·3
Aug. 6·94	588·94	9·1	·935	−0·1
15·96	597·96	6·3	·943	−1·6
25·01	607·01	5·4	·952	−1·0
Sept. 2·90	615·90	3·9	·961	−1·0
12·93	625·93	3·3	·971	0·0
23·89	636·89	1·3	·982	−0·4
Oct. 2·88	645·88	0·9	·991	−0·2
20·79	663·79	2·2	2·008	0·0
29·85	672·85	3·7	·017	−0·3
Nov. 9·79	683·79	5·4	·028	−1·1
17·81	691·81	7·3	·036	−1·0
29·81	703·81	10·4	·048	−0·3
Dec. 8·73	712·73	11·7	·057	−0·6
2006 Oct. 24·86	54032·86	21·9	2·372	−0·5
Nov. 18·81	057·81	21·2	·397	−1·2
Dec. 16·73	085·73	22·6	·424	+0·2
2007 July 7·07	54288·07	21·3	2·623	0·0
25·00	306·00	21·0	·641	−0·1
Sept. 8·01	351·01	20·2	·685	−0·4
Oct. 23·80	396·80	19·2	·731	−0·6
Dec. 12·75	446·75	+19·4	·780	+0·6

TABLE IX (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2008 May 22·11	54608·11	+8·7	2·939	+0·2
July 1·09	648·09	2·8	·978	+0·6
22·06	669·06	2·1	·999	+0·9
Sept. 12·93	721·93	11·2	3·051	−0·1
26·92	735·92	14·2	·065	+0·6
Oct. 11·86	750·86	15·9	·079	+0·5
27·87	766·87	17·0	·095	+0·1
Dec. 2·74	802·74	19·0	·131	0·0
2009 May 30·10	54981·10	22·0	3·306	−0·2
Oct. 22·85	55126·85	22·1	·450	−0·2
Nov. 23·70	158·70	22·1	·481	−0·1
2010 May 24·10	55340·10	21·5	3·660	+0·6
Aug. 23·98	431·98	20·1	·751	+0·7
Oct. 27·83	496·83	18·0	·815	+0·3
2012 May 28·11	56075·11	+23·1	4·384	+0·7

that the *Hipparcos* ω could be 42° (with an uncertainty of only 10°) while the value found here is 192°·1 ± 1°·5.

The astrometrically determined inclination is 60 ± 4 degrees. Inserting the corresponding value of $\sin i$ into the expression for the mass function, and taking the mass of the ~F6 primary star as 1·3 $M_\odot$, one obtains a mass of about 0·75 $M_\odot$ for the secondary; the 1-σ uncertainty attributable to that of the inclination is only about 0·05 $M_\odot$, but the total uncertainty is greater because the mass of the primary is only an estimate. The proposed secondary mass corresponds to that of an early-K star whose luminosity could be expected to be about 2½ magnitudes fainter than that of the F-type primary (more like 3 magnitudes in the blue where the *Coravel* sees it). Such a star, measured in isolation, would be expected to give in radial-velocity traces a dip having a depth of 25–30% of the continuum. Diluted by the continuum of a star three magnitudes (sixteenfold) brighter, it would be nearly 2% deep. Fig. 9 shows one of two traces that were

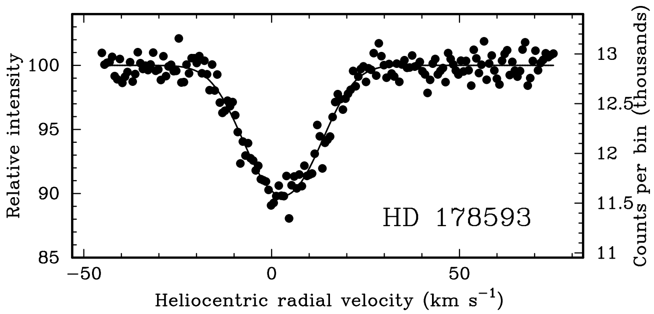

FIG. 9

Radial-velocity trace of HD 178593, obtained with the Cambridge *Coravel* on 2005 September 2, close to a nodal passage. A secondary object could be expected to have a velocity in the vicinity of +40 km s⁻¹.

taken in 2005 September, near the nodal passage, when the velocity of the secondary would be well away from that of the primary, on purpose to look for a second dip, which would be expected to appear at about +40 km s^{-1}. There is certainly no dip that is 2% deep, but largely owing to the presence of a single low point that could easily be a statistical fluke it is impossible to be certain that there is not *any* dip there. If, under duress, the prospects for the secondary could be held to permit a Δm of as much as four magnitudes in the blue, then Fig. 9 could be held not to rule it out; on the other hand, if the secondary were assumed to be a binary it would obviate the need to make a somewhat unscientific effort to reconcile results that do not willingly hang together.

HD 183536

The first paper recorded by *Simbad* for HD 183536 is a 1983 one by Carney[62] entitled 'A photometric search for halo binaries'; it appears to be devoted solely to photometry and does not identify any binaries, nor was HD 183536 subsequently identified as a binary from the photometry. But since it would be manifestly useless to look for halo binaries otherwise than among halo stars, and since HD 183536 does not appear to have been noted previously as metal-deficient, it seems clairvoyant of Carney to have included the star in his paper at all. Possibly it was the considerable proper motion (now quantified at 0″·235 per annum[24], directed nearly northwards) that prompted its inclusion. The object features in Luyten's *LTT Catalogue*[43], and as in the case of HD 110314 *Simbad* adopts the *LTT* number (in this case 15689) as its main designation of the star.

Only two years later, however, Bidelman[63] *did* implicitly identify HD 183536 as a metal-deficient star, by classifying it as Gp with the comment 'mod wk-lined'. Later, Bartkevičius & Lazausaitė[64] seemed to be aware of its character when they included it in a paper on the classification of Population II stars by photometry in the Vilnius photometric system[65]; they derived a pseudo-spectral type of MD-G0V ('MD' standing for 'metal-deficient'), and placed the star in their 'Group D3', described as "thick disk". They estimated some other salient parameters by their photometry, including [Fe/H] = –0·50. The same type of MD-G0V was quoted in a subsequent paper by Bartkevičius & Gudas[56], who also referred to a radial velocity of –49·90 ± 1·78 km s^{-1}. Mason *et al.*[57] observed HD 183536 by speckle interferometry but did not resolve it on the sky. Nordström *et al.*[16] deduced an [Fe/H] of –0·46 from *ubvyβ* photometry, and also gave a mean radial velocity of –53·5 ± 1·7 km s^{-1} from four *Coravel* observations.

The only published radial velocities that are dated and thereby potentially useable for an orbit are three that were taken long ago at the Mt. Wilson Observatory; their mean value was published by Wilson & Joy[59] in 1950, but the individual velocities, with their dates, were made available by Abt[60] in 1973. They are shown at the head of Table X. Actually they prove to be too ragged to help with the orbit, which has, after all, to depend entirely upon the 63 observations, which occupy the rest of the table, obtained with the Cambridge *Coravel*. They readily yield the orbit that is portrayed in Fig. 10; the elements are added to Table XIII. The period of 824·4 days differs by less than one day from the *Hipparcos* value whose own uncertainty is 26 days. The high eccentricity given by *Hipparcos* agrees, within its substantial standard error of 0·18, with the value found here, but as in the case of HD 178593 there is an extraordinary discrepancy in the longitudes of periastron — in the present case between our 155·3 ± 1·1 and *Hipparcos*'s 289 ± 22 degrees. The *Hipparcos* inclination is 148 ± 12 degrees; the corresponding $\sin i$ is about 0·53 ± 0·18, which in conjunction with

TABLE X

Radial-velocity observations of HD 183536

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
1942 June 1·46*	30511·46	−52·2	$\overline{27}$·728	−4·3
1944 Sept. 2·21*	31335·21	−43·7	$\overline{26}$·727	+4·2
1945 Oct. 17·12*	31745·12	−52·8	$\overline{25}$·225	−2·1
2002 Aug. 13·00	52499·00	−49·0	0·399	0·0
Sept. 12·95	529·95	−49·2	·437	−0·4
Oct. 12·93	559·93	−49·0	·473	−0·4
Nov. 14·72	592·72	−48·5	·513	−0·1
Dec. 19·76	627·76	−48·2	·555	+0·1
2003 Apr. 19·13	52748·13	−48·3	0·701	−0·4
June 24·05	814·05	−47·5	·781	+0·4
Aug. 17·04	868·04	−48·3	·847	−0·1
Oct. 18·84	930·84	−50·0	·923	−0·1
Nov. 3·79	946·79	−51·0	·942	+0·1
27·78	970·78	−55·3	·971	−0·6
Dec. 7·75	980·75	−57·2	·983	0·0
9·73	982·73	−57·4	·986	+0·3
15·74	988·74	−59·2	·993	+0·1
17·79	990·79	−60·0	·996	−0·2
28·73	53001·73	−61·4	1·009	−0·3
2004 Jan. 2·74	53006·74	−61·2	1·015	−0·3
9·26	013·26	−60·7	·023	−0·4
15·28	019·28	−59·5	·030	−0·1
Feb. 9·23	044·23	−56·6	·060	−0·3
26·24	061·24	−55·0	·081	−0·2
Apr. 7·17	102·17	−52·2	·131	+0·5
May 17·11	142·11	−51·1	·179	+0·4
June 19·02	175·02	−50·7	·219	+0·1
July 3·05	189·05	−50·6	·236	−0·1
Aug. 8·05	225·05	−49·6	·280	+0·4
2005 Apr. 19·14	53479·14	−48·3	1·588	−0·1
May 8·11	498·11	−47·5	·611	+0·6
June 14·05	535·05	−48·0	·656	0·0
July 18·04	569·04	−47·8	·697	+0·1
Aug. 25·95	607·95	−47·8	·744	+0·1
Oct. 25·86	668·86	−47·9	·818	+0·2
Nov. 18·81	692·81	−48·1	·847	+0·2
Dec. 8·73	712·73	−48·3	·871	+0·2
2006 Mar. 23·20	53817·20	−60·2	1·998	0·0
Apr. 9·15	834·15	−60·7	2·019	0·0
26·15	851·15	−58·1	·039	+0·3
May 3·14	858·14	−58·2	·048	−0·7
6·14	861·14	−57·3	·051	−0·2
June 12·05	898·05	−54·1	·096	−0·1
28·03	914·03	−52·8	·115	+0·4
July 29·08	945·08	−51·9	·153	+0·1
Oct. 24·89	54032·89	−50·4	·260	−0·2
Dec. 2·78	071·78	−49·9	·307	−0·2

