THE

OBSERVATORY

A REVIEW OF ASTRONOMY

PLATE 1.

This beautiful image of the Elephant's Trunk Nebula in Cepheus, part of the IC 1396 complex of emission nebulosity, was kindly supplied by Anthony Ayiomamitis, whose work also featured in the 2006 February issue (see www.perseus.gr for details of the exposure and for more examples of his astrophotography).

PLATE 2.

Here we see Professor Roger Griffin at the controls of the telescope in Cambridge that has contributed so many observations to his remarkable series of papers, which reaches number 200 during 2008. Despite the less-than-perfect weather that characterizes the British Isles, Professor Griffin has amply demonstrated what can be accomplished with a dedicated telescope (and by an equally dedicated observer!).

THE OBSERVATORY

EDITORIAL

Volume 128 will contain a remarkable contribution in its June issue when Roger Griffin's Paper 200 in the series on *Spectroscopic Binary Orbits from Photoelectric Radial Velocities* is published. Beginning in a modest and irregular way in 1975 with short papers discussing single objects, this series has blossomed into a regular — some might say essential — feature, with comprehensive discussions of the stars treated, often several in one paper. (And yet this is not the only repository for Professor Griffin's binary-star data: many papers, even series, have appeared elsewhere taking his tally to many hundreds of stars.) To commemorate this extraordinary feat, this first issue of Volume 128 carries a photograph of our dedicated observer at the eyepiece of his (equally dedicated and effective) telescope in Cambridge collecting data for future papers. Will our celestial batsman push his score on to 250, or even 300? Watch this space.

The year just passed witnessed two remarkable, naked-eye comets, and the Editors are pleased to celebrate those events with fine images of both. The first, Comet McNaught (C/2006 P1), was independently discovered by the Managing Editor of this *Magazine* during a casual glance from his west-facing bedroom window on 2007 January 6 (admittedly five months after Rob McNaught had first spotted it from Australia!). A striking-enough object at that time in the twilight sky, it went on to display a wonderful banded tail to southern observers. Equally spectacular has been the unprecedented 2007 October 24 rise to prominence of Comet Holmes, which suddenly brightened a million fold to reach second magnitude and naked-eye visibility. Readers might like to note that this comet was first reported by Edwin Holmes on page 441 of the 1892 December issue of *The Observatory*.

To round out our colour section we have another excellent image from Anthony Ayiomamitis, this time of an interesting part of IC 1396, itself one of the largest nebular complexes in the sky.

NEW INSIGHTS INTO THE NATURE OF THE ECLIPSING SYSTEM V609 AQUILAE

By D. G. Turner
Saint Mary's University, Halifax, Nova Scotia, Canada

E. A. Panko and O. Sergienko
Kalinenkov Astronomical Observatory, Mykolaiv State University, Ukraine

D. J. Lane and D. J. Majaess
Saint Mary's University, Halifax, Nova Scotia, Canada

A photometric study of the near-contact binary (NCB) system V609 Aql reveals it to be the westernmost star of a close double, with brightness variations and implied parameters more extreme than those derived in an earlier photographic study, in which images of the variable and companion were almost certainly blended. The system's brightness variations exhibit deep primary eclipses ($\Delta V = 1\cdot 04$) and secondary eclipses ($\Delta V = 0\cdot 44$) matched to a model fit with a derived orbital inclination of $i = 84°\cdot 8 \pm 0°\cdot 2$ and estimated component spectral types of F8–F9 and K2–K3. The primary overfills its Roche lobe in the optimum eclipse solution, inconsistent with the definition of NCBs. Period changes in the system are studied from 23 published times of light minimum and 21 newly-established values: 18 from examination of archival Harvard plates, and three from ASAS data and new CCD observations. $O - C$ variations from 1891 to 2007 exhibit a long-term parabolic trend indicative of a period decrease, $dP/dt = -(7\cdot 75 \pm 1\cdot 39) \times 10^{-8}$ d yr^{-1}, corresponding to mass transfer to the secondary of $(6\cdot 5 \pm 1\cdot 2) \times 10^{-8}\ M_\odot$ yr^{-1}. Superposed variations may indicate fluctuations in the mass flow. The system is estimated to be ~ 513 pc distant.

Introduction

The number of well-studied eclipsing binary systems in the Galaxy is a small fraction of the number listed in the 1969 and 1985 editions of the *General Catalogue of Variable Stars*[1,2], and some systems with several bibliographic entries in the ADS (Astronomical Data System) may be relatively poorly studied. A good example is V609 Aquilae (2000 co-ordinates 20h 09m 58s·77, $+14°$ 38′ 14″·7), originally described as an Algol-like variable[3], but now recognized as a β Lyrae system[4], primarily from a photographic study by Ishtchenko & Leibowitch[5]. The same study appears to be the basis for later summaries of more detailed system parameters and the object's designation as a detached system[6], as well as the cited spectral types of the component stars as F8 and G0[7]. With a period $P = 0^d\cdot 796565 = 19\cdot 1$ hours, V609 Aql undergoes a primary or secondary eclipse most clear evenings, making it ideal for observational study.

In 1994 V609 Aql was included in a list of near-contact binaries (NCB)[8], a new subclass of close-binary systems (CBS) defined by Shaw[9]. NCB systems have periods of less than a day, exhibit the effects of tidal interaction, and have facing surfaces less than $0 \cdot 1$ orbital radius apart, but are not in contact. Such systems may be the evolutionary precursors to the A-type W UMa systems, and are probably in the early stages of mass transfer. NCBs may also be X-ray sources, although V609 Aql itself is not detected in the *ROSAT* All-Sky Survey[10].

In *An Atlas of $O-C$ Diagrams of Eclipsing Binary Stars*[11] V609 Aql is noted to be a β Lyrae-type or W UMa-type system, but insufficiently researched. Only 19 times of light minimum over the interval 1937 to 1996 are cited, including unpublished results. Four additional times of light minimum since 2000 have been published[12,13,14,15], increasing the number of such estimates to 23. But the only publicly available light curve for the star[5] was derived from visual inspection of plates in the collection of Tashkent Astronomical Observatory, and is not of high precision.

Our interest in V609 Aql originated with its remarkable $O-C$ diagram, which displays irregular trends[11]. We therefore initiated a new study of the system in order to find additional times of light minimum, the intent being to clarify the nature of its period variability. V609 Aql was therefore observed photometrically to establish times for current minima, and was also investigated using the Harvard College Observatory Photographic Plate Collection to obtain archival or 'historical' times of minima. As we describe here, our new observations for V609 Aql reveal it to be a much more interesting and different system than found by previous investigators.

Observational data and $O-C$ analysis

New *V*-band observations were obtained for V609 Aql on 21 nights between 2006 September 22 and December 18 using a Celestron 28-cm Schmidt-Cassegrain telescope at the Abbey Ridge Observatory (Lane), an automated facility located at a dark site outside of Halifax, Nova Scotia. The telescope is equipped with a SBIG ST9 CCD camera and an Optec IFW filter wheel, although for the present study of V609 Aql only *V* observations were measured. All data represent means for combinations of short-exposure images that were analyzed by aperture photometry and normalized relative to GSC 01085–01422, our adopted reference star for the field (at an adopted magnitude of $V = 10 \cdot 59$), with HDE 354987 and three other stars in the field serving as check stars (see Table I and Fig. 1). The standard deviations for all observations of the reference star and check stars were $\pm 0^m \cdot 006$ to $\pm 0^m \cdot 008$, typical of other observations being made from the observatory. The data are summarized in Table II.

Additional observations of V609 Aql were obtained on one night (2006 October 7) using the 70-cm telescope of the Kalinenkov Astronomical Observatory of Nikolaev State University, equipped with a SBIG ST-7 camera in an instrumental photometric system closely approximating the standard *V*-band. The CCD exposures for the observations were of shorter duration than those obtained from Abbey Ridge, in an attempt to prevent image overlap for the newly-discovered companion star (see below). The resulting data represent means of ten separate exposures, obtained by aperture photometry and tied to the same reference stars. Unfortunately, residual image overlap contaminates the photometry, making it difficult to calibrate relative to our reference stars, although the data display excellent overall agreement with our primary observations when combined with them after normalization (Table III).

Table I

Reference stars for observations of V609 Aql

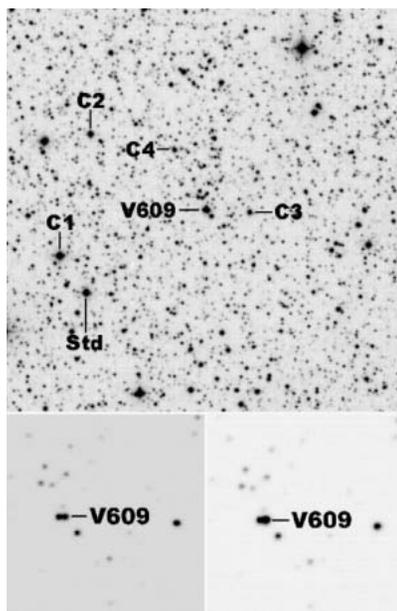| Star	RA(2000)	Dec(2000)	V	Notes
V609 Aql	20^h 09^m 58^s·58	+14° 38' 12''·9	var	
Companion	20^h 09^m 58^s·94	+14° 38' 12''·9	12·35	See text, 5''·6 separation
Std	20^h 10^m 17^s·43	+14° 35' 07''·1	10·59	GSC 01085–01422
C1	20^h 10^m 21^s·40	+14° 36' 28''·8	9·77	HDE 354987
C2	20^h 10^m 16^s·74	+14° 41' 01''·3	11·07	
C3	20^h 09^m 52^s·00	+14° 38' 07''·9	12·35	
C4	20^h 10^m 03^s·65	+14° 40' 26''·7	12·68	

Fig. 1

A finder chart for the field centered on V609 Aql from the red image of the Palomar Observatory Sky Survey (top). The field of view measures 15' × 15' and shows the location of the variable, the adopted reference star, and four check stars used for the observations. The lower portion of the figure displays two enlargements from CCD images of V609 Aql at phases 0·9998 (lower left) and 0·8700 (lower right).

All data for V609 Aql were phased using an existing ephemeris[11], namely:

$$\text{HJD}_{\text{min}} = 2429365\cdot7284 + 0\cdot7965639\,E,$$

where E is the number of elapsed cycles.

The phased Abbey Ridge *V*-band observations of V609 Aql are plotted in Fig. 2. They were initially constrained to only a few hours on each clear night, but the star was also monitored continuously on three nights near the end of the run in an attempt to delineate critical portions of the light curve. Although full phase coverage for the binary system was not obtained, the data are sufficiently complete

<center>TABLE II</center>

<center>_New observations for V609 Aql and companion_</center>

HJD	Phase	V	HJD	Phase	V
2454000·5525	0·3628	11·095	2454050·5003	0·0668	11·292
2454000·5510	0·3608	11·095	2454050·4975	0·0633	11·292
2454000·6086	0·4332	11·229	2454050·5027	0·0699	11·265
2454000·6985	0·5461	11·230	2454050·5074	0·0758	11·242
2454001·6424	0·7309	11·026	2454050·5125	0·0821	11·221
2454001·6819	0·7806	11·047[a]	2454050·5174	0·0882	11·195
2454005·5400	0·6240	11·082	2454050·5222	0·0943	11·179
2454005·5951	0·6932	11·036	2454050·5272	0·1006	11·172
2454006·5393	0·8785	11·115	2454050·5319	0·1064	11·156
2454006·6468	0·0134	11·555	2454050·5371	0·1130	11·137
2454009·5083	0·6058	11·107	2454050·5417	0·1188	11·125
2454009·5469	0·6542	11·057	2454050·5468	0·1251	11·111
2454009·6679	0·8061	11·066	2454050·5517	0·1313	11·111
2454014·5487	0·9334	11·320	2454050·5567	0·1377	11·099
2454014·5896	0·9848	11·605	2454050·5620	0·1443	11·093
2454015·5801	0·2283	11·034	2454050·5667	0·1502	11·090
2454015·6180	0·2758	11·018	2454050·5711	0·1556	11·076
2454016·5038	0·3879	11·120	2454051·4683	0·2821	11·028
2454016·5404	0·4338	11·218	2454051·5133	0·3385	11·057
2454017·6510	0·8280	11·069	2454061·4318	0·7902	11·035
2454019·5127	0·1652	11·053	2454061·4318	0·7902	11·035
2454024·4986	0·4245	11·178	2454061·4364	0·7958	11·040
2454024·5393	0·4756	11·304	2454061·4412	0·8019	11·044
2454025·4686	0·6422	11·066	2454061·4462	0·8082	11·054[a]
2454025·5140	0·6991	11·027	2454061·4509	0·8141	11·058[a]
2454025·6108	0·8207	11·066	2454061·4561	0·8206	11·047[a]
2454038·5357	0·0465	11·384	2454061·4607	0·8264	11·060[a]
2454038·5954	0·1214	11·133	2454061·4661	0·8331	11·058[a]
2454041·4385	0·6907	11·028	2454061·4722	0·8409	11·080
2454041·4484	0·7031	11·031	2454061·4771	0·8470	11·083
2454041·4554	0·7119	11·029	2454061·4822	0·8534	11·095
2454041·4624	0·7207	11·020	2454061·4870	0·8594	11·111
2454041·4694	0·7295	11·027	2454061·4923	0·8661	11·111
2454041·4764	0·7383	11·014	2454061·4970	0·8720	11·120
2454041·4834	0·7470	11·022	2454061·5020	0·8783	11·148
2454041·4904	0·7558	11·020	2454061·5069	0·8844	11·151
2454041·4970	0·7641	11·032	2454061·5118	0·8906	11·165
2454041·5053	0·7745	11·021	2454061·5169	0·8970	11·190
2454041·5108	0·7815	11·028	2454061·5217	0·9029	11·207
2454050·4434	0·9954	11·641	2454061·5269	0·9095	11·230
2454050·4434	0·9954	11·641	2454061·5316	0·9154	11·245
2454050·4479	0·0010	11·623	2454061·5366	0·9217	11·296
2454050·4528	0·0071	11·609	2454061·5400	0·9259	11·298
2454050·4579	0·0136	11·570	2454062·5201	0·1563	11·082
2454050·4627	0·0196	11·536	2454081·4531	0·9247	11·284
2454050·4680	0·0262	11·498	2454082·4309	0·1522	11·084
2454050·4828	0·0448	11·398	2454082·4723	0·2042	11·037
2454050·4876	0·0509	11·357	2454088·4494	0·7077	11·018
2454050·4928	0·0573	11·324			

<center>[a] Observation of low quality.</center>

that one can map almost a complete light curve by using the symmetry of the light curves of close binaries and mirroring the data about primary minimum (lower portion of Fig. 2). Mirroring the light curve also allowed us to estimate the time of primary minimum accurately using the robust software used for matching Cepheid light curves[17], the result being a derived phase shift of $\Delta\varphi = -0\cdot0097 \pm 0\cdot0018$, corresponding to $O-C = +0^d\cdot0077 \pm 0\cdot0018$, the uncertainty

TABLE III

Nikolaev observations of V609 Aql

HJD	Phase	V
2454029·2410	0·3781	11·538
2454029·2486	0·3876	11·565
2454029·2597	0·4015	11·613
2454029·2657	0·4091	11·626
2454029·2734	0·4187	11·693
2454029·2793	0·4262	11·674
2454029·2871	0·4360	11·712
2454029·2932	0·4436	11·766
2454029·3064	0·4602	11·795
2454029·3239	0·4821	11·842
2454029·3349	0·4959	11·830
2454029·3527	0·5182	11·756
2454029·3597	0·5270	11·708
2454029·3743	0·5454	11·675
2454029·3804	0·5530	11·657
2454029·3851	0·5589	11·626

established by the fitting procedure used to minimize the resulting scatter in the data matched through mirroring. The corresponding time for primary minimum associated with the start of cycle 30989, following which we began a continuous run on V609 Aql, is HJD 2454050·4548 ± 0·0014. That value is listed in Table IV.

In similar fashion the single-night observations for V609 Aql observed from Nikolaev were used to delineate a secondary minimum for the system, and yielded an O − C datum through mirroring. That result is listed in the second-last row of Table IV.
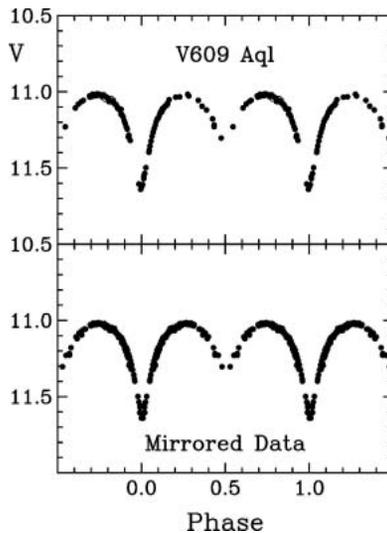

FIG. 2

V-band CCD observations for V609 Aql from the present programme (upper). Open circles depict low-quality observations. The lower portion of the figure displays the same data mirrored about zero phase.

<div style="text-align:center">

Table IV

Newly derived epochs of minimum light for V609 Aql

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$HJD_{min}(obs)$	Cycle (E)	$HJD_{min}(calc)$	$O - C$ (d)	Year
2411964·6344	−21845·0	2411964·7900	−0·1556	1891
2412348·5912	−21363·0	2412348·7338	−0·1426	1892
2412360·5611	−21348·0	2412360·6823	−0·1212	1892
2412368·5377	−21338·0	2412368·6479	−0·1102	1892
2414925·5472	−18128·0	2414925·6180	−0·0708	1899
2414933·5536	−18118·0	2414933·5837	−0·0301	1899
2414947·4798	−18100·5	2414947·5235	−0·0437	1899
2415289·5874	−17671·0	2415289·6477	−0·0603	1900
2415548·9022	−17345·5	2415548·9293	−0·0271	1901
2415618·5976	−17258·0	2415618·6286	−0·0310	1901
2415724·5048	−17125·0	2415724·5716	−0·0668	1901
2416639·7569	−15976·0	2416639·8235	−0·0666	1904
2416785·5235	−15793·0	2416785·5947	−0·0712	1904
2417094·5966	−15405·0	2417094·6615	−0·0649	1905
2418543·5561	−13586·0	2418543·6113	−0·0552	1909
2421092·5566	−10386·0	2421092·6157	−0·0591	1916
2428426·5910	−1179·0	2428426·5796	+0·0114	1936
2433484·7483	+5171·0	2433484·7603	−0·0120	1950
2453872·7789	+30766·0	2453872·8133	−0·0344	2006
2454029·3323	+30962·5	2454029·3382	−0·0059	2006
2454050·4548	+30989·0	2454050·4471	+0·0077	2006

We also obtained an estimate for the time of light minimum using *V*-data from the ASAS-3 (All Sky Automated Survey 3) project[17] matched to our resulting light curve adjusted for the phase offset. The ASAS-3 data exhibit a phase shift of $\Delta\varphi = -0.0432$ relative to our best-fitting light curve, and also match the present observations to within a few millimagnitudes in *V*. The resulting $O - C$ value ($-0^d·0344$) is listed in the third-last row of Table IV.