TABLE X (*concluded*)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
2007 Sept. 29·91	54372·91	−47·2	2·672	+0·8
2008 Mar. 31·19	54556·19	−49·5	2·894	−0·5
May 22·10	608·10	−53·1	·957	−0·5
July 1·09	648·09	−61·0	3·006	0·0
24·07	671·07	−58·3	·034	+0·7
Aug. 19·02	697·02	−55·5	·065	+0·4
Sept. 18·91	727·91	−53·6	·103	+0·1
2009 Mar. 30·19	54920·19	−50·2	3·336	−0·7
July 1·06	55013·06	−49·0	·449	−0·2
Oct. 8·88	112·88	−47·7	·570	+0·5
2010 June 23·06	55370·06	−48·4	3·882	+0·3
Aug. 15·93	423·93	−51·1	·947	+0·4
Sept. 15·94	454·94	−57·2	·985	+0·3
20·89	459·89	−58·6	·991	+0·2
Oct. 11·88	480·88	−60·5	4·016	+0·4
27·83	496·83	−58·7	·035	+0·1
2011 Aug. 10·00	55783·00	−49·7	4·383	−0·6
Sept. 14·95	818·95	−49·2	·426	−0·3
29·93	833·93	−49·4	·444	−0·6

*Mt.Wilson photographic observation[59,60]; weight 0.

the spectroscopic $a_1 \sin i$ of 54·4 Gm gives the semi-axis of the primary's orbit as 102 Gm with a range from 78 to 148 Gm (0·68 AU; 0·52–0·99 AU). The *Hipparcos* orbit has $a_0/\pi \sim 0{\cdot}70 \pm 0{\cdot}23$ AU, so the two results are quite consonant with one another, although the significance of the agreement is reduced by the

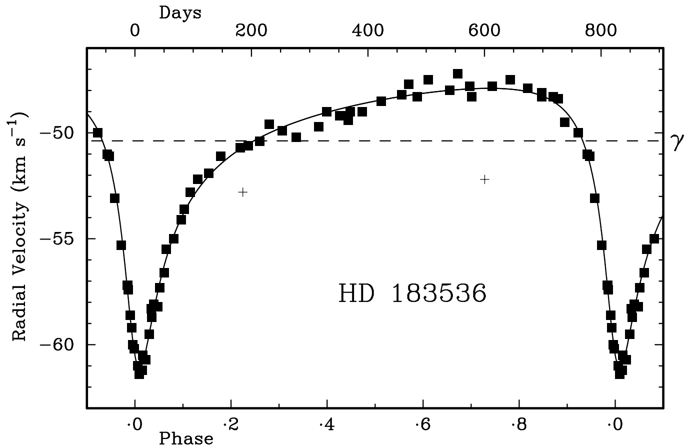

FIG. 10

Orbit of HD 183536. The two plusses (there ought to be three, but one is off the top of the plot) indicate Mount Wilson photographic velocities published by Wilson & Joy[59,60]. They were not used in the solution of the orbit.

laxity of the astrometric elements and the likelihood of correlation between a_0 and i in the derivation of those elements.

The absolute magnitude implied by the parallax is $4^{m}\cdot22$ with an uncertainty of only $0^{m}\cdot09$. Thus the star has the luminosity that would correspond to one of type F9V. Its metal deficiency is no doubt responsible for the fact that in the radial-velocity traces it gives smaller dips than are normal for stars of that type. In fact the mean equivalent width (defined in the same way as equivalent widths in stellar spectra — the area of the 'absorption line') of the dips in traces of HD 183536 is only 2·56 km s^{-1}, which may be compared with the mean of 2·78 km s^{-1} in the case of the preceding star, HD 178593, which being $0^{m}\cdot7$ more luminous is expected to be very appreciably earlier in type. Because the spectra are cross-correlated with a K2 mask in the *Coravel*, equivalent widths normally increase monotonically towards later types throughout the F and G sequence, as the spectra become more similar to the one on which the mask is based. The dips are slightly broadened, by an amount which, expressed as a rotational velocity which is probably its origin, is 3·8 km s^{-1} with a formal uncertainty of 0·3 km s^{-1}. Nordström *et al.*[16] gave $v \sin i = 8$ km s^{-1} from their four observations.

The range of values of $\sin i$ that correspond to the orbital inclination and its 1-σ uncertainties, given above, becomes a very large range, from about 0·019 to 0·22, for the quantity $m_2{}^3/(m_1 + m_2)^2$ when cubed for insertion into the equation for the mass function. If the mass of the primary star is taken to be 1·15 $M_\odot$ (the result is not very sensitive to the small changes that might be plausible to that mass), the central value for the inclination requires a secondary mass of about 0·6 $M_\odot$, while the 1-σ limits are 0·35 and 0·95. Especially in view of the fact that 1 σ does not by any means represent an outer limit to the possible range of the quantity concerned, it seems possible that the mass of the secondary could approach that of the primary, and consequently that the secondary star might give a detectable, even measurable, dip in the radial-velocity traces. No such dip has been noticed, but it would have been intelligent of the writer if he had made an explicit search for one, after the fashion of Fig. 9, near a nodal passage when the primary velocity was at a minimum. Fig. 10 arouses a distinct suspicion that the points exhibit systematic 'dragging' towards the γ-velocity in the relatively shallow slope of the rising branch of the velocity curve — a common diagnostic of a weak unresolved secondary.

There is a star nearly 80″ away from HD 183536, in a position angle close to 240°, that was measured three times out of curiosity; the dates were 2003 April 19·13 and August 17·04, and 2004 July 3·05, and the velocities found were −11·0, −11·0, and −10·8 km s^{-1}, respectively. The object has been identified as *Tycho* 2662-387-1, with $V = 10^{m}\cdot14$ and $(B - V) = 1^{m}\cdot01$.

HD 188307

The literature is even less informative concerning HD 188307 than it is about the preceding stars. The items of potential interest are three papers giving radial velocities — but none of them gives dates. Two of them would in any case not be helpful for determining the orbit, being by Fehrenbach and his collaborators[66,67] and giving means of velocities measured by his objective-prism method; the third one[16] has a mean of −52·1 ± 0·4 km s^{-1} from four observations, whose mutual discrepancies were not quite great enough to demonstrate with certainty the binary nature of the star. There are, however, 65 Cambridge radial velocities, set out in Table XI and yielding the orbit plotted in Fig. 11; the elements are in Table XIII.

TABLE XI

Cambridge radial-velocity observations of HD 188307

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2002 Aug. 17·02	52503·02	−48·9	0·207	+0·6
Sept. 26·85	543·85	−49·5	·286	−0·2
Oct. 12·93	559·93	−49·7	·317	−0·4
Nov. 14·73	592·73	−48·8	·380	+0·6
Dec. 19·76	627·76	−49·2	·448	+0·3
2003 May 6·10	52765·10	−50·6	0·714	0·0
June 19·08	809·08	−51·7	·799	−0·3
July 15·00	835·00	−52·1	·850	+0·1
Aug. 9·01	860·01	−53·1	·898	+0·3
Sept. 10·95	892·95	−56·6	·962	−0·3
22·92	904·92	−57·6	·985	−0·3
Oct. 7·94	919·94	−56·2	1·014	−0·2
17·89	929·89	−54·4	·033	−0·3
27·79	939·79	−52·5	·053	+0·1
Nov. 27·76	970·76	−50·5	·113	−0·1
Dec. 28·78	53001·78	−50·2	·173	−0·5
2004 Apr. 23·13	53118·13	−49·7	1·398	−0·3
May 24·09	149·09	−49·6	·458	−0·1
June 19·04	175·04	−49·6	·508	0·0
July 5·08	191·08	−49·6	·539	+0·1
Aug. 12·99	229·99	−49·9	·614	+0·1
Sept. 4·02	252·02	−50·4	·657	−0·1
25·93	273·93	−50·5	·700	0·0
Oct. 25·86	303·86	−51·1	·758	−0·1
Nov. 26·76	335·76	−51·9	·819	−0·2
Dec. 16·72	355·72	−52·3	·858	+0·1
2005 Jan. 12·72	53382·72	−53·8	1·910	0·0
22·29	392·29	−54·8	·929	−0·2
Apr. 19·15	479·15	−51·1	2·097	−0·3
May 15·13	505·13	−49·9	·147	0·0
June 23·04	544·04	−49·0	·223	+0·5
July 17·08	568·08	−49·0	·269	+0·4
Aug. 25·95	607·95	−49·3	·346	0·0
Oct. 2·89	645·89	−49·2	·420	+0·2
2006 Apr. 9·14	53834·14	−51·5	2·784	−0·2
June 1·11	887·11	−53·1	·887	0·0
22·08	908·08	−54·2	·928	+0·3
July 3·08	919·08	−55·7	·949	−0·1
17·03	933·03	−56·7	·976	+0·3
21·10	937·10	−57·4	·984	−0·2
24·01	940·01	−57·2	·989	+0·1
29·09	945·09	−56·7	·999	+0·3
Aug. 8·05	955·05	−55·4	3·019	+0·1
10·04	957·04	−55·0	·022	+0·2
15·96	962·96	−53·9	·034	+0·2
28·97	975·97	−51·8	·059	+0·4
Sept. 8·00	986·00	−51·3	·078	0·0
Nov. 1·86	54040·86	−49·9	·185	−0·3
Dec. 2·79	071·79	−49·7	·245	−0·3
2007 May 23·11	54243·11	−50·5	3·576	−0·6
June 28·07	279·07	−49·7	·646	+0·5
Dec. 5·81	439·81	−56·0	·957	+0·1

TABLE XI (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O–C)* *km s*$^{-1}$
2008 Jan. 17·74	54482·74	−53·9	4·040	−0·4
July 4·09	651·09	−49·2	·366	+0·2
Aug. 3·07	681·07	−49·5	·424	−0·1
Oct. 10·91	749·91	−49·7	·558	+0·1
27·88	766·88	−50·1	·591	−0·2
Nov. 22·78	792·78	−50·3	·641	−0·1
Dec. 11·82	811·82	−50·7	·678	−0·3
2009 May 30·11	54981·11	−56·5	5·005	+0·2
2010 Aug. 24·07	55432·07	−52·7	5·879	+0·2
Oct. 27·84	496·84	−56·9	6·004	−0·1
Nov. 15·83	515·83	−53·5	·041	0·0
2011 Sept. 14·95	55818·95	−50·1	6·628	0·0
Nov. 9·82	874·82	−50·7	·736	+0·1

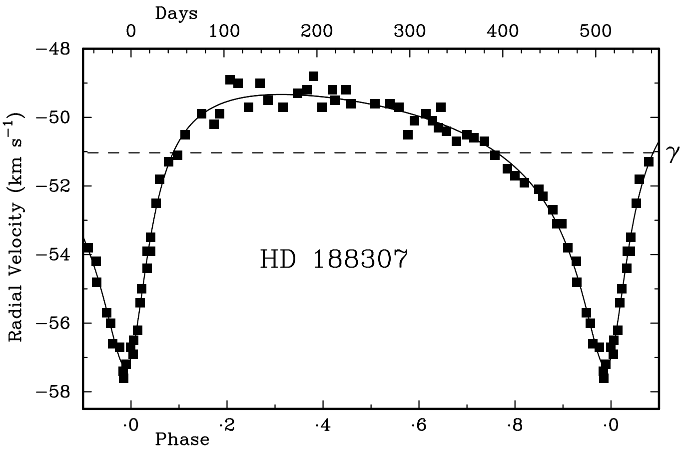

FIG. 11
Orbit of HD 188307.