Additional estimates for times of light minimum in V609 Aql, both primary and secondary minima, were obtained through visual scanning of plates in the Harvard College Observatory (HCO) Photographic Plate Collection, using suitable reference stars in the field for comparison[5]. A selection of patrol-series plates was initially scanned for that purpose, but with limited success. Most patrol-series exposures are roughly an hour in duration, which corresponds to a range in phase of ∼0·05. By chance most early patrol-series exposures of the field of V609 Aql correspond to times outside eclipse, and only ∼1% of those examined (two) reveal the star near light minimum. Many higher-resolution plates were exposed near times of mid-eclipse, however, and proved to be a more reliable source of data. Most of the high-resolution plates have exposure times of order 10 minutes, corresponding to an uncertainty in phase of less than ±0·01.

In that manner we were able to estimate 18 times of light minimum for V609 Aql from 1891 to 1950, two being times of secondary minimum. The data are tabulated for reference purposes in Table IV.

The resulting $O - C$ data are plotted in Fig. 3 (upper panel) as filled and open circles. From an analysis of all times of light minima we find the following parabolic solution:

$$\text{HJD}_{min} = (2429365·7233 \pm 0·0062) + (0·796566 \pm 0·000003)\, E$$
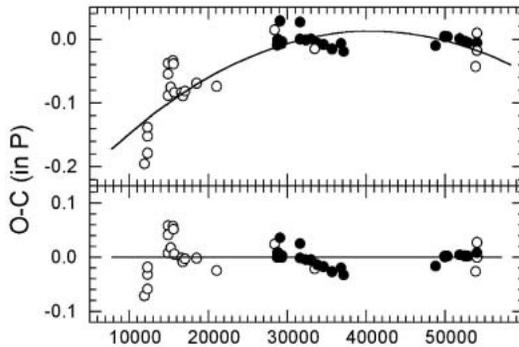$$- (0·845 \pm 0·151) \times 10^{-10}\, E^2$$

FIG. 3

O − C data (in units of phase offset) for V609 Aql plotted as a function of observed (HJD − 2 400 000) of light minimum (upper). The lower plot shows the same data after removal of the parabolic trend evident in the data in the upper portion of the figure. Filled circles denote published times of light minimum, open circles the data of this paper.

The parabolic fit is shown in Fig. 3 (upper panel). The period is clearly decreasing, the measured rate being $dP/dt = -(7 \cdot 75 \pm 1 \cdot 39) \times 10^{-8}$ d yr^{-1}. There may be additional trends in the O − C variations, but the evidence is not well established.

The scatter resulting from meshing the mirrored observations with the actual observations is only about ± 0$^m \cdot$011 for the optimum fit, not much larger than the estimated uncertainties in the data. Given the range of nights and phase over which the observations were obtained, such small residuals suggest that any non-symmetric deviations of the actual light curve arising from starspots or an accretion disc are negligibly small. In fact, both features were considered in modelling the system, but were found to be unimportant.

Light-curve analysis

It seems clear from our new light curve for V609 Aql (Fig. 2) that the system undergoes deeper eclipses than implied by the original photographic study[5]. Another unexpected discovery from the CCD observations is that the star is an optical double. The lower portion of Fig. 1 contains two CCD images, one near light minimum (lower left) and one near light maximum (lower right), illustrating that the eclipsing system is the westernmost (right hand) star of the pair. The two stars are only 5·6 arcseconds apart (Table I) and the pair is always blended in our observations, so the data of Table II refer to the combined light of both stars, as established from aperture photometry.

Reliable separation of the light of the variable from the combined light of the pair requires knowledge of the brightness of the contaminating star, which is not readily established. Our Nikolaev observations generated magnitude estimates for both stars separately, but contain residual contamination arising from scattered light from the neighbouring star, which was eliminated by normalizing the data to the Abbey Ridge data. We were also unable to derive reliable estimates for the two stars through crude profile fitting methods, owing to the pixel scale for the CCD. Instead, we were able to solve for the brightness of the (assumed) non-variable optical companion of V609 Aql by proceeding as follows.

<center>TABLE V</center>

Reduced observations for V609 Aql

Phase	V	Phase	V	Phase	V	Phase	V
0·0002	12·439	0·1811	11·452	0·5056	11·842	0·8254	11·436
0·0059	12·402	0·1869	11·446	0·5082	11·830	0·8255	11·463
0·0104	12·365	0·1891	11·463	0·5196	11·826	0·8300	11·445
0·0120	12·373	0·1932	11·432	0·5275	11·795	0·8313	11·455
0·0183	12·267	0·1993	11·426	0·5306	11·756	0·8329	11·468
0·0184	12·296	0·2050	11·419	0·5394	11·708	0·8380	11·452
0·0245	12·230	0·2050	11·419	0·5441	11·766	0·8389	11·486
0·0311	12·159	0·2091	11·422	0·5509	11·709	0·8395	11·478
0·0496	11·982	0·2137	11·409	0·5517	11·712	0·8430	11·489
0·0514	11·958	0·2146	11·436	0·5578	11·675	0·8450	11·498
0·0557	11·913	0·2207	11·399	0·5613	11·690	0·8457	11·484
0·0617	11·852	0·2310	11·415	0·5615	11·674	0·8509	11·502
0·0622	11·858	0·2331	11·418	0·5620	11·707	0·8518	11·488
0·0681	11·806	0·2393	11·398	0·5654	11·657	0·8575	11·511
0·0692	11·816	0·2481	11·400	0·5690	11·693	0·8583	11·505
0·0705	11·794	0·2569	11·389	0·5707	11·629	0·8639	11·529
0·0735	11·813	0·2642	11·406	0·5712	11·626	0·8643	11·529
0·0747	11·763	0·2657	11·408	0·5786	11·626	0·8700	11·529
0·0798	11·732	0·2745	11·398	0·5861	11·613	0·8709	11·529
0·0806	11·727	0·2806	11·395	0·6001	11·565	0·8737	11·561
0·0856	11·709	0·2833	11·410	0·6072	11·542	0·8763	11·549
0·0870	11·695	0·2869	11·409	0·6096	11·538	0·8768	11·542
0·0922	11·673	0·2874	11·395	0·6106	11·523	0·8822	11·567
0·0931	11·655	0·2921	11·413	0·6289	11·486	0·8831	11·584
0·0982	11·647	0·2960	11·408	0·6343	11·505	0·8833	11·535
0·0991	11·630	0·3020	11·420	0·6471	11·463	0·8887	11·596
0·1046	11·609	0·3045	11·409	0·6566	11·450	0·8892	11·588
0·1054	11·620	0·3410	11·450	0·6590	11·450	0·8946	11·620
0·1108	11·588	0·3434	11·450	0·6955	11·409	0·8954	11·609
0·1113	11·596	0·3529	11·463	0·6980	11·420	0·9009	11·630
0·1167	11·535	0·3657	11·505	0·7040	11·408	0·9018	11·647
0·1169	11·584	0·3711	11·486	0·7079	11·413	0·9069	11·655
0·1178	11·567	0·3894	11·523	0·7126	11·395	0·9078	11·673
0·1232	11·542	0·3904	11·538	0·7131	11·410	0·9130	11·695
0·1237	11·549	0·3928	11·542	0·7167	11·410	0·9144	11·709
0·1263	11·561	0·3999	11·565	0·7194	11·395	0·9194	11·727
0·1291	11·529	0·4139	11·613	0·7255	11·398	0·9202	11·732
0·1300	11·529	0·4214	11·626	0·7343	11·408	0·9253	11·763
0·1357	11·529	0·4288	11·626	0·7358	11·406	0·9265	11·813
0·1361	11·529	0·4293	11·629	0·7431	11·389	0·9295	11·794
0·1417	11·505	0·4310	11·693	0·7519	11·400	0·9308	11·816
0·1425	11·511	0·4346	11·657	0·7607	11·398	0·9319	11·806
0·1482	11·488	0·4380	11·707	0·7669	11·418	0·9378	11·858
0·1491	11·502	0·4385	11·674	0·7690	11·415	0·9383	11·852
0·1543	11·484	0·4387	11·690	0·7793	11·399	0·9443	11·913
0·1550	11·498	0·4422	11·675	0·7854	11·436	0·9486	11·958
0·1570	11·489	0·4483	11·712	0·7863	11·409	0·9504	11·982
0·1605	11·478	0·4491	11·709	0·7909	11·422	0·9689	12·159
0·1611	11·486	0·4559	11·766	0·7950	11·419	0·9755	12·230
0·1620	11·452	0·4606	11·708	0·7950	11·419	0·9816	12·296
0·1671	11·468	0·4694	11·756	0·8007	11·426	0·9817	12·267
0·1687	11·455	0·4725	11·795	0·8068	11·432	0·9880	12·373
0·1700	11·445	0·4804	11·826	0·8109	11·463	0·9896	12·365
0·1745	11·463	0·4918	11·830	0·8131	11·446	0·9941	12·402
0·1746	11·436	0·4944	11·842	0·8189	11·452	0·9998	12·439

Inspection of our image of the system near primary minimum indicates that the eclipsing system is marginally fainter than the companion at that epoch. The limits for eye detection of brightness differences between stars is typically[18] $\sim 0^{m} \cdot 1$, so we estimated the brightness of the optical companion by subtracting its light from the combined-light data using various trial values, until the brightness of V609 Aql at primary minimum was $\sim 0^{m} \cdot 1$ fainter. The result was a companion at $V = 12 \cdot 35$, identical in brightness to check star C3, which lies conveniently close to the pair. The images of star C3 in the lower portion of Fig. 1 are sufficiently close in apparent size and brightness to those for the eastern optical companion of V609 Aql to confirm its inferred magnitude, although it is clearly a result in need of verification.

We summarize in Table V the inferred uncontaminated brightness of V609 Aql from the Abbey Ridge and Nikolaev observations, including mirrored values, and plot the data in Fig. 4. The results are clearly at variance with previous conclusions concerning the depths of primary and secondary minimum, and also about the brightness of the star in and out of eclipse (see Table VI).

We modelled the light curve for V609 Aql using BINARY MAKER 3[19] along with reasonable estimates for the properties of the two components. A low-dispersion (120 Å mm^{-1}) spectrogram of the system near light maximum, taken with the DAO's *Plaskett* telescope, implies a spectral type of $\sim$F8–9 V, consistent with previous estimates[7], but the spectral type of the fainter star in the system cannot be established directly, except through analysis of the light curve. We found through trial and error, in conjunction with examination of the residuals for various trials, the solution given in Table VI. An initial temperature for the primary was established from its F8–F9 V spectral type, corresponding to an intrinsic $B - V$ colour of $0 \cdot 54 - 0 \cdot 57$, in conjunction with the $B - V$ colour–T_{eff} relation of Gray[20], which implies $T_{\text{eff}} = 5988 - 6083$ K. The final solution implies $T_{1\text{eff}} = 6050 \text{ K}$ and $T_{2\text{eff}} = 5000 \text{ K}$, the latter corresponding to a K2–K3 dwarf. Both stars are larger than expected for dwarfs, presumably a consequence of stellar evolution and the changes occurring in a close-binary system with mass transfer.

TABLE VI

Derived system parameters for V609 Aql

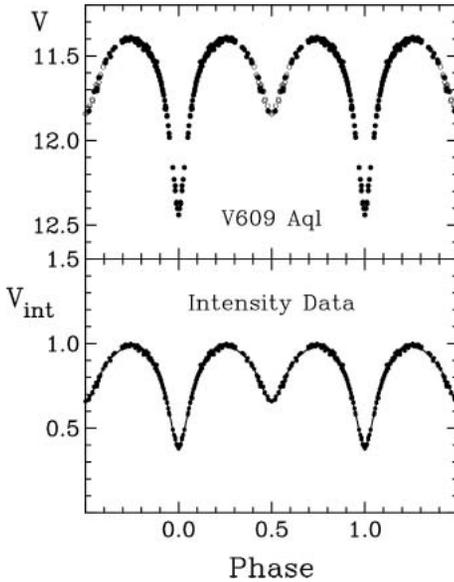| Parameter	Ref. 5	Ref. 6	This Paper
V	...	...	$11 \cdot 40$
ΔV_1	...	...	$1 \cdot 04$
ΔV_2	...	...	$0 \cdot 44$
B	$11 \cdot 7$	...	...
ΔB_1	$0 \cdot 4$	...	...
ΔB_2	$0 \cdot 2$	...	...
Separation	...	$4 \cdot 97 \, R_{\odot}$	$4 \cdot 39 \, R_{\odot}$
R_1	...	$1 \cdot 49 \, R_{\odot}$	$1 \cdot 84 \, R_{\odot}$
R_2	...	$1 \cdot 24 \, R_{\odot}$	$1 \cdot 47 \, R_{\odot}$
RL_1	...	74%	113%
RL_2	...	71%	98%
L_1	...	$2 \cdot 34 \, L_{\odot}$	$2 \cdot 70 \, L_{\odot}$
L_2	...	$1 \cdot 43 \, L_{\odot}$	$0 \cdot 80 \, L_{\odot}$
T_1	...	5870 K	6050 ± 25 K
T_2	...	5680 K	5000 ± 25 K
M_1	...	$1 \cdot 49 \, M_{\odot}$	$1 \cdot 05 \, M_{\odot}$ (adopted)
M_2	...	$1 \cdot 10 \, M_{\odot}$	$0 \cdot 74 \pm 0 \cdot 02 \, M_{\odot}$
M_1/M_2	...	$0 \cdot 74$	$0 \cdot 70 \pm 0 \cdot 02$
$Sp.T._1$	...	F8	F8–F9
$Sp.T._2$	...	...	K2–K3
i	...	...	$84° \cdot 8 \pm 0° \cdot 2$

FIG. 4

V-band observations (including mirrored data) for V609 Aql (upper) corrected for contamination by a companion of $V = 12\cdot35$. Open circles represent the Nikolaev observations normalized to the Abbey Ridge data. The same data are plotted as intensities (lower) along with the best-fitting model light curve.

The mass ratio for eclipsing systems is difficult to establish without radial-velocity information[21], although our solution yielded reasonable results. A mass of $M_1 = 1\cdot05\ M_\odot$ was adopted for the primary from its main-sequence spectral type F8–F9 and luminosity[22], and the eclipse solution yielded a reasonably well-defined mass ratio of $M_2/M_1 = 0\cdot70 \pm 0\cdot02$. The resulting implied secondary mass of $M_2 = 0\cdot72 \pm 0\cdot02\ M_\odot$ is, in fact, the value expected for a K2–K3 dwarf[22], apparently confirming the eclipse solution. Although we cannot exclude the possibility of systematic effects in our iterative technique, since the various system properties depend directly upon each other, the results should encourage others to observe the star in a more comprehensive fashion to establish the system parameters more reliably. High-precision radial-velocity observations of the system are essential for confirming the inferred masses of the two components, as well as for constraining the light-curve solution for the system, which is illustrated in the lower portion of Fig. 4.

A model for the V609 Aql system from the eclipse solution is given in Fig. 5. The primary star in the system is indicated to overfill its Roche lobe, since an alternative solution for a star just filling its Roche surface produced clear discrepancies with the observed light curve. The primary is therefore in the process of transferring mass to the secondary. The derived rate of period decrease can be used to find the rate of mass flow from the primary in the system in the case of conservative mass transfer[23], namely from:

$$\frac{dM_1}{dt} = \frac{1}{3P}\frac{dP}{dt}\left(\frac{M_1 M_2}{M_1 - M_2}\right).$$
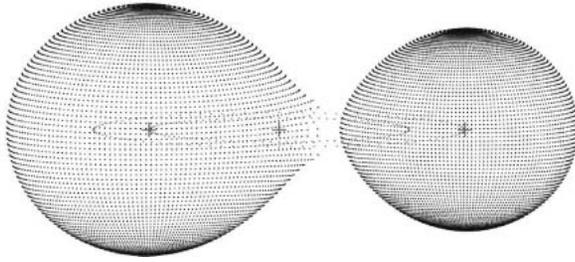
<div align="center">Fig. 5</div>

A model for the V609 Aql system at phase 0·25 from BINARY MAKER 3

In the present case the derived parameters for the system correspond to a rate of mass transfer to the secondary of $(6·5 ± 1·2) × 10^{-8} M_\odot$ year^{-1}, atypically large for a close binary system but not for a system in which one star overfills its Roche lobe. The fact that matter from the primary in the system is flowing directly to the secondary without the presence of an accretion disc presumably accounts for the lack of X-rays from the system.

The light curve of V609 Aql bears some similarity to the light curves of the NCBs WZ Cyg[24] and MT Her[25], which have eclipse depths and inferred parameters like those of V609 Aql. However, neither of those systems displays the extreme light-curve curvature of V609 Aql, and both are undergoing period increases rather than a period decrease. They are likely in a different phase of evolution as close-binary systems than V609 Aql. In fact, given all of the available evidence, V609 Aql no longer satisfies the criteria of a NCB, since the primary overfills its Roche surface and both components are oversized. In contrast, most NCBs and their subclasses consist of a primary at or near its Roche lobe, with only the secondary in the system being oversized[8].

The distance to V609 Aql

The eclipse solution for V609 Aql allows one to establish a reasonably reliable estimate for the distance to the system. Although the components are non-spheroidal and in near-contact, the view of the system during secondary eclipse is toward the side of the primary facing away from the secondary. One can adjust the orbital inclination in BINARY MAKER 3 so that secondary eclipse is an occultation, the effective radius of the primary at that instant being $1·846 R_\odot$ for the component masses estimated previously. With the effective temperature estimated from the model (which we assume applies to the back hemisphere) and inferred parameters for the Sun[26], we obtain a luminosity for the back hemisphere of the primary of $4·095 L_\odot$, or $M_V = +3·29$. The light originating from the primary during secondary eclipse is $V = 11·84$, resulting in an observed distance modulus of $V - M_V = 8·55$.

It can be argued that V609 Aql must be unreddened. The available broadband B and V magnitudes, primarily photographic, refer to the combined light of the optical double, whereas the JHK colours[27] for the individual stars imply that the eastern component is a red star, with $J - H$ colour comparable to unreddened late-type stars of $B - V \cong +1·1$. The $J - H$ colour for V609 Aql is that of a yellow dwarf, but uncertainties of as much as $± 0·1$ in the JHK colours make it difficult to be more specific.

A more direct estimate is made as follows. The assumed spectral type of F8–F9 for the primary corresponds to $(B-V)_0 \cong +0\cdot55$. Our photographic estimates of the brightness of V609 Aql on the Harvard plates, and the original study of Ishtchenko & Leibowitch[5], imply $B \cong 11\cdot7$ for the combined light of the optical double at light maximum. The eastern component should have $B \cong 13\cdot45$ according to our estimates for its visual brightness and broad-band colour, making the brightness of the eclipsing component roughly $B \cong 11\cdot94$ at maximum brightness. The observed visual maximum brightness is $V = 11\cdot39$, resulting in an observed colour of $B-V \cong +0\cdot55$, identical to the expected unreddened broad-band colour. Small changes to the calculations, within the magnitude of potential uncertainties in the estimates, do not alter the results significantly, so it seems clear that any interstellar reddening of the system must be negligibly small.