As usual, the *Hipparcos* period is well within its standard error of the much more accurate one determined here: in this case it is 512 ± 9 days, while the radial-velocity one is 516·40 ± 0·29. This is another system for which *Hipparcos* found a definitely non-zero eccentricity, $e = 0{\cdot}43 \pm 0{\cdot}13$, but the ω of 346 ± 23 degrees seems ludicrously remote from the spectroscopic ω of 202°. The inclination of 142 ± 9 degrees allows the substitution of a (not very accurate) numerical value for $\sin^3 i$ in the expression for the mass function, which is so small that the secondary cannot be expected to contribute appreciably to the luminosity of the system. The parallax points to an absolute magnitude near $4^{\mathrm{m}}{\cdot}07$, suggesting a spectral type of F8 — which is in fact exactly the *HD* type, which seems not to have been superseded — and a mass of about 1·2 $M_{\odot}$. The mass of the secondary then comes out at about 0·25 $M_{\odot}$, such as is appropriate to a star a considerable way down the M-dwarf sequence.

The star has a small rotational velocity that is quantified at 4·6 km s^{-1}, with a formal standard deviation less than 0·3 km s^{-1}; Nordström *et al.*[16] agree, putting it at 5 km s^{-1}.

HD 193554

The *Simbad* bibliography consists of only three papers. There is one by Bartkevičius & Gudas[56], which simply reproduces (twice each!) the parallax and proper motion found by *Hipparcos* and *Tycho*; there is an unsuccessful effort by Mason *et al.*[57] to resolve the system by speckle interferometry; and there is a paper by Guillout *et al.*[68] which refers to a computer-accessible list that has two dated radial velocities of HD 193554. Those velocities (adjusted by +0·8 km s^{-1} to account for differences in zero-point) have been interpolated into their chronological places in Table XII, which otherwise consists of the 50 measurements made with the Cambridge *Coravel*. The Guillot *et al.* velocities have not actually been used in the computation of the orbit, with which, however, they are seen in Fig. 12 to be fully in accord. There are some unusually bad residuals in Table XII; it is not possible to distinguish between stellar and instrumental origins for them, and it seems better to retain them in the solution of the orbit than to reject them for no better reason than that we don't like them and wish that they were not there. Of course they raise the standard errors of the elements beyond those which would pertain if the offending measurements were rejected — but there is justice in that, because the presence of bad residuals does indicate some extra uncertainty in the elements. In the light of that precept, no rejections have been made; the orbital elements are shown in Table XIII.

The *Hipparcos* orbital period is close, to well within its substantial (50-day) uncertainty, to the much more accurate spectroscopic one; the same is true of e and even, this time, of ω. The inclination is given by *Hipparcos* as 36 ± 11 degrees; at the central value, $\sin^3 i$ is just over 0·2. The parallax leads to $M_V = 4^{\rm m}{\cdot}94$, with an uncertainty of only $0^{\rm m}{\cdot}07$, so we might expect HD 193554

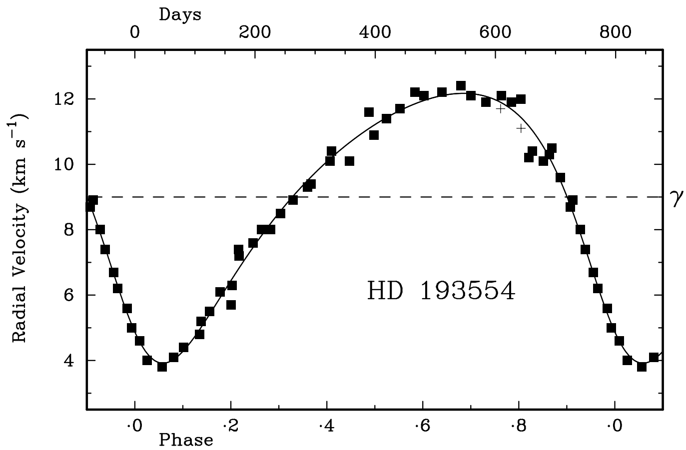

FIG. 12

Orbit of HD 193554. The two plusses plot the velocities of Guillout *et al.*[68], which were not included in the solution of the orbit although they are obviously consonant with it.

TABLE XII

Radial-velocity observations of HD 193554

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2002 Aug. 17·02	52503·02	+8·9	0·913	+0·4
Sept. 26·87	543·87	6·2	·964	–0·1
Oct. 12·93	559·93	5·6	·984	+0·2
Nov. 14·83	592·83	4·0	1·025	–0·2
Dec. 9·77	617·77	3·8	·057	–0·1
2003 May 24·11	52783·11	8·0	1·264	+0·2
June 25·03	815·03	8·5	·304	–0·1
July 16·02	836·02	8·9	·330	–0·1
Aug. 9·02	860·02	9·3	·360	–0·2
15·00	866·00	9·4	·368	–0·2
Sept. 14·91	896·91	10·1	·406	–0·1
Oct. 17·91	929·91	10·1	·448	–0·6
Nov. 27·79	970·79	10·9	·499	–0·3
2004 Jan. 9·72	53013·72	11·7	1·552	+0·1
June 25·04*	181·04	11·7	·762	–0·2
26·06	182·06	12·1	·763	+0·2
July 29·01*	215·01	11·1	·805	–0·3
Aug. 11·08	228·08	10·2	·821	–1·0
Sept. 4·12	252·12	10·1	·851	–0·4
13·89	261·89	10·3	·863	+0·1
Oct. 18·92	296·92	8·7	·907	–0·1
Nov. 4·83	313·83	8·0	·928	+0·1
12·81	321·81	7·4	·938	0·0
26·78	335·78	6·7	·956	0·0
Dec. 26·72	365·72	5·0	·993	–0·1
2005 Jan. 8·72	53378·72	4·6	2·009	0·0
Apr. 19·16	479·16	4·8	·135	–0·2
May 23·09	513·09	6·1	·178	+0·2
June 23·05	544·05	7·4	·217	+0·6
July 17·09	568·09	7·6	·247	+0·1
Aug. 15·07	597·07	8·0	·283	–0·2
2006 Apr. 12·17	53837·17	12·2	2·584	+0·4
June 28·02	914·02	12·4	·680	+0·2
July 14·06	930·06	12·1	·700	–0·1
Aug. 8·07	955·07	11·9	·731	–0·2
Sept. 19·92	997·92	11·9	·785	+0·2
Oct. 24·93	54032·93	10·4	·829	–0·6
Nov. 25·76	064·76	10·5	·868	+0·4
Dec. 9·71	078·71	9·6	·886	+0·1
2007 May 31·09	54251·09	4·4	3·102	+0·1
July 13·04	294·04	5·5	·156	+0·1
Aug. 31·07	343·07	7·2	·217	+0·4
2008 July 4·11	54651·11	12·1	3·603	+0·1
Aug. 3·10	681·10	12·2	·640	+0·1
Dec. 11·79	811·79	12·0	·804	+0·6
2009 Sept. 4·95	55078·95	5·2	4·138	+0·2
Oct. 24·91	128·91	5·7	·201	–0·8
2010 June 11·10	55358·10	11·6	4·488	+0·5
July 10·11	387·11	+11·4	·524	0·0

TABLE XII (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
2011 Sept. 27·89	55831·89	+4·1	5·081	+0·1
2012 Jan. 2·73	55928·73	6·3	5·202	−0·2
June 16·09	56094·09	+10·4	·409	+0·2

*Observed by Guillout *et al.*[68]; weight 0.

to be of type G3 or G4 V and to have a mass of nearly 1 $M_{\odot}$. Inserting the $\sin^3 i$ factor into the expression for the mass function, one finds that the secondary should have a mass of about 0·35 $M_{\odot}$, such as might belong to a main-sequence star of type M2 or M3, about five magnitudes fainter than the primary. The semi-axis of the relative orbit would be nearly four times that of the primary's orbit around the centre of gravity, which (allowing for $\sin i$) is about 73 Gm, so it would be nearly 300 Gm or 2 AU, and would therefore subtend an angle of about twice the parallax or 0″·04 if presented perpendicularly to the line of sight.

Discussion

Remarks about the individual stars are included in their respective sections above; it remains only to refer to the overall comparison of *Hipparcos* and spectroscopic orbits. There is a substantial general disparity in precision between the elements obtained by the two techniques; that is not surprising, since it is apparent, from the fact that *Hipparcos* was able to find orbits for much less than 0·1% of the total number of its stars, that orbit determination was a rather marginal bonus to its main activity. In the comparisons made here, the uncertainties of the spectroscopic elements are relatively so small that it is expedient to regard those elements as being perfectly accurate and to assign any discrepancies to *Hipparcos*; the reader is invited to accept that that is done as a matter of convenience and not of conceit on the part of the author.

In general, the periods derived by the two methods are in agreement. Half of them are within one *Hipparcos* standard deviation, and two more are within 2σ. The two outliers (2·9 and 3·2 σ) refer to the two longest periods, both over 1000 days and thus comparable with or longer than the duration of the *Hipparcos* campaign itself. Those two discrepancies themselves are therefore not surprising, and it is the assessment of their uncertainties that is possibly questionable.

The *Hipparcos* eccentricities are mostly far from accurate. Two of them are smaller than their own standard errors, and three others are less than twice as great, so in those cases they can scarcely be said to be non-zero. The five cases where the eccentricities are significant (2·8–5·9 σ) include four of the five largest values among the ten stars, as established spectroscopically. It might well be expected that where e is not found to differ significantly from zero, the longitude ω of periastron would be effectively indeterminate, with a minimum formal standard error of $\sigma(e)/e$ radians. It has been noted above, in the section on HD 138369, that that precept is infringed in that instance.