The field of V609 Aql at Galactic co-ordinates $l = 55°\cdot20$, $b = -10°\cdot03$ is adjacent to nearby Galactic fields where the reddening has been studied previously[28]. In those fields, stars appear to be unreddened at distances of up to ~ 500 pc, beyond which dust extinction produces colour excesses of $E_{B-V} = 0\cdot3$ or larger. Since V609 Aql is unreddened, its implied distance modulus is $V_0 - M_V = 8\cdot55$, corresponding to $d = 513$ pc ($\pi = 0''\cdot0019$), *i.e.,* roughly the maximum distance beyond which dust extinction becomes important. The solution is consistent with the known spatial distribution of dust in adjacent Galactic fields[28], but is larger than the original estimate of the system's distance[6], which was 385 pc. The difference appears to originate in the larger radii found here for the primary and secondary stars in the system.

Conclusions

From 18 new times of light minimum for V609 Aql obtained from examination of images in the HCO Photographic Plate Collection and three new estimates for light minimum obtained from recent observations of the system, we have calculated a new ephemeris for V609 Aql that includes a parabolic term. The inferred rate of period decrease, $dP/dt = -(7\cdot75 \pm 1\cdot39) \times 10^{-8}$ d yr^{-1}, implies a rate of mass transfer of $(6\cdot5 \pm 1\cdot2) \times 10^{-8}\,M_\odot$ year^{-1} from the primary in the system to the less-massive component, the primary overfilling its Roche lobe according to the new eclipse solution presented here. Small irregularities in the rate of period decrease for the system may simply be indicative of inhomogeneities in the rate of mass flow between the two components. The inferred parameters are at variance with the characteristics displayed by other members of the class of near-contact binaries[8], of which V609 Aql can no longer be considered a member.

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THE DOUBLE-LINED BINARY γ CANIS MINORIS

By C. D. Scarfe
University of Victoria

Since the first detection of the secondary component of γ Canis Minoris by Scarfe[1], enough observations have been obtained for a definitive spectroscopic orbit. The period is close to a year, so adequate phase coverage takes some time. The orbit solution is presented, and the physical nature and evolutionary status of the system discussed. The system is of interest because both components have left the main sequence, and are similar in mass but not in luminosity.

Introduction

The bright star γ CMi (HR 2854, HD 58972, BD +09°1660, α = 7^h 28^m 10^s, δ = 8° 55′ 32″ (2000)) was found to be a spectroscopic binary by Reese[2]. Its velocity variation is slow, and the orbital period, 389 days, exceeds a year by so little that several seasons are required to obtain full phase coverage. This may in part account for the long delay before the appearance of the first published orbital solution, that of Christie[3]. Despite the lapse of over 30 years, that solution was still of rather poor quality, meriting only a 'd' in the ranking system of Batten[4].

The MK spectral type of γ CMi was found to be K3 III by Roman[5]. Its *UBV* magnitude and colours have been determined several times[6,7,8,9], but all the results cluster around the values $V = 4\cdot32$, $(B−V) = 1\cdot42$, $(U−B) = 1\cdot54$, which are consistent with its spectral type. The fourth (1995) edition of the *General Catalogue of Trigonometric Parallaxes*[10] (*GCTP4*) gives a parallax of 0″·0177 ± 0″·0058, which leads to a visual absolute magnitude of 0·6 ± 0·7. However, the *Hipparcos*[11] parallax is 0″·0082 ± 0″·0010, which yields $M_V = −1\cdot2 \pm 0\cdot3$, rather more luminous than might be expected from its spectral classification. *Hipparcos* also measured annual proper motions of −0″·0593 in right ascension and +0″·0108 in declination. Together with the parallax these yield a space motion of 34·4 km s^{-1} perpendicular to the line of sight, almost as large as the systemic radial velocity.

Observations and orbital solution

The author's interest in γ CMi began in the late 1970s, with a couple of photographic plates at 2·4 Å mm^{-1} obtained with the DAO 1·22-m telescope and coudé spectrograph. But observations began in earnest in 1980, with the radial-velocity spectrometer (Fletcher *et al.*[12]).

However, despite the fact that the early data confirmed the large amplitude that had led to the large mass function (0·26$M_\odot$) found by Christie[3], it was not until the mid-1990s that it was thought worthwhile to extend the length of the traces obtained with the spectrometer, beyond that required for observing the primary, to look for the second 'dip' that would be produced by a late-type secondary star whose luminosity is not much less than that of the primary. Nevertheless, such a feature very quickly became apparent, and led to a preliminary solution[1], although that solution was based on scanty phase coverage for the secondary. However, by 2004, when the spectrometer was decommissioned, much better coverage had been obtained, with the total number of secondary observations increased more than fourfold. All of the DAO data are presented in Table I. The first two observations were photographic, but all the rest were obtained with the spectrometer. In all, they cover more than 25 orbital cycles.

A new orbit has been computed, from all the available data. Its elements are given in Table II, and the velocity curves are displayed in Fig. 1. To give a consistent standard error for an observation of unit weight, the secondary star data were weighted $^1/_4$ with respect to those of the primary. The Lick data of Christie[3] were found to fit the velocity curve from the DAO data well and they have been incorporated into the solution, with weight $^1/_6$, to refine the period. The other data available to Christie depart substantially from the curve representing the DAO data, and have not been included in the solution.

All the DAO velocities of the primary star that fall within about 5·0 km s^{-1} of the systemic velocity have also been given zero weight in the solution, since those velocities were derived from 'dips' distorted by blending, and give velocities systematically closer to that of the system's centre of mass than would be expected

Table I

DAO observations of γ Canis Minoris

Hel. J. D. −2 400 000	Cycle No. and Phase	V_1 km s⁻¹	$(O−C)_1$ km s⁻¹	V_2 km s⁻¹	$(O−C)_2$ km s⁻¹
43215·710	0·9639	32·3	0·4	60·3	−1·0
43550·822	1·8247	56·3	0·0	33·4	−0·9
44257·813	3·6406	62·1	−0·8		
44264·844	·6587	63·5	0·5		
44291·778	·7279	62·6	0·3		
44321·751	·8048	58·2	0·1		
44339·659	·8508	52·1	−1·0*		
44354·681	·8894	46·1	−0·9*		
44371·694	·9331	38·5	0·1*		
44614·845	4·5577	61·0	0·5		
44639·841	·6219	62·7	0·2		
44670·646	·7010	62·9	0·0		
44707·747	·7963	59·3	0·5		
44911·035	5·3185	45·3	0·9*		
45035·716	·6387	63·5	0·7		
45050·690	·6772	63·9	0·8		
45330·909	6·3969	50·9	−0·3*		
45406·709	·5916	61·9	0·1		
45427·715	·6456	63·4	0·5		
45442·702	·6841	63·1	0·1		
45455·663	·7174	62·8	0·2		
45624·090	7·1500	26·5	0·8		
45646·959	·2087	32·2	−0·3		
45716·852	·3883	49·3	−1·3*		
45749·713	·4727	57·2	0·8		
46069·870	8·2950	43·9	1·8*		
46078·841	·3180	46·2	1·8*		
46127·772	·4437	54·4	−0·2		
46163·706	·5360	59·4	−0·3		
46346·063	9·0044	25·2	0·5		
46391·965	·1223	22·2	−0·8		
46458·814	·2940	44·4	2·5*		
46555·684	·5429	61·0	1·0		
46732·965	·9982	24·9	−0·7		
46815·764	10·2109	33·5	0·8		
46834·750	·2597	40·6	2·3*		
46869·692	·3494	46·6	−0·7*		
46902·654	·4341	52·9	−1·0*		
46912·666	·4598	56·0	0·4		
47056·046	·8281	55·3	−0·5		
47073·015	10·8717	49·8	−0·2*		
47090·066	·9154	42·2	0·2*		
47146·868	11·0614	20·1	−0·1		
47150·931	·0718	20·6	0·3		
47164·770	·1073	20·5	−1·3		
47180·765	·1484	25·6	0·1		
47194·768	·1844	29·6	0·0		
47215·727	·2382	37·3	1·4*		
47227·697	·2690	40·7	1·4*		
47240·636	·3022	44·2	1·4*		
47259·652	·3510	47·1	−0·3*		
47444·061	·8247	55·9	−0·3		
47499·877	·9681	30·5	−0·5		
47801·003	12·7415	60·6	−1·3		
47939·734	13·0979	21·2	0·0		

TABLE I (*continued*)

Hel. J. D. −2 400 000	Cycle No. and Phase	V_1 km s^{-1}	$(O-C)_1$ km s^{-1}	V_2 km s^{-1}	$(O-C)_2$ km s^{-1}
47962·678	13·1568	26·1	−0·4		
48011·665	·2826	42·7	2·0*		
48184·944	·7277	62·2	−0·1		
48290·716	·9994	24·9	−0·5		
48340·640	14·1276	23·4	−0·1		
48388·675	·2510	38·0	0·7*		
48521·055	·5910	62·2	0·4		
48530·070	·6142	62·9	0·6		
48604·973	·8066	58·5	0·5		
48681·648	15·0035	26·1	1·3		
48997·925	·8159	56·6	−0·5		
49008·868	·8440	52·9	−1·1*		
49014·745	·8591	50·3	−1·7*		
49041·741	·9285	39·9	0·6*		
49084·736	16·0389	20·8	−0·3	72·5	−0·8
49096·665	·0695	20·0	−0·3	73·9	−0·4
49103·679	·0876	20·8	0·1		
49243·044	·4455	54·4	−0·3		
49263·058	·4969	57·6	−0·2		
49271·071	·5175	58·9	0·0	31·2	−0·3
49285·876	·5555	60·0	−0·5	29·6	−0·1
49337·834	·6890	63·5	0·5	27·1	0·2
49369·846	·7712	60·9	0·3	30·0	0·4
49382·773	·8044	58·5	0·3	32·4	0·2
49393·805	·8328	54·9	−0·4		
49417·753	16·8943	46·1	0·0*		
49442·634	·9582	33·7	0·6	60·2	0·2
49459·671	17·0019	24·9	−0·1	67·9	−1·0
49602·038	·3676	47·6	−1·3*		
49629·050	·4370	53·0	−1·1*		
49676·993	·5602	61·4	0·7	28·2	−1·2
49753·737	·7573	61·0	−0·2	30·5	1·8
49788·692	·8471	52·7	−0·9*		
49803·650	·8855	47·0	−0·7*		
49840·677	·9806	29·6	1·0	64·8	−0·1
49849·682	18·0037	24·6	−0·1	68·2	−1·0
50020·038	·4413	54·0	−0·4		
50046·981	·5105	59·6	1·2	32·8	1·0
50066·864	·5616	60·3	−0·4	30·0	0·7
50072·891	·5770	60·6	−0·7	25·6	−3·2
50124·768	·7103	62·0	−0·7	25·5	−1·7
50160·686	·8026	58·2	−0·2	32·1	0·1
50213·676	·9387	37·2	0·0*		
50436·845	19·5119	58·2	−0·4	29·7	−2·0
50461·854	·5761	61·6	0·3	27·5	−1·3
50475·802	·6119	62·6	0·3	28·4	0·7
50503·755	·6837	64·3	1·3	26·4	−0·5
50517·716	·7196	62·5	−0·1	28·6	1·3
50531·681	·7555	61·6	0·2	28·5	−0·2
50712·044	20·2188	33·8	0·2	60·5	1·1
50713·025	·2213	34·4	0·4	56·0	−3·1
50803·905	·4547	54·4	−0·9		
50858·719	·5955	62·0	0·2	28·5	0·4
50860·773	·6008	61·9	−0·2	27·7	−0·2
50872·711	·6314	63·3	0·6		

TABLE I (*concluded*)

Hel. J. D. − 2 400 000	Cycle No. and Phase	V_1 km s^{-1}	$(O−C)_1$ km s^{-1}	V_2 km s^{-1}	$(O−C)_2$ km s^{-1}
50917·670	20·7469	61·3	−0·4	27·6	−0·7
50931·672	·7829	59·3	−0·5	30·5	0·1
51071·049	21·1409	24·7	−0·1	68·0	−1·2
51085·044	·1768	28·4	−0·3	63·3	−1·6
51153·979	·3539	47·4	−0·2*		
51202·808	·4793	56·8	−0·0	32·7	−1·1
51223·759	·5331	59·4	−0·2	29·8	−0·9
51243·716	·5844	61·1	−0·4	27·9	−0·6
51284·676	·6896	62·5	−0·5	25·1	−1·8
51436·046	22·0784	20·2	−0·2	73·6	−0·5
51453·056	22·1221	23·8	0·8	70·9	−0·3
51466·073	·1555	27·2	0·9	65·1	−2·4
51485·032	·2042	32·4	0·4	60·5	−0·8
51622·722	·5579	60·5	−0·1	28·8	−0·8
51631·742	·5811	61·5	0·0	29·1	0·5
51633·709	·5861	61·4	−0·2	27·1	−1·4
51634·744	·5888	61·3	−0·4	27·1	−1·3
51811·039	23·0416	20·7	−0·2	73·8	0·2
51825·065	·0776	19·9	−0·5	74·5	0·4
51831·987	·0954	20·7	−0·3	73·9	0·5
51867·030	·1854	29·8	0·1	63·2	−0·6
52009·661	·5518	60·4	0·0	29·2	−0·6
52026·672	·5955	61·6	−0·3	27·6	−0·5
52164·033	·9483	36·0	0·9		
52387·708	24·5228	58·8	−0·3	31·6	0·5
52565·056	·9783	29·2	0·2	64·6	0·2
52599·928	25·0679	20·1	−0·2	76·0	1·7
52619·882	·1192	22·8	0·0	64·9	−6·5*
52625·874	·1346	23·8	−0·3	68·5	−1·5
52647·942	·1912	31·1	0·7	61·6	−1·3
52745·723	·4424	53·1	−1·4		
52761·672	·4834	55·0	−2·0*	30·0	−3·5*
52768·681	·5014	58·0	−0·1	33·9	1·5
52886·030	·8028	59·2	0·9	30·9	−1·1
52965·011	26·0057	25·0	0·5	68·3	−1·2
52982·884	·0516	20·5	0·0	73·7	−0·3
52996·860	·0875	21·2	0·5	76·7	3·0
53040·846	·2004	32·5	1·0	61·4	−0·3

*Observation rejected, zero weight in solution.

from their phases, as can readily be seen in Fig. 1. The standard error of an observation of unit weight is 0·60 km s^{-1}, and the minimum values of the masses of the components both exceed $1·5 M_\odot$. The mass of the secondary is $0·902 ± 0·007$ times that of the primary.

Properties of the system

The well-resolved traces obtained with the spectrometer show dips for the secondary that are about $1/5$ the size of those for the primary. Making some allowance for the fact that more luminous stars show stronger dips than those for fainter objects, this indicates that the secondary star is about 1·5 magnitudes fainter than the primary. This conclusion is supported by measures of the high-dispersion plates, on which the secondary is detectable only with difficulty, and

<div align="center">

TABLE II

Orbital and physical parameters of γ Canis Minoris

</div>

Period (days)	$389 \cdot 322 \pm 0 \cdot 016$
Hel. J.D. of periastron $- \, 2\,400\,000$	$49848 \cdot 2 \pm 0 \cdot 8$
Velocity amplitude of primary (km s^{-1})	$21 \cdot 41 \pm 0 \cdot 07$
Velocity amplitude of secondary (km s^{-1})	$23 \cdot 73 \pm 0 \cdot 18$
Eccentricity	$0 \cdot 259 \pm 0 \cdot 004$
Argument of periastron	$139° \cdot 6 \pm 0° \cdot 8$
Systemic velocity (km s^{-1})	$45 \cdot 86 \pm 0 \cdot 05$
$a_1 \sin i$ (Gm)	$110 \cdot 7 \pm 0 \cdot 4$
$a_2 \sin i$ (Gm)	$122 \cdot 7 \pm 0 \cdot 9$
$m_1 \sin^3 i$ ($M_\odot$)	$1 \cdot 76 \pm 0 \cdot 03$
$m_2 \sin^3 i$ ($M_\odot$)	$1 \cdot 59 \pm 0 \cdot 02$
Mass ratio m_2/m_1	$0 \cdot 903 \pm 0 \cdot 007$

<div align="center">

FIG. I

</div>
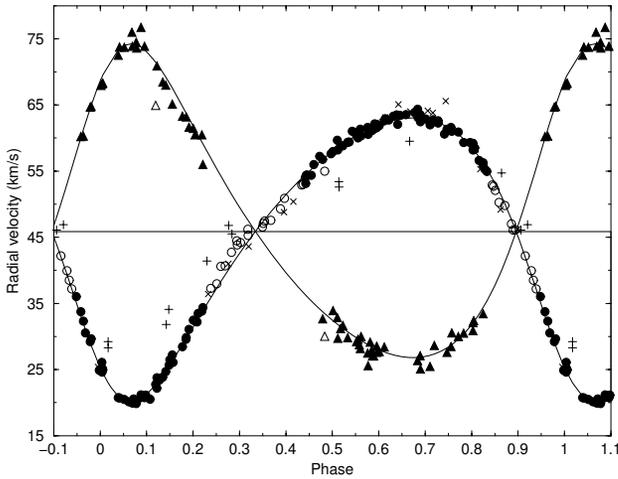
The radial-velocity curves of γ Canis Minoris. Circles represent DAO velocities of the primary star and triangles those of the secondary, with open symbols representing those of zero weight. The Lick velocities used by Christie (weighted $1/_6$) are shown as crosses, and his other data (weighted 0) as plus signs. The curves represent velocities calculated from the solution in Table II. The effect of dip blending on the zero-weight DAO velocities near the systemic velocity is particularly noticeable between phases $0 \cdot 25$ and $0 \cdot 45$.

yields only very uncertain measurements. The secondary's spectral type is unknown, but must be fairly late, since it shows a sharp dip on the scanner traces, consistent with a low rotation velocity, and since it seems to have little effect on the colour indices of the system, which are consistent with the primary's spectral type. All this leads to the supposition that the secondary is also an evolved star, probably a subgiant. It thus appears that γ CMi is a system of two evolved late-type stars, as was found by Scarfe *et al.*[13] to be the case for HR 6046.

There the similarity ends, however. In HR 6046 the components' masses are nearly identical, so much so that they are probably ascending the giant branch in the H–R diagram together, one following the other. In γ CMi, however, they are quite different, the secondary having only 90% of the mass of the primary.

The time scales of stellar evolution are such that they should not both be on the subgiant-giant branch at the same time. One possible way to explain their current status is to suppose that the primary has already passed the tip of the giant branch and is now consuming its core helium, while the secondary has yet to do so. Another system in which that is believed to be the case is that of Capella, according to Barlow *et al.*[14] In the latter system, tidal action near the time when the cooler star's radius was near its maximum value is thought to have circularized the orbit. That this has not happened in γ CMi may be attributable to its longer period and larger orbit. However, Pilachowski & Sowell[15] found that the abundance of lithium in the cooler component of Capella is much less than that in the hotter component, and attribute this to destruction of lithium in the cooler component by deep convection when it was near the red-giant tip. It would be worthwhile in the future to determine the lithium abundances in the components of γ CMi as a test of the hypothesis that the primary is now a helium-burning star.