In the instances of non-significant eccentricity there is little point in comparing the values of ω; the sample of five is in any case too small for the distribution of discrepancies to be meaningful. On the other hand, unless the

TABLE XIII

Orbital elements (spectroscopic and astrometric) for the ten binary systems

There are two lines for each star. The first gives the spectroscopic elements determined in this paper; the second gives the corresponding quantities, and also a_0 and the inclination, from the Hipparcos Catalogue, Vol. 10, pp. DO1–3. (The Hipparcos figures are rounded here: it does not make any sense to give a standard error to six 'significant' figures.)

HD no.	*P* days	*T* MJD	γ km s^{-1}	*K* km s^{-1}	*e*	ω °	$a_1 \sin i$ Gm	*f(m)* $M_\odot$	a_0 ″·001	*i* °	r.m.s.(wt.1) km s^{-1}
32850	205·800 ± 0·025	53893·2 ± 0·4	+24·95 ± 0·04	10·43 ± 0·05	0·302 ± 0·004	253·5 ± 1·0	28·15 ± 0·14	0·02103 ± 0·00031			0·20
	204·4 ± 2·4	48444 ± 41			0·14 ± 0·24	293 ± 81			10·1 ± 1·3	29 ± 36	
*106516 a	853·2 ± 8·2	46749 ± 70	+4·69 ± 0·14	7·87 ± 0·24	0·046 ± 0·029	201 ± 30	92·3 ± 2·9	0·0421 ± 0·0040			0·65
b	843·9 ± 1·1	47580 ± 47	+4·41 ± 0·09	7·88 ± 0·13	0·041 ± 0·016	196 ± 20		0·0427 ± 0·0021			0·44
c	843·2 ± 0·6	47560 ± 25	+5·37 ± 0·07	7·71 ± 0·12	0·064 ± 0·014	188 ± 11	89·3 ± 1·3	0·0400 ± 0·0018			0·52
	853 ± 8	48515 ± 77			0·081 ± 0·046	53 ± 32			29·0 ± 0·9	73·9 ± 2·4	
110314	1506·4 ± 2·4	53071·4 ± 2·7	+9·22 ± 0·06	10·94 ± 0·08	0·459 ± 0·006	205·2 ± 1·0	201·3 ± 1·7	0·1437 ± 0·0035			0·29
	1132 ± 117	48556 ± 157			0·25 ± 0·09	36 ± 56			21·5 ± 1·2	123 ± 6	
137687	389·92 ± 0·16	53427 ± 3	−92·73 ± 0·04	10·35 ± 0·05†	0·099 ± 0·004	260 ± 3	55·22 ± 0·26‡	0·0442 ± 0·0006§			0·21
	399 ± 6	48339 ± 47			0·20 ± 0·16	246 ± 51			7·7 ± 0·7	46 ± 8	
138369	619·3 ± 1·4	53802·2 ± 3·4	+4·55 ± 0·09	8·39 ± 0·14	0·406 ± 0·014	43·2 ± 2·6	65·3 ± 1·2	0·0290 ± 0·0016			0·53
	616 ± 21	48221 ± 37			0·27 ± 0·22	204 ± 22			17·0 ± 3·3	145 ± 9	
156558	891·4 ± 2·7	53470 ± 11	−50·89 ± 0·04	2·61 ± 0·06	0·246 ± 0·019	96 ± 5	31·0 ± 0·7	0·00149 ± 0·00010			0·27
	883 ± 26	48133 ± 109			0·12 ± 0·16	202 ± 58			11·4 ± 1·2	159 ± 16	
178593	1014·8 ± 1·8	53655·4 ± 2·0	+18·12 ± 0·10	10·70 ± 0·17	0·614 ± 0·009	192·1 ± 1·5	117·8 ± 2·2	0·0634 ± 0·0035			0·57
	897 ± 41	48635 ± 16			0·65 ± 0·11	42 ± 10			16·3 ± 1·9	60 ± 4	
183536	824·40 ± 0·34	53818·8 ± 0·8	−50·38 ± 0·05	6·60 ± 0·07	0·687 ± 0·006	155·3 ± 1·1	54·4 ± 0·7	0·0094 ± 0·0004			0·35
	825 ± 26	48024 ± 14			0·79 ± 0·18	289 ± 22			11·3 ± 3·7	148 ± 12	
188307	516·40 ± 0·29	53945·5 ± 0·9	−51·03 ± 0·04	3·97 ± 0·06	0·616 ± 0·008	201·8 ± 1·5	22·2 ± 0·4	0·00164 ± 0·00008			0·26
	512 ± 9	48260 ± 21			0·43 ± 0·13	346 ± 23			10·4 ± 1·2	142 ± 9	
193554	798·6 ± 2·0	54170 ± 6	+9·00 ± 0·05	4·12 ± 0·08	0·302 ± 0·015	140·2 ± 3·3	43·2 ± 0·9	0·00504 ± 0·00031			0·31
	832 ± 50	48574 ± 51			0·32 ± 0·14	147 ± 39			14·9 ± 1·4	36 ± 11	

*106516 (= HR 4657): (a) Latham *et al.*[36]; (b) Carney *et al.*[37]; (c) this paper †$K_2 = 13{\cdot}15 \pm 0{\cdot}17$ km s^{-1}
‡$a_2 \sin i = 70{\cdot}2 \pm 0{\cdot}9$ Gm §$m_1 \sin^3 i = 0{\cdot}290 \pm 0{\cdot}009\ M_\odot$; $m_2 \sin^3 i = 0{\cdot}228 \pm 0{\cdot}004\ M_\odot$

uncertainty of ω is greatly inflated from other causes in particular instances, one might hope that where e is significant (HD 110314 and the last four stars in Table XIII) ω would be somewhat reliable. That hope is dashed when one looks at the five values of the discrepancies from the spectroscopic ωs, which are, in order, 169, 150, 144, 144, and 7 degrees. Four of the five, therefore, are much nearer to 180° than to 0°! Alerted to that set of discrepancies, Dr. van Leeuwen has kindly explained that, in the *Hipparcos* orbital solutions, reversal of both ω and Ω (the latter being the position angle of the node) usually makes little difference to the quality of the solution, so in many cases there is an inherent ambiguity. An orbit as seen on the sky is unchanged by simultaneous reversal of ω and Ω — what is changed is the rate of progression around it as a function of position in the trajectory.

To a spectroscopist it seems counter-intuitive that a 180° change in ω would have no effect upon T, the epoch of periastron. It is difficult to make a comparison between the spectroscopic and *Hipparcos* epochs just by inspection of Table XIII, because the epochs tabulated in the table from the two methods are in no case the same ones; they ought, however, ideally to differ by an integral number of periods. A comparison has been made by computing the phase corresponding to the *Hipparcos* epoch according to the spectroscopic orbit. The result is that the *Hipparcos* epochs of periastron are surprisingly (to the writer) accurate, even though most of the ωs are apparently mistaken. The phases of the *Hipparcos* T for the five stars with significant orbital eccentricities are, in order, ·003, ·053, ·029, –·010, and –·007. Expressed as multiples of the standard deviations of the respective *Hipparcos* epochs, they are 0·04, 1·31, 0·92, 0·58, and 0·11. Thus *Hipparcos* could evidently determine epochs correctly, even for orbits in which it got ω reversed.

Acknowledgements

It is a pleasure to thank Dr. R. E. M. Griffin for reassurance about evolutionary tracks in connection with HD 137687, and Dr. F. van Leeuwen for the benefit of his unrivalled insight into the complexities of *Hipparcos* astrometry.

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Appendix: the 'orbit' of HD 110897 (HR 4845, 10 CVn)

With a view to demonstrating that the 5·9-day orbit[32] of HD 110897 did not 'hold water', soon after its publication the writer took advantage of a settled spell of weather to obtain measurements with the original radial-velocity spectrometer on the Cambridge 36-inch telescope on seven nights in a one-week spell in 1988 May–June, as shown in Table App. I. They are plotted, together with Abt & Willmarth's observations[32], in Fig. App. 1. For the cosmetic advantage of making them appear at the level of the supposed γ-velocity, they have been subjected to an empirical adjustment of $-1{\cdot}8$ km s^{-1}. They are seen not to support the orbit; in fact their r.m.s. spread is only 0·4 km s^{-1}, unusually small for the original spectrometer. A subsequent study by Duquennoy & Mayor[69] of the multiplicity of bright solar-type stars included HD 110897 and judged (as here) that its velocity is constant. Comparatively recently, Abt & Willmarth[70] themselves have undertaken another such investigation and come to that same conclusion, making no reference to their earlier work at all.

TABLE APP. I

Cambridge radial-velocity observations of HD 110897 (10 CVn)

Date (UT)	*Velocity km s^{-1}*
1988 May 26·95	+79·0
27·92	79·7
28·88	79·9
29·94	78·9
30·94	79·3
31·98	79·1
June 2·95	+78·8

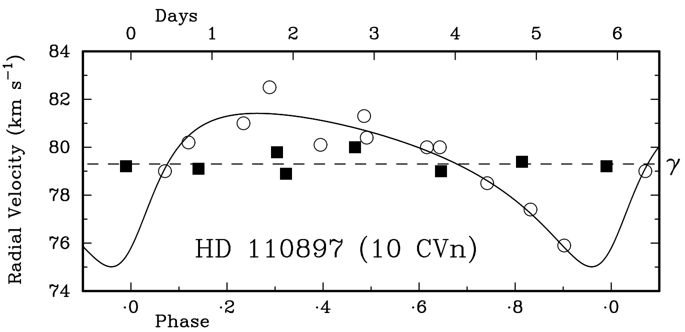

FIG. APP. 1

The open circles show the data upon which Abt & Willmarth[32] divined the orbit indicated by the curved line. Filled squares represent measurements obtained with the original spectrometer at Cambridge, all within an interval of one week.

Note added in proof. The reference noted as absent in the section on HD 110314 has been located: it is T. S. H. Graham, *JRAS Canada*, **12**, 129, 1918. It gives velocities for 20 stars, obtained by an experimental objective-prism method and each measured four times from the same plate, and is not useful for the present (if any!) purpose.

CORRESPONDENCE

To the Editors of 'The Observatory'

The Rays are not Coloured

In a review of the book *Treasures of the Southern Sky* (*The Observatory*, 2012 August, p. 280) Colin Cooke notes that "colour is such a dominant feature of the photographs" and questions "whether reality in deep space is truly as kaleidoscopic as it is here portrayed."

Isaac Newton gave the answer three centuries ago: "For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour."[1] Yet, even today, the cone cells of the retina are widely considered to be "colour receptors", as if colours existed in the external world.

When viewing photographs such as those in *Treasures of the Southern Sky*, most people are unaware that they are attributing a unique property of the neural photograph in their brain to the external photograph in their hands, and subsequently to the object portrayed in the photograph. Properly speaking, the nebulae depicted in *Treasures of the Southern Sky* are not coloured, and neither are the photographs. The camera or eye does not detect colours; the brain creates them. Prior to the evolution of life forms possessing frequency-discriminating vision, colours did not exist.

Yours faithfully,
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The Colour Black and the Planet Saturn

In the 2011 August issue, Richard Stothers[1] put forward an alternative scenario for the colour black assigned in ancient times to the planet Saturn. He does not champion the idea[2] that it was due to the Saturnian Phoebe Ring. The alternative scenario derives from Babylonian cuneiform (omina) texts referring to Saturn as black or dark, and as 'night-sun'. He links 'night-sun' with disceus — a comet likened to the Sun and analogous with Saturn.

According to omina texts of the Babylonians, blackness and darkness are eclipse colours in relation to the direction South[3]. The Babylonians also combined the colour black with a shooting star or meteor[4]. Lying to the South is the path of ten stars and the Sun road[5]. The latter, in the context of black or dark, is analogous with the Sun in the lower hemisphere, to which Macrobius refers[6].

Black as a dominant colour of planet Saturn — son of the Sun — occurs also in India. There Saturn figures with Rahu and Ketu, the lunar ascending and descending nodal points[7]. The head of Rahu relates to solar and lunar eclipses; the tail of Ketu heralds meteors and comets.

From the available evidence, it appears blackness or darkness assigned to Saturn links with the Sun in the lower hemisphere, and, in India, with the lunar nodes and associated occurrences of extra-terrestrial phenomena.

Yours faithfully,
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REVIEWS

Galileo, by J. L. Heilbron (Oxford University Press), 2012. Pp. 508, 23·5 × 15·5 cm. Price £12·99 (paperback; ISBN 978 0 19 965598 4).

Although this biography has been widely praised, and is undoubtedly a work of great scholarship, as someone who is not an astronomical historian, I must say that I did not find it an easy read. This is not just because this involves understanding, to a certain extent, the complexities of the relationships between the various Italian states at that period, the different degrees to which liberal views were encouraged (or suppressed) in Tuscany, Venice, and Rome, and the complex heirarchy of religious orders (with Jesuits and Dominicans at the top) and their internecine feuding. Heilbron handles all these ramifications well, and is obviously a master of the subject as borne out by more than 120 pages of notes and references.

No, some of the problems in reading this book arise from a simple cause. Surprisingly, for a work published by Oxford University Press, the editing is, in places, very poor. There are a number of instances where punctuation, vital for a correct and easy understanding of a sentence, is simply missing. Even worse, perhaps, are the problems with quotations. It is regrettably too common for it to be difficult to determine whether words are to be attributed to Heilbron, Galileo, a third party, or whether they are Heilbron's imagined reconstructions of someone's words. The wide-scale omission of quotation marks makes these even more disconcerting.

There are one or two instances where the text is rather inelegant, such as the point (p. 116), regarding Sarpi's theory of tides, where it is said that it "... corresponded perfectly with the nature of Galileo." However, Heilbron immediately, in one of many appropriate comments, says: "And, also characteristic of many of Galileo's simplifications, it was wrong."

But what of Galileo himself? To someone primarily familiar with Galileo's astronomical and scientific contributions, this work is particularly valuable in the insight it gives into Galileo as a person. It shows how, after an initially fairly dissolute life-style, he developed a confidence in his own intellectual ability, and a self-righteous, somewhat arrogant attitude towards others, which was, of course, eventually to lead to his confrontation with the Church and his downfall.

Many aspects of Galileo's character are explained, and one of the most interesting — to me at least — is the fact that some judge him to be a great master of Italian prose, second only to Machiavelli, and that his commentaries on Ariosto and Tasso are still considered essential reading. The clarity of his prose was, in fact, a factor held against him when he was eventually questioned by the Holy Office about having been forbidden to hold or promulgate the Copernican theory of the Universe. As Heilbron puts it (p. 310) "The celebrated clarity of Galileo's prose left him no hiding place."

There was however, a lighter side to Galileo's writing, exhibited at one stage by a diatribe against the compulsory wearing of academic gowns, and his riposte by way of a lampoon in the dense Paduan dialect, to the philosophers Cremonini and Lorenzini, who had attacked peripatetic scholars' reaction to the 'nova' (*i.e.*, the supernova) of 1604.

Galileo's intellectual arrogance is made clear in his treatment of various scholars, such as Kepler and Scheiner; his refusal to have any contact with Tycho Brahe; and the way in which he appropriated the credit for others' discoveries (such as the actual invention of the telescope, the discovery of sunspots, and that the Galaxy consisted of innumerable stars). It also appears in the opportunistic way in which he exploited the discovery of the Medicean stars to gain a position in Florence, discounting his recent substantial promotion by the Venetian state. Later, it would appear that he had persuaded himself that, contrary to the strict injunction that he had received in 1616, he alone could ensure that the Church did not fall into the error of rejecting Copernican views.

To modern views, it seems extraordinary that the controversy that surrounded Galileo's book *Il Saggiatore* (*The Assayer*) in which he criticized the book on the comets of 1618 by the Jesuit mathematician, Orazio Grassi (whose views were actually correct), should have been couched in terms of arguments over the eucharist and transubstantiation. Heilbron sets such matters, and Pope Urban's intransigent attitude towards Galileo that eventually led to his trial in 1632/33, within the context of the Counter-Reformation and the complex religious opinions of the time. I am somewhat disconcerted, however, by Heilbron's final sentence (p. 365) "Who can doubt that within another 400 years the church will recognize Galileo's divine gifts, atone for his sufferings, ignore his arrogance, and make him a saint?" I find it depressing that some 400 years after the injunction on Galileo not to hold, discuss or teach Copernicanism, "because it contravened scripture and the teachings of the holy fathers", modern-day Muslim medical students should be encouraged to demonstrate against being taught evolution, because it is "against the tenets of Islam". Galileo may not have said *Eppur se muove*, but we might say with Karr, *Plus ça change, plus c'est la même chose*. — STORM DUNLOP.

Fritz Zwicky: An Extraordinary Astrophysicist, by A. Stöckli & R. Muller (Cambridge Scientific Publishers, Cottenham), 2012. Pp. 258, 25 × 17·5 cm. Price £40 (hardbound; ISBN 978 1 904868 78 1).

An alarming 45 years ago — *tempus fugit*! — I was in the process of writing a small research essay on supernovae for my undergraduate degree. The name of Fritz Zwicky appeared regularly in my reading and it was clear that at the time, and for some while previously, he was one of the leaders in the field. He had made finding supernovae a priority at Palomar, first with the 18-inch Schmidt that he had a large hand in constructing, and afterwards with the 48-inch. Those data provided the first real statistics on the occurrence of those important objects, and the photometry, in conjunction with spectroscopy, allowed Zwicky to derive a classification scheme involving five classes (now whittled down to two). He also featured in early research on pulsars, being a pioneer proposer (with Baade) of neutron stars, just one year after the discovery of neutrons by Chadwick. Around the same time, on the basis of applying the Virial Theorem to the motions of galaxies in clusters, he was way ahead of the game in proposing the existence of Dark Matter. And later, he was heavily involved in cataloguing compact galaxies, just at the right time to provide optical input to the radio hunt for quasars.

But Zwicky was a gadfly not just in astronomy. Showing exceptional intelligence and ability from an early age, he later worked in solid-state physics, and perhaps more importantly in rocketry, where, at least early on, he was taken seriously by the US Government. In fact, he had novel ideas in all sorts of fields, some sound, some rather more fantastical. It's clear that he had a mind that worked rather differently from those in the mainstream, and his approach to almost everything came to be encapsulated in his 'Morphological Method'. This seems to involve applying an holistic eye to solving problems, where one creates multi-dimensional grids of parameters that need to be considered prior to zeroing in on a solution. In astronomy, this was the subject of his Halley Lecture (recorded in these pages: **68**, 121, 1948), while the technique is detailed in his book *Morphological Astronomy* (Springer, 1957) and outlined in the present volume in a 'chapter' by author Stöckli.

These topics are all covered in this fascinating book, which takes the form more of a diary of Zwicky's life than a biography. Thus it jumps from topic to topic, reflecting the extremely busy schedule he adopted, rushing all over the world, but especially around the USA and his beloved Switzerland. The text is accompanied by many photos — of people, places, and documents — which provide a nice background to the story. For astronomically inclined readers, there is a 'chapter' by Straumann & Tammann summarizing the astrophysical legacy of Zwicky; and clearly the authors, Stöckli & Müller, are still in awe of Zwicky, who died in 1974, and perpetuate his methods and memory in the Glarus (Switzerland)-based Fritz Zwicky Foundation.

While Zwicky was respected and admired in many quarters for his ideas and work — he received the RAS's Gold Medal in 1972 — he clearly had a strong personality, which made some find him difficult to deal with. But astronomy needs such characters to remind us that simply following the 'thundering herd' is not always the right way forward. — DAVID STICKLAND.

How It Began: A Time-Traveler's Guide to the Universe, by C. Impey (W. W. Norton, London), 2012. Pp. 434, 24 × 16·5 cm. Price £17·99 (hardbound, ISBN 978 0 393 08002 5).

Most books which (incompletely) cover the entire history of the Universe usually adopt an historical approach, either with respect to human history, *e.g.*, from the ancient Greeks through the Renaissance to modern times, or with respect to the history of the Universe, starting at the Big Bang and working up through galaxy formation to the recent history of the Solar System. Impey adopts the latter approach, but with a twist, starting at the Moon and moving outward in space and of course backward in time (hence the sub-title). In addition to the novelty, this is probably a good approach for the target readership (the "interested layman"), moving from the more to the less familiar. How the various things discussed — planets, galaxies, the Universe — began is mentioned but this is just one aspect of the narrative.

There are three parts with five chapters each — essentially the Milky Way and things within it, extragalactic astronomy, and the early Universe — though there are some chapters which depart somewhat from the spatial/temporal theme: on black holes, accretion-powered energy sources, life, and the multiverse. Rather than discussing everything in almost no detail, various aspects are highlighted: the human-interest angle of manned space flight, recent developments (*e.g.*, extrasolar planets), *etc*. This, along with personal anecdotes, makes the book more than just an update on what we know about the Universe and how it came to be; even someone familiar with most of the material will learn something new. Presumably some of the emphasis reflects the interests of the author, and this comes through well. The style is casual; however, there are a few too many metaphors for my taste, some of which are stretched a bit too far. Apart from the occasional $E = mc^2$, there are no equations, but some back-of-the-envelope calculations are carried out in the text; these illustrate some basic principles without becoming too technical. A good point is the inclusion of an index.