To the author's knowledge, no eclipse observations have ever been published for γ CMi. On the assumption that no eclipse in fact occurs, plausible values of the stellar radii (30 and 15 solar radii for the primary and secondary stars, respectively) yield an upper limit to the orbital inclination close to 80°. The masses of the components must therefore be at least $1 \cdot 84$ and $1 \cdot 66 \ M_\odot$. If on the other hand we assume that the primary star's mass does not exceed $3 \ M_\odot$, then the minimum mass from the orbital solution implies an inclination of at least 57°. Without additional information, such as would be provided by resolution of the pair on the sky, one cannot constrain the masses or the inclination more closely.

No such resolution has yet been published, although unsuccessful attempts have been made by McAlister[16] and by Hartkopf & McAlister[17]. We can use their negative results to determine lower limits to the system's distance. At the time of McAlister's[16] observation in late 1976 the projected separation should, from the elements in Table II, have been close to its maximum possible value, and very little less at the time of that of Hartkopf & McAlister in early 1980[17]. Both of those observations lead to the conclusion that the system's parallax is less than $0'' \cdot 019$ if the inclination is 81°, and less than $0'' \cdot 016$ if it is 56°. Both of these are consistent with the mean value of $0'' \cdot 0177$ in *GCTP4*, and yield absolute magnitudes between zero and $+ 1$. If the parallax is smaller still, as the value of $0'' \cdot 0082$ found by *Hipparcos* indicates, the absolute magnitude is of course correspondingly brighter, near to $- 1$, and the expected angular separation smaller. Nonetheless, these values are near to those expected for giant stars, and thus we are led to conclude that the speckle observers must have come quite close to achieving the desired resolution of the system. It would probably yield to an attempt with an 8-m telescope, and even more surely to observation with a long-baseline interferometer. Such observations would be all the more valuable in combination with the present double-lined solution, since they would then enable accurate masses and luminosities to be obtained for the components of γ CMi.

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SPECTROSCOPIC BINARY ORBITS
FROM PHOTOELECTRIC RADIAL VELOCITIES

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

By R. F. Griffin
Cambridge Observatories

The first three objects are (at least for the purposes of this paper) single-lined binaries in which the observed star is a late-type giant; β Sct appears to most instruments to be an analogous object, but spectra at short wavelengths show faintly an additional component of early type, making the system a composite-spectrum one. The orbital periods are 621, 434, 1222, and 833 days, while the eccentricities are 0·32, 0·12, 0·29, and 0·32, respectively. The secondary star in 48 Psc appears to be marginally detected in radial-velocity traces near nodal passage; the mass function of 16 Aur is large enough to suggest that the secondary star might be detectable, and there is possible photometric evidence of an eclipse.

Introduction

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

the present state of astronomical research that much interest is centred on the faintest and most elusive objects, while so many bright stars, even ones visible to the naked eye, are known to be binaries and yet nobody has bothered to determine their orbits. That said, it should be recorded that the derivation of orbits for the first three stars discussed here was reported[1] at an AAS meeting nearly 20 years ago; only an abstract, with no orbital elements or other details, was published, but incomplete sets of preliminary elements had been presented for two of the stars, 16 Aur and 5 Her, at another conference[2] (IAU Colloquium 88, in Schenectady) some years previously. An orbit that was acknowledged by its author to be provisional was published[3] as long ago as 1936 for one of the three, 16 Aur, and proves to be very near the one derived below. β Scuti was recognized as a spectroscopic binary in the 19th Century, and a determination of its orbit was made 80 years ago. It is hardly surprising that we are in a position now to present an improved one; some of the earlier elements differ from the new ones by 10–40 standard deviations of the latter.

In a paper presented to the above-mentioned Colloquium in 1984, Beavers[2] gave a progress report on the observing programme undertaken with the photo-electric radial-velocity spectrometer[4] at the Fick Observatory at Ames, Iowa; he referred to the interest in bright late-type giant stars which exhibit radial-velocity variations in what were then regarded as long periods, and gave some preliminary orbital elements for certain of them, including 16 Aur and 5 Her among the objects of immediate interest here. Only the elements P, γ, K, and e were given, but not T or ω. At an AAS meeting in 1988, Beavers & Eitter[1] evidently reported orbital elements for no fewer than 18 spectroscopic binaries (many of them newly discovered by them) whose primaries are late-type giants. It is to be supposed that the orbits must by then have been much less preliminary than they had been four years previously, but the paper was reported[1] only as an abstract containing no information beyond the identities of the stars concerned. Already at that time the paper's senior author had left Ames and was no longer working in the field of astronomy. When several years had passed and it had become evident that the paper that had been presented to the AAS had not been worked up for publication in full, the present writer looked at the list of binaries to see whether any of them could usefully be added to his observing programme. The majority were in the southern celestial hemisphere and were inaccessible to the Cambridge telescope; two were already on the programme; but a few, including the three treated here, were adopted. The initial observations of all three of them were all made within a 24-hour interval in 1993 February. The observations upon which Beavers & Eitter depended, at least those made up to a certain point, had already been published[5] by those authors and provided a flying start to the campaign. The three stars have been systematically followed ever since. The fourth star discussed here, β Scuti, whose orbit was determined by Young[6] in 1927 on the basis of 17 spectra obtained with the DAO 72-inch reflector, was placed on the writer's observing programme in response to interest shown in it by devotees of stellar winds.

48 Piscium (HR 106, HD 2436)

About 4° following and 1° north of Algenib (γ Pegasi, the lower left-hand star of the Great Square as seen from moderate northern latitudes) is the sixth-magnitude star 48 Psc. Its magnitude and colours have been measured by Rybka[7] at $V = 6^m{\cdot}06$, $(B-V) = 1^m{\cdot}58$, $(U-B) = 2^m{\cdot}00$. Such extreme redness could easily characterize an early-M giant, but the accepted type of 48 Psc (as given, for example, in the *Bright Star Catalogue*[8]) is K5 III. It seems, however, as if no actual MK

classification is to be found in the literature; the _Bright Star Catalogue_ type may represent the Mount Wilson[9] type of K5 with a luminosity class assigned to it to correspond with the spectroscopically estimated[9] absolute magnitude. The _HD_[10] type is K2. In the second[11] of the large papers from Mount Wilson on spectroscopic absolute magnitudes, the 'estimated' type is given as K5 and the 'measured' type as K1; the distinction is that 'estimation' was performed in the classic manner, by direct visual comparison of the spectrum with suitable standards, whereas 'measurement' involved the quantitative comparison of the strength of the hydrogen lines Hγ and Hδ with specified nearby iron lines. Analogous comparison of luminosity-sensitive pairs of lines produced a value of $+0^m \cdot 5$ for the absolute magnitude; in a later paper[9] that value was revised to $+0^m \cdot 1$. The _Hipparcos_ parallax of only $0'' \cdot 00293 \pm 0'' \cdot 00072$ corresponds to a distance modulus of about $7^m \cdot 7 \pm 0^m \cdot 6$ and thereby to an absolute magnitude as bright as -1 or -2. The _Hipparcos_ data could advantageously be re-reduced with account taken of the orbital motion of the photocentre, which probably has an amplitude of about $0 \cdot 5$ AU.

Little interest has been shown in 48 Psc in recent years. Its infrared magnitudes have been measured by Kidger & Martin-Luis[12], who also gave results for $V (6^m \cdot 06)$ and $(B - V) (1^m \cdot 61)$, and the apparent angular diameter, as modelled by a conventionally limb-darkened disc, has been given[13] as $1 \cdot 99 \pm 0 \cdot 022$ milliseconds of arc.

Adams _et al._[14] were the first to measure a radial velocity for 48 Psc, no doubt from the same plates as they used[11] for classification and luminosity estimation; they gave a mean of $-1 \cdot 5$ km s^{-1} with a 'probable error' of $0 \cdot 6$ km s^{-1}. Nearly 50 years later Abt[15] very helpfully published the individual velocities and dates, which show that the plates were taken in 1916–1918. Adams _et al._ were unlucky not to discover the velocity variations: their four plates were all taken within a small range of phase though not all in the same cycle. Young[16] published a mean velocity of $-11 \cdot 1$ with a 'probable error' of $2 \cdot 6$ km s^{-1} from four plates taken at 66 Å mm^{-1} at Hγ with the 74-inch David Dunlap Observatory (DDO) reflector. An asterisk against the entry for 48 Psc in Young's paper draws attention to the fact that it was one of "a number of stars which showed a somewhat larger range than the agreement of the lines would lead one to expect", and the ensuing number, 19, specifies the range of the four velocities. It will be very useful if someone does the same for the DDO as Abt has done for Mount Wilson, by providing the individual data for velocities that were published only as means. In the text of his paper, Young mentions that "the detection of the binary character of those stars with small range, less than 20 km, is uncertain and doubtless some of these have been included as of constant velocity." (The perception of what constitutes a "small range" has evidently undergone considerable revision since the development of photoelectric measurement of velocities!) Adding to the data from Mount Wilson and the DDO, four radial-velocity measures[17] were made by the French objective-prism observers led by Fehrenbach. They have not been included in the discussion here; such measurements are never reliable enough for the purposes of orbit determination, and in fact only two of them would fall within the boundaries of the diagram (Fig. 2) of the orbit.

One might think that the discrepancy between the Mount Wilson and DDO means, coupled with the range of the DDO velocities, would have sufficed to identify 48 Psc as a binary, but in the event it was left to Beavers so to identify it, in the progress report[2] that he gave in 1984. The large listing[5] of Ames velocities by Beavers & Eitter includes 23 measurements of the star. Those measurements, together with those of Adams _et al._[14,15], are listed at the head of Table I. Some of the Ames observations are noted[5] as being of quality 'B' and are here identified

Table I

Radial-velocity observations of 48 Piscium

Except as noted, the sources of the observations are as follows:
1976–1983 — published by Beavers & Eitter[5] (weighted $^1/_{20}$ in orbital solution);
1987–1998 — Haute-Provence Coravel (wt. $^1/_2$); 1999–2006 — Cambridge Coravel

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
1914 Oct. 28·21*	20433·21	−0·7	$\overline{36}$·406	−0·1
1915 Jan. 2·12*	20499·12	−1·8	$\overline{36}$·512	−0·9
1916 Sept. 17·38*	21123·38	+1·8	$\overline{35}$·517	+2·7
Nov. 13·27*	180·27	−2·2	·608	+0·1
1976 Sept. 22·30	43043·30	−8·8:	0·792	+0·2
Dec. 15·09	127·09	−17·7:	·927	+0·9
22·07	134·07	−20·2	·938	−0·9
1977 Sept 10·39	43396·39	−1·4:	1·360	−0·5
1978 July 27·43	43716·43	−15·2:	1·875	−0·5
Aug. 5·40	725·40	−17·3:	·890	−1·5
23·36	743·36	−19·1:	·919	−1·1
Sept. 5·30	756·30	−20·1:	·940	−0·7
Oct. 5·27	786·27	21·8	·988	−1·1
Nov. 8·23	820·23	−15·9	2·043	+2·0
Dec. 10·07	852·07	−12·2:	·094	+0·9
1980 Aug. 23·36	44474·36	−14·5:	3·095	−1·6
Sept. 7·32	489·32	−10·7	·119	0·0
23·29	505·29	−8·9:	·145	−0·2
Nov. 25·10	568·10	−3·6	·246	−0·3
26·09	569·09	−3·6	·248	−0·3
1982 Jan. 8·03	44977·03	−15·7	3·904	+1·2
Oct. 22·23	45264·23	−1·9	4·366	−1·0
Nov. 17·15	290·15	−0·4	·408	+0·2
Dec. 17·06	320·06	−2·8:	·456	−2·2
1983 Aug. 25·38	45571·38	−11·6	4·861	+1·9
Sept. 9·31	586·31	−16·7	·885	−1·3
23·30	600·30	−19·4	·907	−2·3
1987 Nov. 20·86†	47119·86	−0·7	7·353	+0·3
1988 Nov. 26·86†	47491·86	−19·8	7·951	+0·2
1993 Feb. 11·76	49029·76	−0·9	10·426	−0·3
July 8·11	176·11	−3·3	·662	+0·3
Nov. 4·19‡	295·19	−13·2	·853	−0·2
Dec. 24·82	345·82	−18·8	·935	+0·3
25·91	346·91	−18·7	·937	+0·5
1994 Jan. 1·80	49353·80	−19·4	10·948	+0·4
Feb. 19·76	402·76	−19·1	11·026	+0·1
July 31·12	564·12	−2·2	·286	0·0
Dec. 10·83	696·83	−0·5	·500	+0·3
28·80	714·80	−0·9	·529	+0·2
1995 Jan. 4·80	49721·80	−1·0	11·540	+0·2
9·78	726·78	−0·9	·548	+0·4
June 3·11	871·11	−8·8	·780	−0·5
Dec. 31·81	50082·81	−10·6	12·121	0·0

Table I (*continued*)

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

TABLE I (*concluded*)

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

*Published Mount Wilson measurement[11,15]; weight 0.
†OHP observation[19], provided through the *CDS*, wt. 1/2.
‡Observed with ESO *Coravel*.
§Observed with Cambridge *Coravel*.
¶Observed with DAO 48-inch telescope; weight 1/2.

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

In papers that are not retrieved by *Simbad* for 48 Psc, the *Coravel* observers de Medeiros & Mayor[18] included the star in a listing (their Table 6) of "Double-lined spectroscopic binary systems SB2 with an evolved component", and de Medeiros, Udry & Mayor[19] gave a mean velocity of −11·53 ± 9·54 km s^{-1} (from *two* observations) and a $v \sin i$ of <1·7 km s^{-1}. Spurred on by the assertion of its SB2 character, the writer made careful observations of 48 Psc at the nodal passage of 2000 November, when any secondary should have been clearly visible in radial-velocity traces as an entity more or less separate from the primary dip. One such trace is shown in Fig. 1. There seemed to be just enough of a depression near the expected place to warrant saying that the secondary is probably detected, with a Δm of 3–4 magnitudes and a mass ratio not very far from unity, although for practical purposes the system could hardly be said to be double-lined. There are analogous or worse difficulties over many of the other stars in the two papers, which are by no means self-consistent. For example, all seven of the stars in ref. 19 Table 3, entitled "Rotation and radial velocity for 6 [*sic*] apparently single evolved
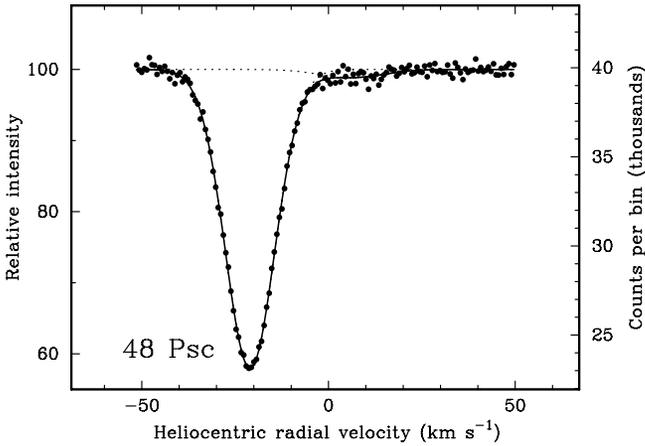
Radial-velocity trace of 48 Piscium, obtained with the Cambridge *Coravel* on 2000 November 3, showing an indication of a very shallow second dip. The observation was made very close to the more favourable node, at which the difference in radial velocity between the obvious component and any secondary would be a maximum. Analogous indications are seen in other traces obtained near the node. They are, however, so marginal that the author has not deigned to treat them as measuring the radial velocity of a companion star. The γ-velocity is $-7 \cdot 4$ km s^{-1}, from which the velocity of the primary differs in this observation by about -13 km s^{-1}, so an equally massive secondary could be expected to show a dip at about $+6$.

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

In the solution of the orbit of 48 Psc, the Mount Wilson observations have not been utilized, but the Ames ones have been included with a weight of 0·05. The OHP, ESO, and DAO spectrometer measurements have been half-weighted. The solution is illustrated by Fig. 2; the elements are as follows:

$$P = 621 \cdot 39 \pm 0 \cdot 13 \text{ days} \qquad (T)_{15} = \text{MJD } 51871 \cdot 9 \pm 1 \cdot 0$$
$$\gamma = -7 \cdot 44 \pm 0 \cdot 03 \text{ km s}^{-1} \qquad a_1 \sin i = 81 \cdot 5 \pm 0 \cdot 4 \text{ Gm}$$
$$K = 10 \cdot 09 \pm 0 \cdot 04 \text{ km s}^{-1} \qquad f(m) = 0 \cdot 0561 \pm 0 \cdot 0008 \, M_\odot$$
$$e = 0 \cdot 325 \pm 0 \cdot 004$$
$$\omega = 192 \cdot 7 \pm 0 \cdot 7 \text{ degrees} \qquad \text{R.m.s. residual (wt. 1)} = 0 \cdot 21 \text{ km s}^{-1}$$

For comparison, it should be recorded that Beavers[2] listed the period as 620 days and K as 9 km s^{-1}; he did not give any of the other elements.

The mass function requires the minimum mass of the secondary star to be 0·75 $M_\odot$ if the primary mass is supposed to be 2 $M_\odot$, or almost 1 $M_\odot$ if the primary were 3 $M_\odot$. If the secondary is indeed detected in radial-velocity traces (Fig. 1), then it cannot be a white dwarf but must be a tolerably late-type, probably F, star.