There are a few dozen black-and-white photographs, graphs, and line drawings. This is about the right number and these are all well done. High-quality, glossy, colour photographs would have been more impressive, but as these are readily available on the web, it was a wise decision to include none and keep the price reasonable. There are 54 pages of notes (about one-eighth of the total number of pages), which is good for someone like me who likes notes. A few of these are just references, but most are several sentences of additional material. A book like this really needs them, so that the basic narrative can unfold without becoming bogged down in details, but the details are there for those interested in them. However, this means much flipping back and forth; it would have been better to have them as footnotes.

Each chapter begins and ends with vignettes describing a dream. These allow for some poetic licence, but in general I think that they add too little to the text and are somewhat distracting. However, altogether these make up only a small number of pages. More annoying are a few dozen passages which are unclear, confusing, or wrong. These are almost certainly not errors on the part of the author but rather of the editing process. Someone familiar with the material will notice these and be distracted from the narrative; someone not probably won't notice them during casual reading, but might when following up a topic in more detail. The book could have been better edited and hopefully these problems will be corrected in future editions.

In summary, I recommend the book for those interested in an overview of our current knowledge of the Universe and how it began. — PHILLIP HELBIG.

Ancient Astronomical Observations and the Study of the Moon's Motion (1691–1757), by John M. Steele, (Springer, Heidelberg), 2012. Pp. 168, 26 × 18 cm. Price £81/$124/€89·95 (hardbound; ISBN 978 1 4614 2148 1).

Like all sciences, astronomy has a history. But there is a difference. Old astronomical observations can sometimes be of considerable importance. Take star positions. The proper motions of the stars would not have been discovered in the 18th Century if Edmund Halley, England's second Astronomer Royal, had not believed in the veracity of much-earlier observations. He realized that the relative differences in certain stellar positions over the millennia were significant, and not just a matter of early observational errors. Another example was the timing of ancient eclipses. Extrapolating to these early observations from contemporary data led Halley to suggest that the Moon was accelerating along its orbit and that the Earth–Moon distance was changing.

It is this latter suggestion, made in 1695, that Professor John Steele (an expert on Mesopotamian astronomy, now at Brown University, Rhode Island, USA) has used as a test case for the blossoming of the study of ancient Greek, Arabic, Babylonian, and Chinese observations by 18th-Century European astronomers such as Richard Dunthorne, Tobias Mayer, and Jérôme Lalande. His book is scholarly, thorough, well referenced, and eminently readable. It is a fascinating tale built on a detailed study of primary sources and previously unstudied manuscripts. We see how Halley's casual aside, in a paper on the ruins of the ancient city of Palmyra (in central Syria), was at first ignored, but subsequently followed by a detailed analysis of historical evidence trying to establish an actual value for the acceleration and finally an attempt to understand the underlying physics of the phenomenon. — DAVID W. HUGHES.

Interplanetary Outpost, by E. Seedhouse (Springer, Heidelberg), 2012. Pp. 281, 24 × 16·5 cm. Price £35·99/$39·95/€39·95 (paperback; ISBN 978 1 4419 9747 0).

Maybe I'm getting old and cynical, but it seems as though everything these days promises a lot and delivers nothing but disappointment. First this year there was Ridley Scott's *Prometheus*, and now this: *Interplanetary Outpost*, a book by Erik Seedhouse, purports to be a study of the future manned exploration of the outer planets with a view to finding extraterrestrial life. If I may, I'll quote the blurb on the back cover: "Water has been discovered on the Saturnian moon Enceladus, and on Jupiter's moons, Europa, Ganymede, and Callisto. Where there is water, could there be life?"

With this thrilling question pulsing through your veins, let me tell you that this book dismisses all but one of those locations from consideration in the first chapter, and doesn't discuss Ganymede in any depth at all. Indeed, the back cover appears to be only one of a few instances where the word Ganymede appears.

In fact this book is a tedious, stupid, and ultimately pointless rehash of an engineering study that was concerned entirely with setting up a manned base on Callisto. Whilst I have nothing but respect for engineers, and particularly those who have designed and built the most incredible vehicles of planetary exploration, their NASA study obviously plumped for the safest option for a manned outpost in the outer Solar System. Unfortunately this also happens to be one of the least interesting locations in the outer Solar System. In using only this report as a basis for his book, Seedhouse finds himself in the preposterous position of having to justify a mission to Callisto over any other possible location on scientific grounds. This is *attempted* by either glossing over everything interesting about the other possible icy destinations — the geysers of Enceladus, the ocean and icy volcanoes of Europa, the ocean and amazing tectonics of Ganymede (not to mention its metal core and magnetic field) — or by making ludicrous claims about the hazards. For example, Titan is ruled out because of the "choking smog" in its atmosphere, as if we went to the Moon for its sweet alpine air!

This is all over and done with in the first twenty pages, after which I just wanted to throw the book in the bin. However, it then settles down into a bizarre mixture of boring prose, useless tables, and science fiction. Not just small bits of science fiction, I mean pages of shooting script from movies like *Avatar* and *Pandorum*. There are sentences such as "...this is the 2040s, by which time genetic screening will most likely be as commonplace as it was in the film *Gattaca*," which is accompanied by a gratuitous picture of Ethan Hawke. There are also pictures of the cast of *Solaris* (the new one, not the original), *Alien*, and *Moon*; oh, and there's a picture of a squirrel. Yes, you read it correctly, there's a half-page colour picture of a squirrel. I have no idea what purpose any of these images serve. Equally pointless are the tables that will probably be anachronistic ten years from now let alone in the decades when any of this might come to pass: the table of algorithms for navigating over alien terrain, for example — you might as well have asked the Wright Brothers to come up with the protocols for a modern airliner's instrument-landing system.

Whatever you do, don't waste your money on this. — DOMINIC FORTES.

Our Explosive Sun, by P. Brekke (Springer, Heidelberg), 2012. Pp. 168, 21 × 20 cm. Price £26·99/$29·95/€29·95 (hardbound; ISBN 978 1 4614 0570 2).

In his preface, the author tells us that he has long been fascinated by the Sun, and expresses the hope that his book will inspire an increased interest in both the Sun and natural science in general. This suggests that his book is targeted at those with little or no previous knowledge of those subjects, and a study of its contents bears this out. The Sun as a star, its place in the Solar System, how it works, and its impact upon the Earth and on humans are successively described at an elementary level; but the book is far from being the dull basic primer suggested by this summary. Proclaimed on its cover as a "Visual Feast", it lives up to this boast with many more pictures than text upon its pages; and these, which are vivid, instructive, and colourful, together with the compact, stylish, and attractive presentation of the book itself, make for an unusually enjoyable albeit light-hearted publication.

The illustrations, a few being photographs but the majority diagrammatic, are exuberant in their use of colour and imaginative in their display of information, and the descriptive text accompanying them is brief and simply expressed. A few "Fun Facts" are inserted here and there (*e.g.*, driving a car to Proxima Centauri at a steady 100 kph will take 47 million years), and the author's wish to entertain as well as inform is readily apparent. I found the book particularly helpful about the Aurora Borealis, with appropriate reference to the Terella experiment of the pioneering Norwegian scientist Kristian Birkeland, clear diagrams of the Earth's magnetosphere doing its good work, and a fine illustration of polar lights on Jupiter and Saturn; and I was also interested to learn of the Aurora-related rocket research at Andøya and the associated ALOMAR project.

My only reservation concerning this book is its occasional use of wording which is exuberant rather than precise. Its very title, *Our Explosive Sun*, is not only alarming but in astronomical parlance downright wrong, and for the same reason the chapter heading 'The Sun: a variable star' and the page heading, 'When the Sun went berserk', both imply a situation which is hardly compatible with our continued existence. Other examples of 'could do better' are on page 38, where we are told that "energy is created" in the core of the Sun (why not "mass is changed into energy"), and page 66, where it is stated that the USA "confiscated German V2 rockets and used them for science". Wernher von Braun would hardly agree that he was confiscated, Russia also obtained much German V2 know-how, and any scientific use of rockets was secondary to cold-war defence for many years after the war. And we are told on page 78 that solar eruptions can eject "several billion tons of particles corresponding to 100,000 large battleships". Writing as someone who once served in battleships I have to point out ruefully that this is no longer a meaningful simile (and in the context I doubt that it ever was).

It is perhaps a little unfair and even pontificatory to make these points, given that the author is not writing a textbook or addressing experts, but rather presenting an exciting topic to a largely ignorant audience in a manner intended to win their interest and fire their enthusiasm, but it is hard to over-value the merit of accurate language in writing about astronomy or cosmology, particularly since quantum physics became involved (the more inherently incomprehensible a subject is, the more one must attempt linguistic precision). But in general terms I enjoyed the humour and ebullience with which this book has been written — there is a splendid picture on page 125 of power cables leading directly from the Sun to Earth — and would not hesitate to present a copy to a young relative not yet aware of the wonders of the Solar System. — COLIN COOKE.

New Eyes on the Sun, by J. Wilkinson (Springer, Heidelberg), 2012. Pp. 260, 23·5 × 15·5 cm. Price £31·99/$34·95/€34·95 (paperback; ISBN 978 3 642 22838 4).

The Sun has been studied by humans since time immemorial, whilst records of sunspot observations by ancient civilisations go back several millennia. However, the coming of the Space Age has revolutionized scientists' understanding of our nearest star. In recent years, increasingly sophisticated space observatories, complemented by advanced ground-based instruments, have carried out 24-hour surveillance of the Sun at multiple wavelengths. Today, it is possible to observe the entire Sun — including the far side, which has usually been hidden from Earth-based observers — and to probe deep beneath its visible surface. Spacecraft also record changes in the solar wind and sudden outbursts which send radiation and enormous clouds of plasma streaming into interplanetary space.

Written by an Australian science educator and amateur astronomer, this book provides a broad overview of our current knowledge of solar physics for the general reader. However, the author's stated primary objective is to present a guide to satellite images and amateur observation. Although one section describes some techniques and equipment which amateurs can use to observe the Sun, most of the chapters are devoted to general descriptions of the Sun and the wide variety of solar phenomena. The author also makes a point of referring to Sun-observing satellites and the spacecraft data which can be accessed by the general public on various websites. Also included is a short chapter which attempts to discuss the role of solar activity in global climate change, and another which looks at star formation and stellar evolution.

The book is well illustrated, including numerous colour images, and the text is clear and concise. The editing is a little careless in places, and some of the text seems to have been written a few years ago: for example, the ESA–NASA *Ulysses* mission and the Japanese *Yohkoh* mission are described as if they are still operational. However, the author has succeeded in his objective of bridging the gap between advanced astrophysics and elementary knowledge of the Sun, reaching out to a readership of amateur enthusiasts who may seek to enjoy "the growing hobby of Solar Astronomy". — PETER BOND.

The Sun, the Stars, the Universe and General Relativity, edited by S. E. Perez Bergliaffa, M. Novello & R. Ruffini (Cambridge Scientific Publishers, Cottenham), 2012. Pp. 250, 25·5 × 18 cm. Price £60 (hardbound; ISBN 978 1 908106 12 4).

In 1919, Andrew Crommelin of the Greenwich Observatory led an expedition to Sobral in Brazil to observe a total eclipse of the Sun and verify the General Theory of Relativity. Ninety years on, in the International Year of Astronomy, a conference was held in Fortaleza, Brazil, to celebrate those events and Brazil's other involvements in high-energy science. Thus 'Sobral 2009' was an opportunity to highlight the emergence on the world stage of a rapidly developing country with enormous potential in astronomy as well as in many other areas, making these well-produced proceedings a benchmark from which to chart future progress.

We learn here something of Brazil's interest in observational astronomy with the development of the *SOAR* telescope, now located on Cerro Pachón in Chile, and in some of its theoretical interests. However, well over half of the book is given over to a very substantial review by Ruffini *et* many *al.* on 'Black hole energetics and GRBs', which on its own makes the book worthy of consideration for your library. — DAVID STICKLAND.

The Fourth Hinode Science Meeting: Unsolved Problems and Recent Insights (ASP Conference Series, Vol. 455), edited by L. R. Bellot Rubio, F. Reale & M. Carlsson (Astronomical Society of the Pacific, San Francisco), 2012. Pp. 376, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 792 6).

The fourth in the annual series of *Hinode* science meetings was held in Palermo, Italy, in 2010 October, the first to be held in continental Europe. As with previous meetings, and reflecting the now-huge fleet of solar spacecraft, there is a large variety of subjects covered in this volume. Some of the papers actually rely more on data from the *Solar Dynamics Observatory*, then recently launched, the images of which complement those from the three main instruments of *Hinode*.

The papers on the possibility of small-scale dynamos in the Sun, based on observations from *Hinode*'s *Solar Optical Telescope* (*SOT*), are among the more interesting of the contributions. With the increase in solar activity by the time of this conference, studies of sunspot evolution using the *SOT* data as well as high-resolution ground-based observations are evidently becoming much more sophisticated than was possible before *Hinode*; three good summaries of observations are included in these proceedings. Emerging flux as active regions develop has become a major field since *Hinode*, with several papers covering this aspect. Much work has followed the discovery of outflows at the boundaries of active regions using the *EIS* instrument on *Hinode*, and summaries, including the connection with the slow solar wind, are given in a couple of papers here. The old question of nano-flare *versus* wave heating of the corona, particularly in active regions, has an airing in a brief discussion using X-ray images from *Hinode*'s *XRT* instrument.

The large range of subject material and the generally high quality of the papers are a recommendation for this volume. There has been some delay in getting the proceedings published, but the result is more polished than the proceedings of the Fifth Science Meeting which has appeared at almost the same time. — Ken Phillips.

The Fifth Hinode Science Meeting: Exploring the Active Sun (ASP Conference Series, vol. 456), edited by L. Golub, I. De Moortel & T. Shimizu (Astronomical Society of the Pacific, San Francisco), 2012. Pp. 246, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 794 0).

Hinode science meetings have occurred at annual intervals since the launch of the Japanese spacecraft in 2006 and have carried various themes appropriate to the interest shown at the time. The prolonged solar minimum of 2009 meant a lot of re-thinking of science priorities for *Hinode*, but by 2010 solar activity had increased to a level that enabled much research into a number of fields. These proceedings reflect this, with 49 papers covering observations from the *Solar Optical Telescope* (*SOT*), *X-ray Telescope* (*XRT*), and *Extreme-ultraviolet Imaging Spectrometer*, the three major instruments on *Hinode*. There are also many papers summarizing numerical simulations that play a major role in supporting the observations.

There is a wide variety in the quality and length of papers in these proceedings which makes me hesitate to recommend this to a general readership. A large number (27) of the papers are just two or three pages long, just enough to express the summary of the authors' work and a couple of diagrams. Sometimes this is useful, such as the detection of X-ray-bright points (by Pucci *et al.*) and possible identification of current-sheet features (by Takasao *et al.*), both in images from the *XRT* instrument. For many other papers the text is so short it was difficult even to get a flavour of the work being done.

The four sections of the proceedings cover magnetic fields (based on measurements by *SOT* but including simulations), energy transport (though most papers are on observational topics such as active regions and differential emission measures), instabilities (coronal mass ejections, flares, *etc.*), and "future needs" (a collection of three papers that appear not to fit in the other categories). Each of the first three sections has what might be regarded as a keynote paper, though the 32-page-long paper by Steiner & Rezaei on vortical flows in granules that starts the proceedings does not sit well with the remaining papers of the magnetic-field section.

In their *Preface*, the editors discuss the introduction of "e-posters" during the conference, which received much approval from the attenders who voted on this innovation. One wonders whether "e-Proceedings" may soon take the place of printed versions which, in this particular case, has but limited value in view of the fact that most likely many of the papers in it will soon be published or have already appeared in established journals. — KEN PHILLIPS.

Pulsar Astronomy, 4th Edition, by A. Lyne & F. Graham-Smith (Cambridge University Press), 2012. Pp. 345, 25 × 18 cm. Price £85/$140 (hardbound; ISBN 978 1 107 01014 7).

After 45 years it is gratifying to see that pulsar astronomy continues to be an active and fruitful field now covering the whole of the electromagnetic spectrum from radio- to gamma-wave energies. As the number of catalogued pulsars approaches 2000 the only new phenomenon to have been observed since the last edition (2006) is the discovery of pulsars which emit rare, single pulses at intervals of a few minutes to several hours, which makes them hard to detect. These are known as RRATs (rotating radio transient sources). An interesting historical aside, which could have been mentioned, was the observation of pulsed radiation from the Crab Nebula by Charles Schisler in mid-August 1967 when he was manning a ballistic-missile early-warning radar in Alaska. The discovery was not publicized because of secrecy regulations and was first reported in 2007 at a conference held at McGill University in Montreal.

This concise, authoritative, and readable introduction to the whole of pulsar astronomy will be invaluable to advanced students and teachers alike. The authors are hands-on observers with a background in physics and their intention is to provide a guide rather than an encyclopaedia. The 4th edition follows the same pattern as before but has been substantially revised and updated. It contains a considerably larger bibliography of around 900 references corresponding to an increase of 30%. The catalogue of pulsars has been omitted as this is now readily available on a website. — ANTONY HEWISH.

Numerical Modeling of Space Plasma Flows: ASTRONUM–2011 (ASP Conference Series, Vol. 459), edited by N. V. Pogorelov, J. A. Font, E. Audit & G. P. Zank (Astronomical Society of the Pacific, San Francisco), 2012. Pp. 381, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 800 8).

The sixth annual international conference dedicated to the numerical modelling of plasma flows in cosmic contexts, ASTRONUM–2011, was held in 2011 June in Valencia, Spain, attracting around 100 participants. This volume contains 6–8-page summaries of 57 papers presented at the meeting, produced in high-quality colour throughout, as required to illustrate the modelling results presented. The papers are divided into four principal sections, centred on plasma turbulence as a critical element, *e.g.*, in star formation and cosmic-ray transport, astrophysical flows, space-plasma flows in the Solar System context, and papers focussing more on technical aspects such as the efficient parallelization of adaptive-mesh-refinement algorithms. The section on astrophysical flows contains contributions on a wide variety of topics, including star formation in molecular clouds, merging neutron stars, core collapse in supernovae, and accretion discs, illustrating the range of physics that must variously be included over and above standard MHD, such as the effect of intense radiation fields, General Relativity, neutrino physics, and the coupling to dust. The space-plasma research, on the other hand, concentrates on 'real-life' modelling using remote-sensing observations as driving conditions, specifically photospheric measurements as evolving boundary conditions for models of the solar corona, and interplanetary-scintillation measurements for models of the outer heliosphere. Modelling the terrestrial ionosphere and its extension along field lines into the plasmasphere and polar wind is also discussed, parameterized through geomagnetic indices. Overall, this volume presents a timely snapshot of the present status of numerical modelling research in astrophysical and space-plasma flows, and will be of interest to anyone wishing to gain a broad if terse insight into this highly active research area. — STAN COWLEY.

Simulations of Dark Energy Cosmologies, by E. Jennings (Springer, Heidelberg), 2012. Pp. 122, 24 × 16 cm. Price £90/$129/€99·95 (hardbound; ISBN 978 3 642 29338 2).

The on-going increase in the size and quality of galaxy surveys means that they are increasingly capable of performing exciting and fundamental cosmological measurements. To do this, they rely on matching observations of galaxy clustering to theoretical predictions. The methods and results presented in this thesis lie at the forefront of work turning unknown physical parameters in the Universe, such as the exact way in which the expansion of the Universe is accelerating (described by a parameterization of the dark-energy equation of state, w), into predictions that can be tested against data coming from surveys. The first part of the book is, in effect, a recipe book for performing N-body simulations of the Universe allowing for a time-dependent dark-energy equation of state (essentially allowing for modern theories for the physical laws that may govern the observed acceleration). The next part of the book takes these fake Universes and "makes observations" from them, showing where they deviate from simple prescriptions that have previously been compared with data. The importance of the work presented is two-fold. Firstly, it clearly shows that care needs to be taken when comparing models to data: simple prescriptions are shown to be limited in applicability. Secondly, when surveys such as the ESA *Euclid* mission, described in the supervisor's foreword, happen, then it is important that we make sure the theories tested against the data are as accurate as the data: with increasing data quality, we need increasing model accuracy. The work presented here shows the way forward for this modelling when used with forthcoming galaxy-survey data. — WILL PERCIVAL.

The Fourth Source: Effects of Natural Nuclear Reactors, by Robert J. Tuttle (Universal Publishers, Boca Raton), 2012. Pp. 556, 24·5 × 18 cm. Price $49·95 (about £32) (paperback; ISBN 978 1 61233 017 8).

Robert Tuttle's universe is the smallest at least since the time of Kepler. For him, those twinkling things are not sun-like, but more nearly asteroids; the spiral nebulae are the products of nuclearly exploded planets; and the *HST* was not suffering from spherical aberration but from trying to look at nearby sources when its users were expecting photons coming very nearly from infinity. He indicates that the *New Technology Telescope* at La Silla and the *CFHT* in Hawaii had similar problems for similar reasons, when they first came on line, but that their mirrors were flexible enough to be bent into focus.