16 Aurigae (HR 1726, HD 34334)

16 Aur is a $4^1/_2$-magnitude star, to be found nearly $^3/_4$ of the way from Capella towards β Aur. Its Galactic latitude is about $-2°$; although the Milky Way appears
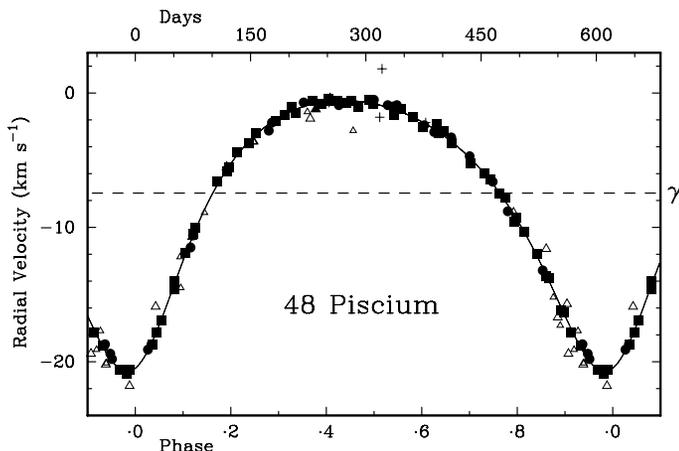
Fig. 2

The observed radial velocities of 48 Piscium plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The filled symbols are the ones that carry the principal weight in the orbital solution — squares represent data from the Cambridge *Coravel*, circles are for OHP observations and one ESO observation, and triangles are for the DAO spectrometer. Measurements published by Beavers & Eitter[5] from the Fick Observatory spectrometer[4] at Ames, Iowa, and weighted 0·05 in the solution are represented by open triangles; Mount Wilson velocities are plotted as plusses. Where certain velocities have been accorded smaller weights than normal for their source, they are shown with smaller symbols and their entries in the corresponding table (Table I) are followed by colons.

thin in that direction ($l \sim 173°$, almost exactly towards the anti-centre) 16 Aur is in the middle of a small cluster of 5^{m}–6^{m} stars that is so striking as to have impelled Melotte[20] to catalogue it as Mel 31. Within a radius of 1° from 16 are 14 (= KW) Aur, 17 (= AR) Aur, the fifth-magnitude but un-numbered IQ Aur, and 18 and 19 Aur. It is nothing more than a chance grouping of stars, as is demonstrated by their disparate radial velocities, proper motions, and parallaxes. At the cost of digression from the main point, however, it may be remarked that the two stars AR and IQ Aur do appear to be a physical pair; that seems to have been first pointed out by Bidelman to Hoffleit in time for the information to be incorporated in the notes to the third edition (1964) of the *Bright Star Catalogue,* and it has been discussed by Sargent & Eggen[21]. The note in the current (fourth) edition[8] of the *Catalogue* goes on to assert that AR Aur (HR 1728) is a member of the Aur OB1 Association, which is not so but has been subscribed to by such authorities as Batten *et al.*[22] and Nordström & Johansen[23]. Aur OB1 is[24] actually about ten times as far away as AR and IQ Aur.

As well as being a spectroscopic binary, 16 Aur is a visual binary, there being a companion of about the eleventh magnitude about 4″ away from the principal star. The companion was discovered by (Otto) Struve[25] at Poulkova in 1846 and carries his 'discovery number' OΣ 103; it features in Burnham's double-star catalogue[26] as BDS 2623 and in Aitken's[27] as ADS 3872. There has been no clear relative motion, so the companion must share very accurately the large proper motion (0″·164 annually) of the primary; the pair has accordingly travelled together some 25″ across the sky since the discovery of the companion, leaving no doubt as to the physical association of the components.

The broad-band magnitudes of 16 Aur have been measured by a number of observers[28–32], with results close to $V = 4^{\text{m}} \cdot 54$, $(B−V) = 1^{\text{m}} \cdot 26$, $(U−B) = 1^{\text{m}} \cdot 27$. The V values show a range of $0^{\text{m}} \cdot 04$, possibly raising a suspicion of slight variability. Indeed, Johansen[33], who was not observing 16 Aur with a view to determining its own magnitude but was using it as a comparison star in a photometric investigation of AR Aur, noted that it appeared slightly ($0^{\text{m}} \cdot 02$) faint on two particular dates, and was perceptive enough to point out that such a decline might be attributable to an eclipse if the orbital period of $434 \cdot 8$ days found for 16 Aur by Christie[3] were only half a day in error.

Spectroscopic estimates were made of 16 Aur's luminosity as early as the 1920s at the DAO by Young & Harper[34], who gave independent assessments of $M_V = +0^{\text{m}} \cdot 2$ and $+0^{\text{m}} \cdot 6$, respectively, and at the Norman Lockyer Observatory by Rimmer[35], who obtained $+1^{\text{m}} \cdot 1$. Adams *et al.*[9] at Mount Wilson later listed it as $+0^{\text{m}} \cdot 4$. Wilson[36] found $M_V = +0^{\text{m}} \cdot 6$ by his K-line method. The star's parallax of $0'' \cdot 01392 \pm 0'' \cdot 00139$, as determined by *Hipparcos*, corresponds to a distance modulus of $4^{\text{m}} \cdot 28 \pm 0^{\text{m}} \cdot 22$ and so to an absolute magnitude of $+0^{\text{m}} \cdot 26$ with the same uncertainty, largely corroborating the efforts of the early spectroscopists.

The MK type was first given by Roman[37], as K3 III. Keenan, who was greatly exercised over spectral classifications in the 1980s, included 16 Aur in several successive catalogues giving revisions of the MK standards for late-type stars. In 1983 he[38] gave the type as K2 · 5 IIIb CN −0 · 5. Certainly it is a fact that CN is extraordinarily weak: in the quantitative measurements made by Griffin & Redman[39] almost half a century ago, 16 Aur had the smallest 'CN ratio' of all among 49 stars classified then as K3 III. But in 1985 Keenan & Yorka[40] dropped the reference to CN and instead called 16 Aur K2 · 5 IIIb Fe −1. Confusingly, in a 1987 paper on the recognition of 'SMR' stars, Keenan, Yorka & Wilson[41] showed low-resolution intensity plots of the blue–violet region of the spectra of four stars that range from the SMR μ Leo through the mild-SMR κ Lyr and the normal HR 6793 to the metal-weak 16 Aur, whose type is given as [K]2 · 5 III CN −1 — and indeed the tracings show that the CN band in 16 Aur is dramatically weaker than it is in the other three stars. All the same, in 1988 Keenan & Yorka[42] had again dropped any reference to CN in favour of Fe, and had adjusted both the temperature and the luminosity classes, to K2 III Fe −1; but in the following year the *Perkins Catalogue*[43] put it at K2 · 5 III Fe −1, so the earlier temperature class was restored. After the results of the *Hipparcos* mission were published, Keenan was naturally concerned to make sure that the MK luminosity classifications accorded with the parallaxes (an exercise which actually resulted in surprisingly modest alterations and went far towards validating all his previous labours on classification), and in a paper[44] with Barnbaum he presented a further listing of MK standards, but 16 Aur is not included. At the time of his death, Keenan had been working on a much larger catalogue which has not been published, but he had sent the first nine hours of right ascension (corresponding to the part of the sky covered in the printed version of the previous one[44]) to the present author in manuscript; there, he reverted to the type K2 · 5 IIIb CN −0 · 5 for 16 Aur — exactly the same as it had been five revisions previously! The catalogue, with its brief introductory text, and extended as far as 14 hours RA which is as far as Keenan got with it (the associated notes still go only to 9 hours), is accessible at the time of this writing at a web site identified in a footnote on the second page of ref. 44.

In an earlier instance of equally bewildering changes of classification (that of ζ Cyg, Paper 105[45] in this series), the situation was so bad that, on reading through the completed paper, its author feared that it read like an attack on Keenan!

Instead of submitting it for publication, therefore, he posted it straight to Keenan with a suitably apologetic covering letter saying that no doubt he (Keenan) could explain everything and inviting him to do so, becoming a co-author of the paper in the process; very sportingly, Keenan accepted, and indeed his explanations did clear the air substantially, to the benefit of everyone. But alas, the same expedient is no longer open to us! During the time that Keenan was evidently wrestling with the problem of classifying 16 Aur, Abt[46] joined the fray with a type of K3·5 III.

16 Aur featured in most of the early Cambridge programmes of narrow-band photoelectric spectrophotometry, beginning with the work already cited[39]. The results can be summarized by saying that the various narrow-band indices were quite normal for the spectral type, apart from the weakness of CN[39]. Subsequent investigations[47–50] made elsewhere of its chemical abundances agree in finding the star to have a modest metal deficiency of something like a factor of two compared with the Sun.

By virtue of its being brighter than $5^m·5$, 16 Aur was included in the Lick programme of systematic measurements of the radial velocities of the bright stars. The first two observations were made in 1905 and 1908; the third, in 1910, exhibited a very large discrepancy which prompted an immediate announcement[51] of the star's variable velocity. The complete results of the programme, with a total of five measurements of 16 Aur, was published by Campbell & Moore[52] in 1928. In the meantime five velocities had been published by Küstner[53] from plates taken with the 12-inch refractor at Bonn; they were all taken within an interval of three weeks in 1913. Two more measurements were provided from the DAO by Harper[54]. In 1936 Christie, working at Mount Wilson, included 16 Aur in a paper entitled *The Provisional Elements of 16 Spectroscopic Binaries*. He did not tabulate his data, but noted that the orbit of 16 Aur had been under investigation since 1933 and that he had five velocities from Lick, 18 from his own observatory, and two from the DAO. There is a graph of the orbital velocity curve, with the data plotted on it; it appears to be one of the best among the 16. (It may be noted that it is captioned 'Boss 1258' — a designation[55] not used for 16 Aur elsewhere in the paper — and the ordinates are labelled with reversed sign.) The elements were not derived mathematically but simply by comparison of the velocities (plotted *modulo* the apparent orbital period) with a set of standard curves; one result is that eccentricities are given only to 0·1 and longitudes of periastron to 10°.

In Abt's listing[15] of the individual dates and velocities for measurements made at Mount Wilson but previously published (if at all) only as mean values, there are but two entries for 16 Aur, dating from 1924 and 1926 and no doubt representing measures of the plates used by Adams *et al.*[9] in their work on spectroscopic luminosities. The other 16 plates whose existence is implied by Christie's paper were evidently not to be found in the Mount Wilson records at the time that Abt compiled his catalogue. It is a curious fact that most plates used by Christie seem to have disappeared without trace: it has been noted previously that three plates were thus lost in the case[56] of HR 4668 and no fewer than 109 in the case[57] of HR 6363. For HR 6046 it looks from Christie's *tabulation* as if there were 11 Mount Wilson plates (all of which are now lost), but his *diagram* of the orbit appears to show 16, so it seems that Christie had already lost sight of some of the plates even before he had compiled his own table!

In his 1984 progress report[2] on work being performed with the Ames spectrometer[4], Beavers presented a tabulation which gave preliminary values for P, K, and e for 16 Aur; more precisely specified values, with standard errors, are noted on a graph of the orbit. The tabulation also showed that he had at his disposal 30

TABLE II

Radial-velocity observations of 16 Aurigae

Except as noted, the sources of the observations are as follows:
1905–1910 — Lick[52], weighted 1/40 in orbital solution;
1913 — Bonn[53]; 1921, 1923 — DAO[54]; 1924, 1926 — Mt.Wilson[15], all wt. 0;
1977–1984 — published by Beavers & Eitter[5]; weight 1/20;
1989–1998 — Haute-Provence Coravel (wt. 1/2); 1999–2007 — Cambridge Coravel

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

TABLE II (*continued*)

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

TABLE II (*concluded*)

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

* OHP observation[18], provided through the *CDS*, wt. 0.
† Observed with Cambridge *Coravel* in preliminary form (wt. 1/4).
‡ Observed with DAO 48-inch telescope (wt. 1/2).
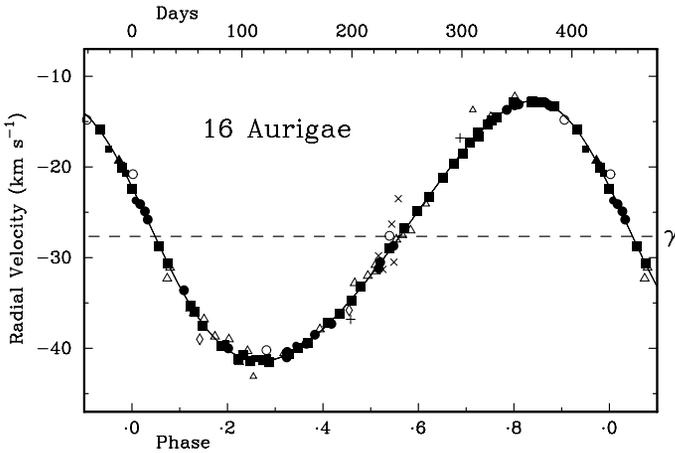
FIG. 3

The observed radial velocities of 16 Aurigae plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The same symbols are used as in Fig. 2 for the corresponding data sources. Additional sources featured here are Lick[52] (open circles; weight 0·025), and the DAO (open diamonds; two measures by Harper[54]) and Bonn (crosses; six measures by Küstner[53]) (both zero-weighted).

radial velocities, including the five published[52] from Lick, so he must have had 25 of his own. Exactly that number of Ames velocities of the star were subsequently published[5]; they are included in Table II, together with the measurements from Lick[52], Bonn[53], the DAO[54], and Mount Wilson[15]. Also in Table II are two measurements made by de Medeiros & Mayor[18] with the OHP *Coravel* in 1989. Starting in 1993, the present writer has made 64 observations of 16 Aur — 18 with the OHP *Coravel* and 45 with the Cambridge one, plus one with the DAO spectrometer — to add to the table. All the published observations, as well as the OHP ones, have been adjusted by $+0.8$ km s^{-1}; in addition, the early Bonn, Mount Wilson, and DAO ones have received the corrections assessed in Table 3 of the *Introduction* to the *Radial Velocity Catalogue*[58]. In the solution of the orbit, the Cambridge *Coravel* observations have been accorded unit weight, except that the six made in 1996/7, when the spectrometer was in a preliminary form, have been weighted $1/4$. The single DAO and 18 OHP ones have been half-weighted. The few published measurements from Bonn, Mount Wilson, the DAO, and de Medeiros & Mayor have not been used in the solution. The Lick velocities have been weighted 0.025, and the Ames ones 0.05, apart from five which are noted[5] as quality B: their velocities are followed by a colon in Table II and their weighting has been halved. In some ways it is a bit unfortunate to be obliged to attribute such derisory weightings to velocities that by earlier standards were excellent. Those velocities, however, greatly increase the time base of the data and thereby contribute significantly to the precision with which the orbital period is determined (in the present case approximately doubling it); that precision would, however, reach illusory heights if the early data were charitably accorded weightings above what their actual variances warrant. The elements found here for the orbit are shown in Table III; those given by Christie[3] and by Beavers[2] are listed for comparison. The velocity curve and the data are illustrated in Fig. 3.

TABLE III

Orbital elements for 16 Aurigae

Element	*Christie*[3]	*Beavers*[2]	*This paper*
P (days)	434.8	441.5 ± 0.1	434.16 ± 0.03
T (MJD)	18689.5	—	51727.2 ± 1.4
γ (km s^{-1})	−27.5	−26.4 ± 0.4	−27.65 ± 0.03
K (km s^{-1})	14.8	14.2 ± 0.6	14.35 ± 0.04
e	0.1	0.12 ± 0.04	0.1189 ± 0.0026
ω (degrees)	40		70.1 ± 1.2
$a_1 \sin i$ (Gm)	—	—	85.09 ± 0.21
$f(m)$ $(M_\odot)$	—	0.13	0.1305 ± 0.0010
R.m.s. residual (wt 1) (km s^{-1})	—	1.8	0.18

The orbit, whose period is more than a year, is seen now to be established with an uncertainty of less than an hour. Agreement between the new elements and the previous ones, as far as those went, is seen to be good (the values of T refer of course to quite different epochs!), apart from the period found by Beavers. Since Christie[3] specifically remarked, "The period is well defined by the early Lick observations", and he thought it appropriate to give it to a tenth of a day and proves to have been right to have done so, *why*, one may ask, would Beavers have made an error of a week although he recorded that he too utilized the Lick measures and indeed claimed a standard error of only 0.1 day for the period? The answer is actually not far to seek, since we have available to us what is presum-

ably the exact data set that Beavers used, encompassing 25 of his own observations plus the five from Lick, so we are able to experiment with his data. He could be expected to have known about the old Mount Wilson observations too, since he used analogous ones from the same source[15] in his orbit of 5 Her, but he does not mention them. If he had started by solving the orbit from his own observations alone, he would have obtained a preliminary period of $435 \pm 1 \cdot 0$ days, which he could then have used as the starting value for a solution that incorporated the Lick velocities and would then have obtained $434 \cdot 12 \pm 0 \cdot 07$ days. But what evidently happened was that he omitted the preliminary step and started the solution of the whole data set at (probably) $P = 440$ days, thinking that that would be 'near enough', and the solution pulled in to the period that he found of $441 \cdot 5$ days (actually it produces $P = 441 \cdot 48 \pm 0 \cdot 12$ days) which corresponds to an error of 1 in the cycle count between the Lick and Ames epochs. That is still a plausible-looking solution if one is not comparing it with the correct one, although the r.m.s. error found for the (A-quality) Ames observations is raised from $0 \cdot 9$ to $1 \cdot 7$ km s^{-1} (Beavers noted it as $1 \cdot 8$, but he may not have down-weighted the B-quality velocities). In the 'wrong' solution the two old Mount Wilson velocities give residuals of $16 \cdot 0$ and $4 \cdot 6$ km s^{-1} whereas in the 'right' one they are only $2 \cdot 1$ and $1 \cdot 8$ km s^{-1}, so it seems likely that Beavers disregarded them. This is not the first time that an error has been found[59–61] in the cycle count between sets of data taken at well-separated epochs.

It is of interest to review Johansen's suggestion[33] that a slight apparent dimming of 16 Aur on two nights might have been due to an eclipse. The dates concerned are 1966 January 23 and 29. There was a conjunction on 1966 January $29 \cdot 3$, with an uncertainty of a little more than a day; at that conjunction (phase $\cdot 047$) the primary star is at the far side of its orbit, so the event would be of the nature of a transit. The mass function is substantial: it requires a minimum mass of about $1 \cdot 05$, $1 \cdot 3$, and $1 \cdot 55$ $M_{\odot}$ for the secondary if the primary mass is taken as 2, 3, or 4 $M_{\odot}$, respectively. If a transit really takes place, then $\sin i \sim 1$ and the secondary has virtually the minimum mass required by the mass function. If a transit of the secondary were indeed responsible for the apparent dimming by about $0^{\mathrm{m}} \cdot 02$, then that object must have covered about 2% of the surface area of the primary. Tabular values of the radii of mid-K giant stars run to about 20 $R_{\odot}$; if that is true for 16 Aur, it would take an occulting body with a radius of about 3 $R_{\odot}$ to cover 2% of it — too big, if we suppose the secondary to be a main-sequence star of little more than one solar mass. We could of course posit that the secondary is beginning its evolution and has recently swollen to the requisite size, but that is rather an artificial and *ad hoc* hypothesis. We could also consult the *Catalogue of Apparent Diameters and Absolute Radii of Stars*[62] for an individual assessment of the diameter of the 16 Aur primary. We find there an angular diameter of $0'' \cdot 00400$, on no less (but no more recent!) an authority than Hertzsprung's[63]; his actual listing, based simply on the brightness and colour of the star, shows an angular *radius* of $0'' \cdot 0020$. The *Catalogue*[62] interprets it as corresponding to a linear radius of $16 \cdot 5$ $R_{\odot}$, but the present writer has difficulty in agreeing. The *Hipparcos* parallax is $0'' \cdot 01392$ with a standard error just one-tenth as large, so the distance is about 72 pc. At that distance, $0'' \cdot 002$ represents $(0 \cdot 002 \times 72)$ AU, *i.e.*, $0 \cdot 144$ AU or about 31 $R_{\odot}$ (still with an uncertainty of 10% stemming from the parallax plus whatever amount we might assign to Hertzsprung's number), exacerbating the difficulty over the size needed for the secondary to cover 2% of it. It might be concluded that Johansen's suggestion — which was responsible for 16 Aur's inclusion in the *New Catalogue of Suspected Variable Stars*[64], where it is no. 1909 — is an

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

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

The *Hipparcos* catalogue includes a (surprisingly short) section[65] giving astrometric orbits; there are 235 of them, of which only 45 are independent, the others utilizing some information derived from already-known spectroscopic orbits. 16 Aur features in the listing, in the latter category: P, e, and ω were adopted from Christie[3], and T, a_0, i, and Ω were derived from the satellite's measurements. It seems hardly worthwhile to cite the values of those quantities here, because Pourbaix & Boffin[66] subsequently rejected them, finding that the orbit did not survive their statistical tests. All the same, it seems reasonable to expect that, since 16 Aur is a single-lined system with an $a_1 \sin i$ of more than half an AU, it should exhibit an astrometric orbit with an angular semi-axis of more than half the annual parallax — as indeed the *Hipparcos* orbit gave for it (0″·00724).

5 Herculis (*HR 5966, HD 143666*)

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

The *UBV* magnitudes of 5 Her have been measured by Roman[67], Argue[29], and Johnson *et al.*[30], with results close — in fact identical in the cases of V and $(U-B)$ — to $V = 5^m \cdot 12$, $(B-V) = 0^m \cdot 99$, $(U-B) = 0^m \cdot 74$. The *HD* type is G5, but in their early assessment of spectroscopic parallaxes Adams *et al.*[11] gave G7 as both the 'estimated' and the 'measured' type (see the section on 48 Psc for explanation), and maintained that classification in their later paper[9]. In both papers the absolute magnitude is given as $+0^m \cdot 7$. At much the same time (1921) as the earlier paper[11], Rimmer[68] determined an M_V of $+0^m \cdot 9$, and Young & Harper[34] each independently found it to be $+1^m \cdot 0$. The *Hipparcos* parallax of 0″·01058 ± 0″·00085 yields a distance modulus of $4^m \cdot 88 \pm 0^m \cdot 18$ and thereby an absolute magnitude of $+0^m \cdot 24$ — a little brighter than any of the early spectroscopic estimates. The *Hipparcos* number stems from an 'acceleration solution'; in view of the fact that 5 Her actually made almost a complete orbital circuit while it was under observation by *Hipparcos*, it is clear that a continuous acceleration must be, at best, a very rough representation of the actual photocentric motion, and one must expect that a re-reduction that takes into account the orbital parameters would lead to a more reliable result.

The MK type was first given by Roman[37,67] as K0 III, but Harlan[69] regarded it as G8 III. Keenan[38,40] initially gave the more refined classification of G8 IIIb Fe -0.5, but then[43] truncated it to plain G8 IIIb. Fig. 1 of ref. 44 shows that the luminosity derived from its parallax places it right on the boundary between luminosity classes III and IIIb; in fact the Keenan luminosity class is aligned better with the estimates of the spectroscopic-parallax pioneers[11,68,34,9] than with the *Hipparcos* measurement, but the difference is not great. The slight metal deficiency that Keenan noted[38,40] for a time in his classifications is supported by deductions both from narrow-band photometric indices[47,48,70–73] and from actual spectra[50,71], which all give results of $[Fe/H] \sim -0.25$. Noticeable also is the fact that they concur in giving values of M_V close to $+1^m\cdot0$, in agreement with Keenan[43] as well as with the early values, and distinctly fainter than is indicated by the *Hipparcos* parallax. By coincidence, in one of the narrow-band papers, that of Gottlieb & Bell[48], 5 Her is the subject of a 'worked example' that demonstrates the procedure used by those authors to interpret the narrow-band indices derived by Spinrad & Taylor[74] from spectral scans at 15-Å resolution. Spectroscopy[71] of the $\lambda6708$-Å region found that the Li I line that is present in some stars at that wavelength was undetectably weak in 5 Her.

Radial velocities of 5 Her were published from no fewer than three observatories in the 1920s. Plaskett *et al.*[75] listed six measurements of the star (under the alias Boss[55] 4075) made at the DAO in 1919 and 1920 with a prism spectrograph giving about 30 Å mm^{-1} at Hγ; they range between $-18\cdot2$ and $-13\cdot9$ km s^{-1} in a non-systematic fashion. Adams *et al.*[14] gave a mean value of $-16\cdot9$ from three plates taken at Mount Wilson, with a 'probable error' of only $0\cdot2$ km s^{-1}. Abt[76] comes to the rescue once again with the individual times and velocities, which show that the dispersion used was 36 Å mm^{-1} at Hγ, thereby identifying also the telescope as the 60-inch; it is seen that two of the plates were taken on the same evening, so their results have been averaged and treated here as a single observation. Then the Lick compendium[52] of velocities of practically all stars brighter than $5^m\cdot5$, derived from spectra taken at 11 Å mm^{-1} at Hγ with the 36-inch refractor, includes five velocities for 5 Her. Four are near -21 km s^{-1}, but the third plate, which is well removed in time from the others, disagrees by an amount that is definitely significant in relation to the normal accuracy of Lick measures on stars with good lines. That fact was evidently noticed, because the plate was remeasured by another person — the two measures gave $-14\cdot5$ and $-15\cdot8$ km s^{-1} — but there is no comment that the velocity is or may be variable, probably owing to commendable caution in view of there being only the one discrepancy.

Events then ran parallel with those relating to 16 Aur: at the Schenectady Colloquium[2] in 1984 Beavers presented, and in the *Proceedings* published, a partial set of preliminary orbital elements. It was based on 33 observations that included the five from Lick[52] and three from Mount Wilson[14,76], so it would seem that he had 25 of his own measurements; 24 was the number subsequently published in his big paper[5] with Eitter. Three other velocities were reported by de Medeiros & Mayor[18] and were later made available from the *Centre de Données Stellaires*. Meanwhile the present writer began observing the star in 1993 and has followed it ever since, accumulating 89 new measurements, of which two came from the DAO spectrometer, 19 from the OHP *Coravel*, and 68 from the Cambridge one.

All of the available velocities are listed in Table IV. The Lick[52], Mount Wilson[14,76], and DAO[75] ones, and those made at OHP, have all been increased by $0\cdot8$ km s^{-1}, as usual. The additional corrections recommended[58] by the *Radial Velocity Catalogue* for Mount Wilson and the DAO have not been applied in this

TABLE IV

Radial-velocity observations of 5 Herculis

Except as noted, the sources of the observations are as follows:
1976–1983 — published by Beavers & Eitter[5], weighted 1/16 in orbital solution;
1986–1998 — Haute-Provence Coravel; 1999–2007 — Cambridge Coravel

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O−C) km s⁻¹
1918 Apr. 17·47*	21700·47	−21·3	$\overline{17}$·078	+0·9
Aug. 7·23*	812·23	−20·3	·169	+0·5
1919 May 19·36†	22097·36	−15·9	$\overline{17}$·403	+1·1
Aug. 8·18*	178·18	−17·4	·469	−1·1
12·18†	182·18	−16·6	·472	−0·4
1920 Feb. 11·58‡	22365·58	−16·4	$\overline{17}$·622	−1·2
24·56‡	378·56	−17·4	·633	−2·2
Apr. 11·45‡	425·45	−13·1	·671	+2·0
May 7·36‡	451·36	−15·7	·692	−0·7
15·30‡	459·30	−14·6	·699	+0·4
25·25‡	469·25	−14·4	·707	+0·6
1922 May 7·46*	23181·46	−20·3	$\overline{16}$·290	−1·7
1924 May 17·44*	23922·44	−19·0	$\overline{16}$·896	−1·5
1976 May 19·28	42917·28	−17·0	0·438	−0·4
June 1·28	930·28	−17·1:	·449	−0·6
20·22	949·22	−16·6	·464	−0·3
July 6·18	965·18	−15·1:	·477	+1·1
1977 Mar. 22·38	43224·38	−13·3	0·689	+1·7
Apr. 27·29	260·29	−15·3	·719	−0·2
July 2·21	326·21	−15·6::	·773	−0·3
6·17	330·17	−15·8:	·776	−0·5
1978 May 16·25	43644·25	−21·6	1·033	+0·4
June 9·20	668·20	−20·0	·052	+2·2
18·18	677·18	−22·4	·060	−0·2
July 15·18	704·18	−22·8	·082	−0·7
Aug. 11·11	731·11	−21·1	·104	+0·8
1979 Mar. 15·42	43947·42	−18·9	1·281	−0·1
May 21·24	44014·24	−15·7	·336	+2·2
24·20	017·20	−17·6	·338	+0·3
June 22·17	046·17	−17·4	·362	+0·1
1982 May 7·25	45096·25	−20·7	2·221	−0·9
June 2·21	122·21	−20·3	·242	−0·9
8·18	128·18	−20·1	·247	−0·8
23·17	143·17	−20·8	·259	−1·7
1983 Apr. 20·32	45444·32	−15·5	2·506	+0·4
May 23·27	477·27	−16·2	·533	−0·5
June 8·25	493·25	−15·9	·546	−0·3
1986 June 4·93§	46585·93	−16·6	3·440	0·0
July 28·87§	639·87	−16·3	·484	−0·2
1987 May 10·10§	46925·10	−15·0	3·717	+0·1

TABLE IV (*continued*)

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

TABLE IV (*concluded*)

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

*Lick observation[52], weight 1/20.
†Mount Wilson observation[14,76], weight 0.
‡DAO observation[75], weight 0.
§OHP observation[18], provided through the *CDS*, wt. 1.
¶Observed with Cambridge *Coravel* in preliminary form, wt.1/4.
‖Observed with DAO 48-inch telescope, weight 1.

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

$-0\cdot 3$ km s^{-1} to bring them into line with the OHP ones, an amount in keeping with the relative offset found previously between the two sources for stars of such a colour as that of 5 Her. As far as weighting is concerned, the *Coravel* measurements have been accorded unit weight, except that the four measures made in Cambridge in 1997, when the instrument was in a preliminary state, were weighted $1/4$ like the corresponding ones for 16 Aur, and the small negative correction made to the later Cambridge data was omitted from those four. The Mount Wilson data[14,76] were deemed too few, and the DAO ones[75] too ragged, to be usefully included in the solution of the orbit and were attributed zero weight. The Lick[52] velocities have been weighted $1/20$ and the Ames[5] ones $1/16$, the weighting being halved for the three Ames B-quality ones (listed with a colon in Table IV) and divided by 5 for the single C-quality measure (double colon). The orbit obtained on the basis just set out is shown in Fig. 4 and its elements are:

$$P = 1222\cdot 2 \pm 1\cdot 0 \text{ days} \qquad (T)_8 = \text{MJD } 52159 \pm 6$$
$$\gamma = -17\cdot 85 \pm 0\cdot 03 \text{ km s}^{-1} \qquad a_1\sin i = 57\cdot 5 \pm 0\cdot 7 \text{ Gm}$$
$$K = 3\cdot 58 \pm 0\cdot 04 \text{ km s}^{-1} \qquad f(m) = 0\cdot 00509 \pm 0\cdot 00018\ M_\odot$$
$$e = 0\cdot 294 \pm 0\cdot 010$$
$$\omega = 137\cdot 2 \pm 2\cdot 1 \text{ degrees} \qquad \text{R.m.s. residual (wt. 1)} = 0\cdot 23 \text{ km s}^{-1}$$

The preliminary elements given by Beavers[2] are $P = 1221\cdot 7 \pm 1\cdot 9$ days, $\gamma = -18\cdot 1 \pm 0\cdot 2$ km s^{-1}, $K = 3\cdot 56 \pm 0\cdot 27$ km s^{-1}, and $e = 0\cdot 15 \pm 0\cdot 08$. The mass function is too small to encourage hope that the secondary object will be detectable at all easily; as in the case of 48 Psc, it is more likely to be a lower-main-sequence star than a white dwarf.
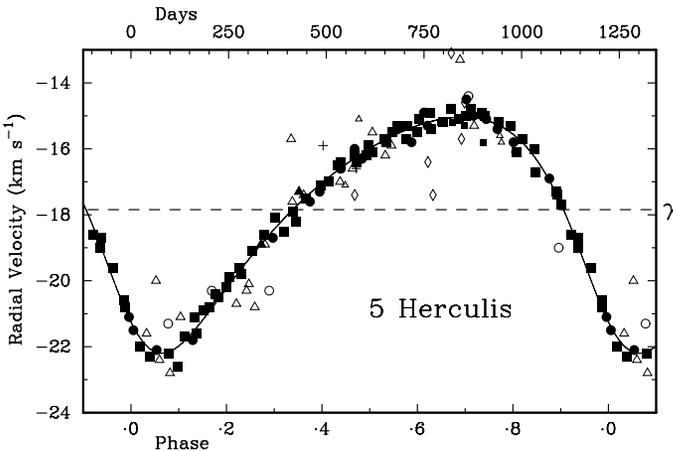
Fɪɢ. 4

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

β Scuti (HR 7063, HD 173764)

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

one thinks of the analogous stars in rich constellations such as Gemini or Orion, it seems that only in a very ill-starred constellation could β be as faint as the $4^m \cdot 22$ of β Scuti. Further misgivings are aroused by the fact that the radial-velocity measurements of the star are set out in Campbell & Moore's great compilation[52] from Lick under the designation 6 Aquilae. Such considerations prompted a small investigation of the relevant matters of nomenclature, with the following results. β Sct is by no means the faintest of its ilk: among the 88 constellations, six are shown in the *Bright Star Catalogue* as not possessing a β at all, and in 17 cases the β is fainter than β Sct; in five of those cases it is fainter than 5^m, and the wooden spoon is adjudicated to β Mic at $6^m \cdot 04$! Moreover, the constellation Scutum has itself had a chequered history. It is not one of the ancient constellations, but was invented by Hevelius[77] as 'Scutum Sobieskii', named by him after King Jan [John] III Sobieski (1629–1696) of Poland, probably as a mark of gratitude for the King's support after his (Hevelius') observatory burnt down in 1676. It appears in Hevelius' map or *Uranographia*[77] (a supplement to his work *Prodromus Astronomiae*, published posthumously, by his widow, in 1690) as a shield with John III's coat of arms, mainly a crucifix, emblazoned upon it. The map is confusingly drawn, as had been the convention in early star maps but had mercifully not been followed by Bayer[78] in early editions of his work, reversed right-to-left, as if one were looking at a globe of the sky from the outside. Bayer, of course, did not attach Greek-letter designations to any of the stars in Scutum because the constellation Scutum had not been devised in his day; as it turned out, neither did he treat any of the relevant stars as meriting such designations as members of adjacent constellations, although two of the seven principal stars of Scutum are shown on his map of Serpens and five on that of Aquila. Flamsteed[79] assigned some of the stars in the area now defined as Scutum to other constellations, thus accounting for the designation 6 Aql in Campbell & Moore[52]. Flamsteed himself did not number the stars but simply listed their positions in order of right ascension for epoch 1690 in each constellation, and it was Lalande[80] who actually attached the 'Flamsteed numbers' to them, merely reflecting their serial positions in the catalogue[79]. Lacaille[81] assigned Greek-letter designations, analogous to Bayer's, in the constellations of the southern sky, but he went only as far north as the Tropic of Capricorn. The constellation Scutum Sobieskii was finally restored to the map by Gould[82], who also assigned the Greek letters, which go only as far as η.

The broad-band magnitudes of β Sct have repeatedly been measured[30,31,83–88], with results for V and $(B-V)$ always close to $4^m \cdot 22$ and $1^m \cdot 10$, respectively, while $(U-B)$ values have not been in such good agreement, ranging from $0^m \cdot 79$ to $0^m \cdot 866$. The $(U-B)$ colour is unusually blue in relation to the $(B-V)$ index, a circumstance that could well have indicated the likelihood of the existence of the hot companion before that object was actually detected; the relationship of the two colours is not without parallel, but analogous cases are mostly variable or other pathological stars and/or possess blue companions themselves, like U Sgr. It is hard to understand why Buscombe & Dickens[89] noted that β Sct exhibits an ultraviolet *deficiency*.

The spectral type, initially listed as H in the *Draper Catalogue*[90] (in which the star is DC 8373) and then as G0 in the *HD*[91], was first given on the MK system by Morgan & Roman[92] as G5 II, a type repeated by Johnson & Morgan[93] and subsequently copied into many papers by others. Vaughan & Zirin[94], however, listed it as G7 II; they did not appear to be saying that they classified it, but neither did they quote a source for it. The same type was quoted by Brown & Landstreet[95]. Morgan & Keenan[96] had meanwhile moved slightly in the other direction, re-

classifying it in 1973 as G4 II CN1, a type repeated in 1980 by Keenan & Pitts[97]. Shortly after that, Parsons[98] recognized the existence of a hot companion to the G star, in UV data collected by the *TD1*[99] satellite; by comparing the flux distribution with tabulated[100] quantities, he considered the type of the companion to be B8 or B9, about four magnitudes fainter than the cool primary, and estimated the interstellar reddening of the system to be $0^m \cdot 12$. In worrying about types and publishing successive catalogues of standards in the 1980s, Keenan first[38] gave the elaborate classification G5 II CN0·5 Fe I Hδ 1 — just in time for it to be incorporated in the *Bright Star Catalogue* — but afterwards he was satisfied with plain G4 IIa, which persisted throughout the next three listings[40,42,43]. Hunsch & Reimers[101], relying on a photometric synthesis over a wide wavelength range rather than actual spectroscopy, put forward types of G8 II + A0V, with an $E(B-V)$ of $0^m \cdot 18$. Seemingly analogous flux-fitting by Parsons & Ake[102], however, yielded a combination of cG4 + B9 with a Δm of $3^m \cdot 3$ and an $E(B-V)$ of $0^m \cdot 20$, and *IUE* spectra indicated a type of B9·2 for the hot component. Bersier[103] interpreted Geneva photometry[104] as indicating a reddening of $0^m \cdot 174$. Comparatively recently, Ginestet, Carquillat & Jaschek[105] have classified the primary from infrared spectra as G6 Ib.

   The luminosity of β Sct was recognized early on to be above that of a normal giant. Young & Harper[34], who classified the spectrum as G6 and made independent estimates of its luminosity, gave absolute magnitudes of $-1\cdot0$ and $-0\cdot4$, respectively, while Rimmer[35] gave it as $-2\cdot7$. Rimmer's work[68,35] on spectroscopic parallaxes, based on observations made with only a 12-inch refractor at the Norman Lockyer Observatory, has been largely overlooked in comparison with the efforts made with much larger telescopes and more manpower at Mount Wilson and the DAO, but it is at least as reliable and there is a lot of it. A Mount Wilson estimate[9], made a decade later than the DAO and Norman Lockyer ones, gave an M_V of $-1^m.9$ and a type of cG7. Wilson & Bappu included β Sct in the first demonstration[106] of *K*-line luminosity dependence, and derived for it an M_V of $-4^m \cdot 3$, which they compared with the $-1^m \cdot 9$ from the Mount Wilson spectroscopic parallax just cited[9] and with a 'Yerkes' value of $-2^m \cdot 0$ which presumably represents an interpretation of the MK luminosity classification. In a quickly ensuing discussion of "Some theoretical aspects of H and K emission in late-type stars", in which the β Sct M_V is given as $-4^m \cdot 4$, Hoyle & Wilson[107] asserted that "The use of the Yerkes magnitudes at luminosity classes I and II introduces quite large errors, which are obvious in many cases", of which they gave β Sct as an example. Robust reinforcement of the same idea comes a few lines later in their paper, with "The implication is that much of the error in our estimation ... has been artificially introduced by the use of incorrect visual magnitudes."