Virtually every page has similar surprises — nearly all the animals (including hominids) surviving the Younger Dryas were down-sized, because the Earth had expanded, stretching the atmosphere over a larger area. Fusion formation of helium is done with deuterium plus deuterium (I think this could be changed without affecting most of the author's arguments). Ditto for the spelling 'Neandertal', which somehow forgets that the fossils first found were from a German river valley.

Since the author has spent most of his career in the nuclear industry, latterly in radiation health physics and nuclear criticality safety, and was born in 1935, I do not propose to attempt to teach my uncle to suck eggs. One item, however, I would like to correct. Because Tuttle's supernovae and gamma-ray bursts are the product of nearby nuclear detonations, he thinks it perfectly possible that they might generate sufficient gravitational radiation to have been detected by the original Weber bars*. But he concludes that paragraph by saying, "Joe Weber found some correlations, but died on September 30, 2000, and there is probably no-one who can now come to his defense". I am happy to report that his widow is alive and well and writing this review. — VIRGINIA TRIMBLE.

The New Astronomy Guide: Stargazing in the Digital Age, by P. Moore & P. Lawrence (Carlton Books, London), 2012. Pp. 192, 29 × 22·5 cm. Price £20/$34·95 (hardbound; ISBN 978 1 78097 064 6).

In a crowded area of general astronomy books this one stands out. At first glance it appears a coffee-table book but on delving deeper there is much good information on every page. There are excellent illustrations — mostly professional pictures though amateurs are represented also. The white text on a black background requires a good light but apart from the maps this is a book for daytime use.

The first part of book sets the context for observing, with basic facts and definitions. Then follows a section on atmospheric phenomena of interest to sky watchers, and it then goes into digital astrophotography with explanations and an outline of theory. This leads on to choosing a telescope. No mention is made of time spent on learning the night sky with the naked eye or binoculars — but this is astronomy for the digital age.

Cautions are given about using 'GOTO' as a substitute for learning the night sky once you have a telescope. Telescope types and mounts are described with their pros and cons. This includes specialist solar 'scopes. The Sun is then discussed with ways of observing it in white, Hα, and calcium-*K* light. There follow chapters on the Moon and especially its photography, and on the planets and imaging, again including advanced topics such as the use of synthetic colour channels and atmospheric-dispersion correctors. There is one captioning error — photo 18 on page 72, a picture of Saturn, could not have been taken by PL using his C14; the incident sunlight is 90 degrees to the line of sight. This can only be achieved from a spacecraft. The outer Solar System is discussed. There follows a section on event-driven astronomy. The description of solar eclipses is particularly evocative although, unusually for this book, it is light on imaging advice. Galactic and extragalactic astronomy are described together with stellar and deep-sky photography.

The latter part of the book proper is devoted to a stellar atlas and in a pocket at the back are two further maps. The atlas contains views of the sky

*Curiously, Tuttle is not quite alone in this view. A speaker on the history of Italian cosmic-ray physics at a conference held in Denver in 2012 June 26–28 indicated his opinion that Supernova 1987A was "seen" both by the Mont Blanc neutrino experiment and by the Weber-type bar then being operated in Rome by Eduardo Amaldi and his associates.

looking both north and south throughout the year for northern- and southern-hemisphere observers. There is a range of horizon lines for the most heavily populated latitudes and good descriptive notes for the seasonal highlights. The maps themselves are the only part of the book to disappoint. They are drawn in portrait mode and yet really each one needs to display 180 degrees of azimuth and 90 degrees of altitude. This they do not do, and the azimuth at ground level ranges from only just east of south-east to only just west of south-west on the south-facing map. There is an equivalent problem on the north-facing map, meaning that the stars lower than about 45 degrees elevation due east and due west are not charted. A simple 90-degree rotation of the page could have avoided this.

The extra maps in the pocket at the rear of the book are a good concept as they enable printing on a far larger page than the book would otherwise allow. There are two circumpolar maps printed back to back, one for each hemisphere. Around the edge is a date scale to make the whole image look like a base plate for a planisphere. It is a pity it was not marked with right ascension and declination circles as well.

Also included is Patrick Moore's lunar map of 1969. This is a masterpiece of cartography but I question its relevance to 'Stargazing in a digital age' as the book is subtitled. It is drawn with south at the top as is normal for viewing with a Newtonian reflector. A straw poll among the members of my local astronomical society showed that in this age of SCT and short-focus refracting telescopes, both generally used with a star diagonal, most visual observing is done with north at the top, albeit east–west reversed.

Despite these minor issues it is an excellent buy, especially for those considering digital imaging. — MIKE RUSHTON.

OBITUARY

David William Dewhirst (1926–2012)

David William Dewhirst was born on 1926 January 14 at Utley, near Keighley in the West Riding of Yorkshire, the son of Ernest Dewhirst (a solicitor in a family firm) and his wife Margaret. Educated at Keighley Boys Grammar School, David won a County Major Scholarship and State Bursary to Cambridge, where he entered Christ's College in 1944, and would have been one of the earliest members of the Cambridge University Astronomical Society. One evening at the Observatories, David found a distinguished member of the Observatory staff using the 8-inch *Thorrowgood* refractor to show members of the public some objects. Castor could not be resolved into a double star until David was asked to help; he made a small adjustment to the focus, and a large adjustment to the declination, and handed the telescope back, saying "I think you will find it is resolved now".

He read Natural Sciences with considerable success, becoming an Exhibitioner of the College in 1945. Wartime constraints meant that he had to specialize in what we now call Materials Science, but was then termed Metallurgy, and he graduated in 1947. Metallurgy was not in fact his true interest but the war continued to have a great influence in education/research and he was able to secure a Studentship from the Government's Department of Scientific and Industrial Research for his graduate studies. David was awarded his PhD in 1953.

Having an interest of long standing in astronomy and alert to possibilities within Cambridge, before the end of his PhD studies David became a Junior Assistant Observer at the University Observatories, then some distance from the edge of town along Madingley Road. His early time as an astronomer was in some ways not dissimilar to that experienced by those starting in the profession now: he spent what would today be termed 'visiting fellowships' at the Mount Wilson and Palomar Observatories in California, and also in Australia. He was promoted to Senior Assistant Observer and became Librarian of the Observatories, both in 1956. Libraries and the history of astronomy were to become lifelong and passionate interests; elected a Fellow of the RAS on 1947 April 11, David was for some time the Chairman of the Royal Astronomical Society's Library and Archive Committee and a member of the University Library Syndicate. Between 1956 August and 1957 August he was an Editor of this *Magazine*, and he also held the post of Director of the British Astronomical Association Solar Section from 1951 to 1957. From 1976 to 1979 he was Gresham Professor of Astronomy in the City of London, and from 1983 to 1985 President of the Junior Astronomical Society, now called the Society for Popular Astronomy.

The Institute of Theoretical Astronomy was established by Fred Hoyle in the Observatories' grounds in 1967, and the two institutions were combined in 1972 to create the Institute of Astronomy, which, under the leadership of Donald Lynden-Bell and Martin Rees, became one of the leading research establishments in the world. David's contribution to the development was not *via* direct research activity but most notably through the creation of a very accessible and effective research library. A significant number of the world's distinguished astrophysicists benefitted from David's contribution to the Institute and also to their individual well-being as graduate students. It is probably true to say that David's quiet and unobtrusive work on behalf of students and staff is not recognized as widely as should be the case, but the esteem in which he was held is evident in a full-page tribute from Richard Ellis, former Plumian Professor Cambridge and now Steele Professor at Caltech, who concluded that, even in his (Ellis') time, as David was retiring from the University, David "was a gentleman and a good spirit at the Institute".

David became a Fellow of Corpus Christi in 1964 as one of the last of the 15 individuals who formed the first group of 'Leckhampton Fellows', whose election was linked to what was then the revolutionary decision for an historic College to make specific provision for graduate students. Serving twice as Bursar for Leckhampton he then took on the key role of Tutor for Graduate Admissions from 1973 to 1981 and served two terms as Warden for Leckhampton 1986–1993. The Leckhampton students regarded David with admiration and affection, and David's visibility and direct support for the students was palpable. The help and influence he gave to Corpus graduate students for a period of three decades is one of his enduring legacies.

While always impeccably correct whatever the situation, David had a well-developed, dry, sense of humour. He was also positively fond of relating somewhat self-deprecating tales from his own experience. One of his favourites from his mid-60s was his story of cycling back from Corpus to Leckhampton one day after lunch. Proceeding down Silver Street, David was overtaken by a middle-aged American couple walking along the pavement. When some five or six metres past, the man turned his head, took another somewhat disbelieving look back at David, turned to his companion and said, quite audibly, "I never knew that it was possible to cycle so slowly and remain upright".

Retiring from the University and from the Corpus Active Fellowship in 1993, David gave up his dual-location existence, returning full-time to his house in north Cambridge. Mark Hurn, the Institute's current Librarian, kindly kept David connected to the Institute and provisioned with astronomical reading material.

Although his life was somewhat sedate and of very modest pace as he entered his 70s, David's abiding desire was to remain at home, with his correspondence, books, and interest in the history of astronomy. For many years now David's wish would not have been possible without the friendship and devotion of his immediate neighbours, John Shakeshaft on one side and Roger and Wendy Bowen on the other.

It was a delight to see that last year he was able to attend the 50th Anniversary of the foundation of Leckhampton, and in July this year he spent the day at the Institute where the Society for the History of Astronomy made him an honorary member of the Society. David's legacy will live on, not just through the former College and Institute students with whom he engaged directly, but also through the influence he brought to how the College and the Institute educate and support graduate students. — P. C. HEWETT & R. V. WILLSTROP.

Here and There

EXTRATERRESTRIAL SURVEILLANCE

Beadle said that an investigator from Mercury indicated that police had a possible suspect in Toronto. — *Victoria Times-Colonist*, 2012 July 5, p. A1.

WHO IS CALLING MAGELLAN A LIAR?

… the great spiral galaxy M 31, the only galaxy apart from our own that is visible to the naked eye. — *Daily Telegraph*, July Night Sky.

THAT REALLY WOULD MAKE IT A *SUPER* GIANT

In … Cepheus, the most interesting object is the Garnet Star, Mu Cephei, that shines like a glowing coal. This is one of the three largest known stars in the galaxy. If the Sun was the size of a golf ball, the Garnet Star would be as big as Greater London. — *Daily Telegraph*, July Night Sky.