   That may prove to be an over-statement of their case, although the last word has still not been said about the real luminosity of β Sct. In Wilson's later work[36] on *K*-line luminosities, he moderated the value for β Sct to $-3^m \cdot 9$; much later, Wallerstein, Machado-Pelaez & Gonzalez[108], and then Parsons[109], proposed recalibrations of the relationship between line-width and M_V, but at least in the case of β Sct the nett result seems to have been to exacerbate the discrepancy, Parsons finding M_Vs of $-4^m \cdot 4$ and $-4^m \cdot 8$ from the supposedly improved relationship. From another angle, Egret, Keenan & Heck[110] re-calibrated the correspondence between MK ('Yerkes') luminosity classes and absolute magnitudes and found that a mean value of $M_V = -2^m \cdot 59$ suited class II stars throughout the range of types from G1 to K3. With β Sct now assigned to Class IIa, its Yerkes absolute magnitude could be said to chime exactly with the value of about -3 inferred

from the *Hipparcos* parallax. As recently as 1983, van Altena & Sawada[111] published a ground-based trigonometrical parallax of $0'' \cdot 024$ for β Sct, and listed the absolute magnitude that followed from it as $+1^m \cdot 12 \pm 0^m \cdot 66$. *Hipparcos*, however, found a parallax of $0'' \cdot 00473 \pm 0'' \cdot 00079$, which corresponds to an absolute distance modulus of $6^m \cdot 63 \pm 0^m \cdot 37$ and thereby yields $M_V \sim -2^m \cdot 4$, with the same uncertainty. Allowance for the interstellar absorption implied by the reddening approaching $0^m \cdot 2$ that seems to be very generally agreed raises the luminosity to $-3^m \cdot 0$. A recent effort by Parsons, Franz & Wasserman[112], however, to determine an astrometric orbit with the *Hubble* telescope's 'fine-guidance sensor' gave only a result that was admitted to be "marginal", owing (it seems) to the orbit being even smaller than expected in angular size, so a further increase in the estimated luminosity of β Sct seems quite likely. The *Hipparcos* authors made use of the known spectroscopic orbital elements in the determination of the parallax from the raw positional data, and they inferred values of the angular semi-axis and the inclination of the orbit and also the position angle of the node. The star was one of only 235 — just $0 \cdot 2\%$ of the whole number of stars surveyed by *Hipparcos* — for which orbital parameters were derived, even with help from spectroscopy, as mentioned above in connection with 16 Aur. However, in a recent discussion of *Hipparcos* data on stars with spectroscopic orbit determinations, Jancart *et al.*[113] found that the β Sct astrometric orbit failed their tests of consistency.

On the other side — *their* side — of the discrepancy noted by Hoyle & Wilson, an exaggeration of the luminosity by the *K*-line width may have arisen through broadening of the line by the star's axial rotation. The rotation is just too small for it to have been detectable in the appearance of the spectrum at the reciprocal dispersion (10 Å mm^{-1}) employed by Wilson, but could nevertheless have contributed a little towards the measured width of the *K*-line reversal. In early papers[114,115] on stellar rotational velocities, only upper limits of 15 and 25 km s^{-1}, respectively, could be set for β Sct. A naïve attribution to rotation of the whole of the excess line-width above the minimum found amongst a large assortment of late-type stars — the present writer's rather cavalier *modus operandi* in the utilization of radial-velocity traces — yields a projected rotation of 9 km s^{-1}, which at least gives a fair impression of the amount by which intrinsic line-broadening, as contrasted with true luminosity effects, would affect measures of the *K*-line width. A luminosity-dependent calibration of line-widths in terms of rotational velocities, as used at Geneva in the reduction of radial-velocity traces, produces a $v \sin i$ estimate[18] of $7 \cdot 8 \pm 1 \cdot 0$ km s^{-1}, not far from the 'naïve' one. Pasquini *et al.*[116] quote what is almost certainly the same result as 8 km s^{-1}. A more sophisticated treatment, however, involving the disentangling in Fourier space of line profiles observed at very high resolution, led Gray & Toner[117] to apportion the broadening seen in β Sct to rotation of $5 \cdot 2 \pm 0 \cdot 4$ km s^{-1} and 'radial-tangential macroturbulence' of $9 \cdot 1 \pm 0 \cdot 1$ km s^{-1}.

Quite soon after Wilson & Bappu[106] demonstrated the correlation between the *K*-line width and stellar luminosity, Kraft, Preston & Wolff[118] investigated whether the same thing was true of the Hα absorption line, which like the *K*-line emission must be formed very high in the stellar atmosphere. A practical advantage of Hα would be that it is far more easily observed and should be useable for much more distant stars, being in a part of the spectrum where interstellar absorption is less severe, and not requiring exposures many times longer than suffice for the continuum as is the case at *K*. They did indeed find Hα to be luminosity-sensitive in the hoped-for fashion, but it seems that the scatter about the mean trend was greater than for the *K* line. Their paper includes a nice reproduction of the Hα region of

a $6\cdot7$-Å mm^{-1} Palomar spectrogram of β Sct. A spectrophotometric profile of the line in β Sct (and in many other stars) was published by Eaton[119]. The line is of course in absorption, so it is surprising to find β Sct included in the listing by The[120] of "previously known Hα-emission stars" in his paper on "a dark region in Aquila and Scutum"; the reference to the source of that information, however, is to a paper[121] listing *K-line*-emission objects.

There are not many papers giving additional information on the spectrum of β Sct. Vaughan & Zirin[94], in an early excursion into infrared spectroscopy, included the star in a survey of the He I λ10830-Å region in a number of bright stars, and found a strong absorption line (equivalent width ∼$0\cdot8$ Å) to be present; they considered it to be an indication of a hot chromosphere. Later, Zirin[122] thought it might indicate a corona rather than a chromosphere. Linsky *et al.*[123] published profiles of 10-Å regions centred on the *H* and *K* lines; at that time they were unaware of the existence of the early-type component, and it must be said that the *K* line does not appear appreciably filled in by the hot star's light. Brown & Landstreet[95] made a search for weak longitudinal magnetic fields in late-type stars but did not see one in β Sct. Luck[124] made a major investigation of abundances in a set of cyanogen-weak giant stars. It is not clear why β Sct was included, since it was not, and never had been, regarded as CN-weak. Individual abundances were derived for as many as 24 elements, which in general were found to be slightly (∼$0\cdot2$ dex) underabundant in β Sct with respect to the Sun; that includes lithium, for which a logarithmic abundance of $0\cdot73$, on the usual scale where log N(H) = 12, was found from the equivalent width of 23 mÅ that was measured for the λ6708-Å line. There seems to be some disagreement even as to the presence, let alone the strength, of the lithium line. It is in fact not a straightforward thing to measure unless it is strong, owing to blending with a closely adjacent Fe I line. Mallik[125] measured it at 50 mÅ and deduced a log N(Li) of $0\cdot93$, whereas Lebre *et al.*, in a very recent paper[126], were unable to detect any Li line at all and considered that log N(Li) < $0\cdot0$. In Luck's paper[124] there is a section specifically headed "HR 237 and HR 7063" (the latter star being β Sct); it merely says, however, that another paper discusses those stars extensively, and it is a disappointment to find that the cited paper actually does not mention them.

Hünsch & Reimers[101] showed a profile of the Mg II analogues of the *H* and *K* lines at $\lambda\lambda$2802 and 2795 Å, demonstrating strong circumstellar (CS) absorption in a massive high-velocity (∼160-km s^{-1}) 'cool' wind. Their photometric decomposition of the flux from the system into components of G8 II and A0 V, noted above, with $E(B-V) = 0^{\rm m}\cdot18$ allowed them to propose for the giant component intrinsic colours of $(B-V) = 1^{\rm m}\cdot01$ and $(U-B) = 0^{\rm m}\cdot82$. Reimers *et al.*[127] noted that the CS wind component was always present in the *K* line in their observations of β Sct.

Eggen[128] at one time assigned β Sct to the 'Pleiades group'; later, he[129] included it as a member of the 'Local Association', which looks as if it might be the same proposed entity under a different name. The star is noted in the back of the *Bright Star Catalogue*[8] as being a member of the 'Scutum OB2' Association, upon whose existence de Zeeuw *et al.*[130] have cast serious doubt. Beta Sct has also featured in a number of papers in which it was not of interest in itself but served as a standard of one sort or another. In recent years it has lent its name to a Milky Way field (its Galactic latitude is about $-1°$) that has become one of the favourites for large CCD surveys such as MACHO[131] and EROS[132] for microlensing stars, since at that Galactic longitude (∼28°) we are looking tangentially through a large depth of one of the inner spiral arms of the Galaxy (the 'Sagittarius–Carina arm').

The radial velocity of β Sct was measured first in 1899 with the [original] *Mills Spectrograph*[133] on the Lick 36-inch refractor. In the following year a change in the velocity was noticed; the fact was promptly announced by Campbell & Wright[134], and by Campbell[135], who credited Wright with the discovery. Although the variation was large, the star was not followed systematically; the final compendium[52] of Lick velocities has a total of 11 measurements of it. One of those that feature in the announcements of variability (that of 1899 June 11) does not appear in the final list. Meanwhile, β Sct had been observed attentively with the then-new 72-inch reflector at the DAO, Victoria, with a one-prism spectrograph giving a reciprocal dispersion of 29 Å mm^{-1} at Hγ, and in 1927 Young[6] published an orbit for the star. It was based on 17 spectrograms, although in order to save part of the substantial computational effort that orbital solutions demanded in pre-computer days he did a certain amount of preliminary averaging and solved for ten 'normal points'. He listed, in addition to his own observations, eleven velocities that the Lick Director, Campbell, had sent to him, plus two that had been made with the Bonn 12-inch refractor and published by Küstner[53]. At first sight it is difficult to understand why Young did not include the Lick measurements, at least, in the solution, instead of using them (as he mentions) merely to fix the period, especially since Lick observations were generally more accurate than DAO ones. It turns out, however, that in this particular case the Lick velocities were uncharacteristically poor, and it would have been less clear to Young than it is now which ones were worthy of rejection. Re-computing the solution anew from Young's data, we find now that the normal-point solution worked well, inasmuch as it differs negligibly from one computed using all of the observations just as they stand. Young, however, obtained very optimistic values for the uncertainties of the elements, even when allowance is made for his use (widespread at that time) of 'probable errors' rather than standard deviations. He may not have taken into account the fact that, by fitting six elements to only ten points, he greatly diminished the number of degrees of freedom.

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

Four radial-velocity measurements of β Sct, which seem not to have come to Young's attention, were published from the Cape of Good Hope by Lunt[139] in 1921; nine more were given by Spencer Jones[140] in 1928. They were obtained with a four-prism spectrograph, giving[141] a reciprocal dispersion of 19 Å mm^{-1} at Hγ, on the *Victoria* 24-inch refractor[142]. The last velocities measured at the Cape and Lick were obtained in 1924; there ensued that long interval in the mid-20th Century when almost no interest was shown in the radial velocities of bright stars. One measurement of β Sct was made casually by the writer in collaboration with J. E. Gunn, in an unpremeditated exploratory programme conducted with the then-newly-constructed radial-velocity spectrometer[143] on the Palomar 200-inch telescope on a night in 1971 when there was a cloud layer that was just short of opaque; as a corollary to that programme, the same stars were re-observed with the original photoelectric spectrometer[144] at Cambridge shortly afterwards, and the two sets of measurements were published[143]. Apart from them, no radial velocities were measured for β Sct between 1924 and 1981/2, when Parsons[145]

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

Parsons was interested in composite-spectrum binaries and made several measurements each for quite a number of them, with a view to updating existing orbits or initiating data-collection for variable-velocity stars lacking orbits. He gave a number of new orbits, some of which have proved to be wide of the mark, and some revisions of existing orbits, one of which was β Scuti's. How he did that is a mystery: not only are some of the revised elements[145] further than Young's[6] from the supposedly much more accurate ones derived here (the various sets of elements are listed in Table VI below), but the standard errors given by Parsons[145] are typically nearly three times larger than those that we think that Young ought to have found from his own data alone. A clue is probably given by his noting that he used a total of 39 measurements: they would presumably have been the 11 from Campbell & Moore[52], two from Küstner[53], 17 from Young[6], two from Griffin & Gunn[143], and his own seven. In an orbit computed from that *ensemble*, with all the measures (including two obviously 'wild' Lick ones) given equal weights, the standard errors come out nearly as bad as Parsons', although the elements are not the same.

Just one velocity of β Sct, obtained in 1981, was published by Beavers & Eitter[5] from the Ames spectrometer[4], and three, taken in 1986/7, were reported by de Medeiros & Mayor[18] from the OHP *Coravel*.

With the routine accessibility of 'space ultraviolet' wavelengths in the 1980s there arose an interest in the chromospheres, coronae, and winds of late-type stars of high luminosity, and in that connection the writer was asked whether he was observing β Sct or knew of an orbit that was an improvement on Young's. The answer was *no*, but the star was forthwith placed on the observing programme; only one observation had been made of it, however, (with the original spectrometer) when it transpired that the interest was of too immediate a nature to admit of a delay while the orbit was re-determined, so the star was deleted again from the programme. Some $3^{1}/_{2}$ years later the same question was raised again, with the same impatience, by the same party! To forestall any further repetition of such a sequence of events, β Sct was then restored to the observing programme and has been retained there ever since, although no further interest in it has been exhibited from the original quarter. The new observations include 64 made with the Cambridge *Coravel* and 20 with the OHP one, as well as four with the DAO spectrometer[146] and the 1988 'original Cambridge' measurement already mentioned. All of the radial velocities, published and new, are set out in Table V.

As usual, to obtain the best orbit there is a need to harmonize the zero-points and variances of the different data sources. To that end, a zero-point adjustment of $+0\cdot8$ km s^{-1} has been made to the measurements from Lick[52], the Cape[139,140], the DAO[6], Ames[5], and OHP[18] (including the writer's own), but such an alteration has been withheld from the Bonn[53] and McDonald[145] observations on the pragmatic grounds that it would be unhelpful. The Cambridge *Coravel* measurements have been adjusted by $-0\cdot4$ km s^{-1}, a quite usual amount for them to need for a G-type star. Unit weight has been accorded to the writer's measurements with his own and the OHP *Coravel*s, except for four early ones made with the Cambridge instrument when it was in a preliminary state; just as in the case of 5 Her they have been given weight $1/4$ and the zero-point correction has not been applied. The velocities obtained with the Ames spectrometer, and by the writer with the Palomar, DAO, and 'original Cambridge' ones, have been weighted $1/4$, while the early photographic measures from Lick, the Cape, and the DAO, and

TABLE V

Radial-velocity observations of β Scuti

Except as noted, the sources of the observations are as follows:
1899–1903 — Lick[52], weighted $^1/_{40}$ in orbital solution;
1913 — Bonn[53], wt. 0; 1918, 1924 — Cape[139,140], wt. $^1/_{40}$;
1920–1923 — DAO[135]; 1981/2 — McDonald[145], both wt. $^1/_{40}$;
1986–1998 — Haute-Provence Coravel; 1999–2006 — Cambridge Coravel

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

TABLE V (*continued*)

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

TABLE V (*continued*)

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

TABLE V (*concluded*)

Date (UT)		MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
2006 Apr.	4·18	53829·18	−25·0	15·622	−0·1
May	3·16	858·16	−23·1	·657	0·0
June	1·13	887·13	−21·4	·692	−0·2
July	4·01	920·01	−18·4	·731	+0·2
Aug.	13·90	960·90	−14·6	·780	+0·4
Sept.	22·83	54000·83	−10·8	·828	+0·1
Nov.	2·72	041·72	−6·8	·877	−0·2
2007 Apr.	5·19	54195·19	−14·6	16·061	−0·1
May	8·12	228·12	−20·5	·101	0·0
June	1·10	252·10	−23·8	·130	+0·2

★Cape observation[139], weight 1/40.
†Lick observation[52], weight 1/40.
‡DAO observation[135], weight 1/40.
§ Author's Palomar observation[143], weight 1/4.
¶ 'Original Cambridge' observation, weight 1/4.
‖OHP observation[18], provided through the *CDS*, wt. 1/4.
★★Observed with DAO 48-inch telescope, wt. 1/4.
††Observed with Cambridge *Coravel* in preliminary form, wt. 1/4.
‡‡Ames observation[5], weight 1/4.
RRejected observation.
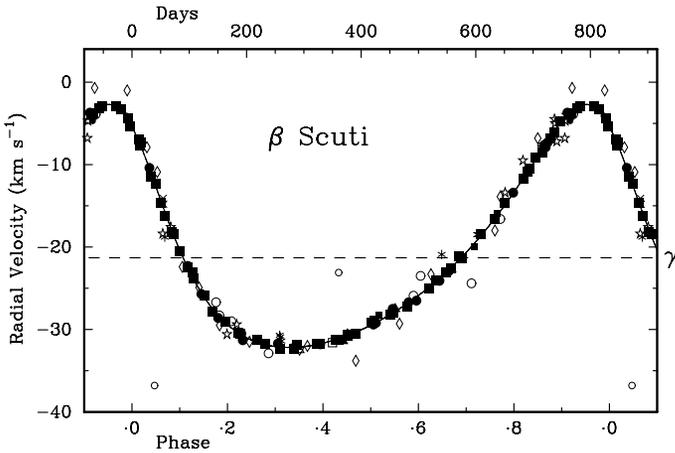
FIG. 5

As Figs 2–4, but for β Scuti. The symbols are identified as before, but in this case there are further additions to the range of sources. Measurements from the Cape Observatory[139,140] and from McDonald[145] (both weighted 1/40) are plotted as asterisks and as five-pointed open stars, respectively. One measurement made at Palomar[142] and two made with the original radial-velocity spectrometer at Cambridge (both weighted 1/4) are, respectively, shown as a six-point star and as open squares.

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

in the original announcements of velocity variation did not appear in the final list-
ing of Lick velocities. It is surely significant that that particular datum, together
with the one that gives a residual of -25 km s^{-1} and must be of the wrong star
or represent some other qualitative mistake, were given in Campbell's letter to
Young[6] only to integer kilometres per second, whereas all the others were given
to two decimals. Mr. A. Misch of the Lick Observatory has very kindly sent me
scans of the relevant plates; unfortunately, unfamiliarity with the character of the
Mills spectrograms leaves me unable to say definitely whether there has been an
error in identification. It should be mentioned that the Lick velocities incorpo-
rated in Table V are copied from Campbell & Moore[52], not from the listing by
Young[6] of those sent to him by Campbell, which in some cases differ slightly.

The scene is now set for the derivation of the final orbit, which is illustrated in
Fig. 5. The elements are displayed in Table VI, which includes for comparison the
elements published by Young[6], those calculated by the present author from Young's
data, and those published by Parsons[145].

TABLE VI

Orbital elements for β Scuti

Element	Young (as published*)	Young (re-calculated†)	Parsons	This paper
P (days)	834 (fixed)	834 (fixed)	$832 \cdot 5 \pm 0 \cdot 7$	$833 \cdot 26 \pm 0 \cdot 07$
T (MJD)	$22480 \cdot 4 \pm 2 \cdot 3$	22481 ± 10	$22484 \cdot 8 \pm 24$	$51644 \cdot 4 \pm 1 \cdot 0$‡
γ (km s^{-1})	$-21 \cdot 9 \pm 0 \cdot 26$	$-21 \cdot 96 \pm 0 \cdot 37$	$-21 \cdot 5 \pm 0 \cdot 9$	$-21 \cdot 30 \pm 0 \cdot 03$
K (km s^{-1})	$16 \cdot 65 \pm 0 \cdot 41$	$16 \cdot 8 \pm 0 \cdot 6$	$15 \cdot 8 \pm 1 \cdot 7$	$14 \cdot 74 \pm 0 \cdot 04$
e	$0 \cdot 35 \pm 0 \cdot 020$	$0 \cdot 348 \pm 0 \cdot 029$	$0 \cdot 37 \pm 0 \cdot 08$	$0 \cdot 3207 \pm 0 \cdot 0026$
ω (degrees)	$33 \cdot 9 \pm 2 \cdot 0$	34 ± 6	35 ± 13	$35 \cdot 2 \pm 0 \cdot 5$
$a_1 \sin i$ (Gm)	178 —	180 ± 7	168 ± 19	$160 \cdot 0 \pm 0 \cdot 5$
$f(m)$ ($M_\odot$)	$0 \cdot 33$ —	$0 \cdot 337 \pm 0 \cdot 037$	$0 \cdot 271 \pm 0 \cdot 091$	$0 \cdot 2354 \pm 0 \cdot 0022$
R.m.s. residual (wt. 1) (km s^{-1})	$1 \cdot 2$	$1 \cdot 25$	$1 \cdot 7$	$0 \cdot 25$

*Young's 'probable errors' have been transformed to standard deviations by multiplication by $1 \cdot 5$,
and the JD of his T is here expressed as an MJD.
†The re-calculation has been performed with the 17 individual measurements, not the ten normal
points. The standard errors come out rather smaller when the calculation is done on the normal
points, because certain large residuals are fortuitously averaged away.
‡The epoch is 35 cycles later than those quoted in the previous columns. The standard deviation is
smallest for the T closest to the weighted mean time of all the observations. When computed for
the same epoch as the other entries, it is increased owing to the period's uncertainty accumulated over
the 35 intervening cycles. The T computed for the early epoch is MJD $22480 \cdot 2 \pm 2 \cdot 6$.

It is seen that Young's orbit[6] is quite a good approximation to the new one, its
principal difference being the larger value for K, which is compounded into a 40%
over-estimate of the mass function (the expression for which includes the factor
K^3). Comment has already been made above on the surprisingly large uncertain-
ties of the revised orbit given by Parsons[145]; normally, any increase in the number
and time-span of the observations could be expected to reduce the standard devi-
ations of the elements. Inasmuch as Parsons gave only the elements, without any
listing of the data, diagram of the orbit, or description of how the solution was
derived, the proffered explanation must remain speculative.

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

in satellite spectra[98] the primary was retained by Keenan[38,40,42,43] as an MK-standard late-type star, so small is the contribution of the companion to the total luminosity at optical wavelengths.

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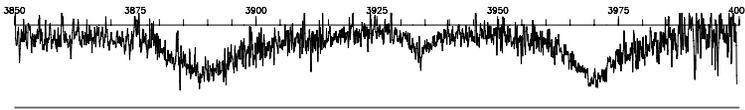
Fig. 6

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

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CORRESPONDENCE

To the Editors of 'The Observatory'

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

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

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

We present here a short discussion on the orbits of WDS 18253 + 4846 (HIP 90284 = ADS 11344 = HD 170109), which was discovered to be double (with components A and B) by Struve at Pulkovo in 1843 and designated OΣ 351. However, in 1883 Hussey found that component B was itself a close double, which became HU 66 BC. An orbital solution already exists[3] for the pair HU 66 AB, with $P = 300$ years and $a = 0''\cdot392$. Now, using a Sector Grid Search (SGS) method[4] we have calculated the orbital elements for pair HU 66 BC.

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

Orbital elements and ephemeris

Orbital elements (J2000)	Ephemeris (2008–2014)	
	$\theta[°]$	$\rho['']$
$P[\text{yr}] = 561\cdot20 \pm 28\cdot74$	293·9	0·718
$T = 2090\cdot38 \pm 26\cdot82$	294·4	0·723
$a[''] = 1\cdot103 \pm 0\cdot151$	294·9	0·728
$e = 0\cdot637 \pm 0\cdot092$	295·4	0·733
$i[°] = 108\cdot9 \pm 1\cdot6$	295·8	0·739
$\Omega[°] = 14\cdot4 \pm 2\cdot0$	296·3	0·745
$\omega[°] = 92\cdot7 \pm 2\cdot4$	296·8	0·752

The values of the orbital elements obtained and their formal errors for the pair BC as well as the ephemeris for the period 2008–2014 are presented in Table I.

Finally, from these two sets of the orbital elements for the pairs AB and BC we calculated the ratio between the sums of masses:

$$q = [(M_C + M_B)/(M_A + M_B)].$$

The value of $q \approx 6$ obtained indicates that component C is the most massive one in this triple system. So we conclude that B orbits C and A. This is in good agreement with measurements available for the pair AC and provides an explanation for the 'strange' motion of component C (*i.e.*, the direction of motion alternates between direct and retrograde).

This research has made use of the *Washington Double Star Catalog* maintained at the US Naval Observatory, and it has been supported by the Ministry of Science of the Republic of Serbia (Project No 146004 'Dynamics of Celestial Bodies, Systems and Populations').

<div align="right">Yours faithfully,
BOJAN NOVAKOVIĆ</div>

Astronomical Observatory Belgrade,
    Volgina 7,
        11160 Belgrade, Serbia
            [bnovakovic@aob.bg.ac.yu]

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REVIEWS

The Solar Tachocline, edited by D. W. Hughes, R. Rosner & N. O. Weiss
(Cambridge University Press), 2007. Pp. 369, 25·5 × 18 cm. Price £80/$150
(hardbound: ISBN 0 521 86101 4).

According to the late Tom Cowling, his Oxford D.Phil. supervisor E. A. Milne
opined — perhaps with tongue in cheek — that as the properties of the deep
solar interior were unobservable, they should be treated as candidates for
Occam's razor. Two developments — neutrino astronomy and helioseismology —
have made this unpalatable and extreme form of positivism irrelevant. In
particular, theoretical analysis of the observed oscillations of the solar surface —
manifestations mainly of standing acoustic modes — enables us to probe the
internal structure and the dynamics of our Sun.

The Sun oscillates in millions of modes, with periods typically between 3 and
15 minutes, coherent over the surface, and over time-scales of weeks or months.
In spherical polars, each mode is a product of a spherical harmonic of degree l
and azimuthal order m — a function of co-latitude θ and longitude ϕ, a radial
function of order n, given approximately by the number of nodes in the radial
direction, and a time-dependent factor $\exp(-i\omega_{nlm}t)$, with angular frequency ω_{nlm}.
As a first application, averaging over m yields a multiplet frequency ω_{nl} that
depends on the run of density and sound speed through the Sun, enabling tests
to be made that confirm our current solar models to be gratifyingly good
approximations. But the real breakthrough came through the exploitation of
rotational splitting of the modes so as to determine the rotation law, $\Omega(r,\theta)$,
through the convective envelope till well into the radiative core.

The previous best guess for the convective envelope had supposed the rotation
to be rapid enough for Ω to be a function just of $\varpi \equiv r \sin \theta$ — the cylindrical
'Taylor-Proudman law', given by adopting the adiabatic pressure–density rela-
tion, and assuming the Reynolds stresses of the turbulence to be small. However,
the first helioseismological analyses found that a far better approximation had Ω
constant not on cylindrical but on conical surfaces — the latitude-dependent
surface rotation seemed to be preserved with depth. The radiative core was found
at least approximately to be rotating uniformly. An even bigger surprise was the
discovery that the transition between the convective and radiative zones occurs in
a very thin layer, of thickness less than 4% of the solar radius, given the name the
'tachocline' by Ed Spiegel and Jean-Paul Zahn. (Subsequent work modified the
details, *e.g.*, picking up the previously inferred thin radial shear layer just beneath
the photosphere, but the essence of the picture has persisted.)

A veritable industry has grown up, studying the emerging hydrodynamic
and magnetohydrodynamic problems. To select: research continues into the
appropriate parametrization of the turbulence that will yield the inferred run of
$\Omega(r,\theta)$ through the convective envelope. Much attention is being paid to the
crucial question: what is it that keeps the tachocline thin, preventing the radiative
smoothing that might be expected to occur well within the solar lifetime?
A convincing answer requires further understanding of the mutual interaction of
turbulent convection, rotation, and a possible remnant 'fossil' magnetic field in
the core. Some authors replace 'possible' by *mandatory*, appealing to evidence
from meteorology against a purely hydrodynamical explanation.

Difficulties with the classical model of the cyclical solar dynamo had led to a
suggestion that the 'Ω-effect' domain, in which rotational shear generates a
toroidal field from a poloidal one, is close to but *separate* from the 'α-effect'

domain, in which the twisting of the toroidal field yields a new poloidal field that completes the dynamo cycle. The tachocline with its strong built-in shear is the obvious location of the Ω-effect. However, an instability of a dominant toroidal field, discussed in particular by the late Roger Tayler, can contribute significantly to regeneration of the poloidal component, so the tachocline could turn out be the location of most of the whole dynamo process.

The present volume emerged from a week-long workshop that was part of the programme on 'Magnetohydrodynamics of stellar interiors', held at the Cambridge Isaac Newton Institute in 2004. It contains fourteen invited reviews, grouped under the headings: 'Setting the scene'; 'Observations'; 'Hydrodynamic models'; 'Hydromagnetic properties'; 'Instabilities'; 'Dynamo action'; and with a concluding 'Overview'. Many of the challenging problems discussed will probably be with us for decades, so the book will become a valuable source, both for established workers and graduate students. It should certainly be in the library of every university with research schools in stellar astrophysics, geophysics, and in basic hydrodynamics and plasma physics. — LEON MESTEL.

Astrophysical Flows, by J. E. Pringle & A. R. King (Cambridge University Press), 2007. Pp. 206, 25·5 × 18 cm. Price £45/$85 (hardbound; ISBN 0 521 86936 6).

My undergraduate degree contained no course on fluid dynamics, so the first thing I had to do as a new graduate student in astronomy was to learn about fluids. The available books were all written from the point of view of an applied mathematician, as was common in the 1960s, and it would have been good to have been given rather more physical insight into fluid behaviour. Current graduate students are more fortunate than me, because this book is now available as their guide — and it does indeed emphasize the essential physics behind the mathematical results. However, it will certainly help such students if they already have some basic knowledge of fluid dynamics in other contexts — it would be possible to use this book as a first text on fluids for graduate students, but it would be a steep learning curve, because that basic knowledge is assumed; the first, introductory, chapter is correspondingly concise and economical and the emphasis is on the application to astrophysics.

A first look at the list of contents suggests a fairly conventional selection of topics, from spherical flows through stellar oscillations to magnetic, thermal, and gravitational instabilities, finishing up with shear flows and the effects of rotation. However, a second look leads one to realize that all this is covered in under 200 pages, so this is by no means a conventional book. What the authors have tried to do — and I think they have succeeded — is to give a flavour of all these problems without getting into all the mathematical complexities of a full treatment. This is done by some drastic simplifications: no viscous or other dissipative processes are included, stars are taken, where appropriate, to be flat or cylindrical, and in general the geometry is taken to be as simple as possible and suitable approximations are made in the equations. The trick, of course, is knowing what approximations will simplify the problem mathematically without losing the essential physics, and the authors have skilfully chosen their approximations in order to display in each example the physical effect they want to emphasize. They have also tried in each case to give a physical discussion of the problem, to explain what result one expects to emerge from the mathematics (and why it does), and to justify their approximations physically.

To give some examples: the treatment of compressible flow introduces characteristics and shocks, all in one dimension; there is an interesting geometrical discussion of spherical accretion (and outflow); there is an honest discussion of the lack of equilibrium in the standard derivation of gravitational instability (what one of my colleagues likes to call "the Jeans swindle"); the essential problem of rotating stars is neatly summarized; there are neat, brief explanations both for rotational splitting of oscillation frequencies and for the existence of r-modes in rotating stars. The reader who is willing to take the mathematics on trust will learn a lot of physics; to check the mathematics will take a bit more work — the reader is expected to fill in the gaps, although the structure of the calculation is always clear. Disappointingly, there are rather too many typographical errors in the equations, which makes the work a bit harder, and some wording errors also. Most of the errors will be spotted easily by experts, but new graduate students may be disconcerted by some of them (for example, the discussion of the Schwarzschild criterion on p. 74, where the words "increase" and "decrease" have been partially swapped in the last two paragraphs).

Most chapters contain references for further in-depth reading on the topics outlined in the text, and some more detailed material is also present in the end-of-chapter problems; it is a pity that there are no hints of how to tackle any of them, although in some cases references are given to articles or books. Nonetheless, this is a very useful book for new graduate students and it also gives new insights to those of us with more experience; I wish it had been available when I was learning the subject. — ROBERT CONNON SMITH.

But It Was Fun: the First Forty Years of Radio Astronomy at Green Bank, edited by F. J. Lockman, F. D. Ghigo & D. S. Baker (NRAO, Greenbank), 2007. Pp. 582, 24 × 16·5 cm. Price $25 plus $10 shipping (about £18) (paperback; ISBN 0 970 04112 8).

Radio astronomy was born in the USA in 1935, and appropriately came of age in 1956 when the National Radio Astronomy Observatory was formed. A remote location in West Virginia was chosen as a radio-quiet site, and the first instrument was to be a 140-foot, fully-steerable telescope, available to all research groups. The common use of a national observatory, and the telescope itself, were new concepts, and the trials and tribulations leading to the present-day success of the NRAO are graphically illustrated in this book.

The story is told in an unconventional way. It is not a history; it is an assembly of anecdote, archive, and conference proceedings, fascinating in every detail especially for those of us who have seen the birth and development of similar and related radio and optical observatories.

The 140-foot was completed very late and badly over budget, and the NRAO was only saved from total disaster by the inspired decision to build the much cheaper and larger 300-foot transit telescope, which was completed within only two years and within a very much lower budget. It was a simple structure, suitable only for long wavelengths, but it was an outstanding success; notably it was used in the discovery of the pulsar in the Crab Nebula. After 26 years, long after its expected useful lifetime, it quietly collapsed. The 140-foot, meanwhile, had also achieved notable success in the discovery of molecular spectral lines, starting the new subject of astrochemistry.

Every funding committee should read and learn from this story: a group of dedicated scientists, well funded and highly motivated, may run through a bad patch and achieve outstanding success only after nearly losing everything. Every

telescope engineer should read the story of the near disaster of the 140-foot, and the collapse of the 300-foot: the lessons were well learnt by NRAO, as is now demonstrated by the success of the 100-metre *GBT* at Green Bank — well funded, well engineered, and in use by a wide community. Every observer who uses VLBI (very-long-baseline interferometry) should read the hilarious, almost incredible account by Kellerman of the first Green Bank/Crimea observation, overcoming every conceivable logistic and bureaucratic obstacle to transport receiver, recorder, and working clock to a site with almost no resources and no telephone, and in the worst time of USA/Soviet tension. I suppose this was part of the forty years of fun; it was certainly fun to read. — F. GRAHAM-SMITH.

The Geology of Mars: Evidence from Earth-Based Analogs, edited by M. Chapman (Cambridge University Press), 2007. Pp. 460, 25·5 × 18 cm. Price £75/$135 (hardbound; ISBN 0 521 83292 6).

This book, in the Cambridge Planetary Science series, will have wide appeal for planetary geologists. Edited by Mary Chapman (US Geological Survey, and Director for NASA's Regional Planetary Image Facility in Flagstaff, Arizona), it stresses the value of Earth-based comparisons in the understanding of images returned from the Red Planet.

After an in-depth introductory review by James Head, successive chapters compare Mars with the Earth in terms of impact structures, layered deposits, dunes, volcanic calderas, cones, lava flows, channels, and canyons. The book is very well illustrated and contains a selection of colour plates. As Horton Newsom notes when discussing Martian meteorites, in terms of crustal evolution, Mars resembles bodies such as the Moon and Vesta, but it has the added complications of surface erosion, alteration, and deposition due to wind and water. The rôle of subsurface water ice and its possible contribution to geologically recent gullies is one of the many topics discussed in this book.

The Geology of Mars concludes with chapters on diverse topics. Nathalie Cabrol, Chris McKay, Edmond Grin and 14 co-authors review signatures of habitats and life in Earth's high-altitude lakes for possible clues concerning Noachian aqueous environments on Mars. Kelly Snook and co-authors look at 'Integrated analog mission design' involving humans and robots, and report the results of various field tests.

As the prospect of a manned mission to Mars continues to recede, this book should prove to be of special importance for some time to come. My only criticism is that the index provided is very poor in terms of arrangement and detail. — RICHARD MCKIM.

Planet Formation: Theory, Observations, and Experiments, edited by H. Klahr & W. Brandner (Cambridge University Press), 2006. Pp. 302, 25·5 × 18 cm. Price £65/$120 (hardbound; ISBN 0 521 86015 6).

The discovery of over 240 extrasolar planets over the last 15 years has provided impetus to many aspects of planet-formation research. The major observational surprise was the existence of so-called 'hot-Jupiters', gas giants orbiting close to their parent stars, which turned on its head the idea that the Solar System formation models are universally applicable. Whilst the Solar System is the best-studied planetary system, it appears to be one of a complex spectrum of planetary-system topologies that can exist. This book brings together a wide range of planet-formation papers, based on a meeting held at Ringberg Castle, Bavaria, in 2004, written by some of the leading academics in planet-formation research.

The book starts with some historical notes on planet formation and searches. Of the latter, the most notable was that of Peter van de Kamp who spent the majority of his career searching for planet(s) orbiting Barnard's star, and failed. But in doing so he honed his astrometric technique and should be recognized for his sheer dogged determination and dedication to the cause. The first extrasolar planets were discovered in 1992 orbiting a pulsar, but it took another three years to discover a planet around a Sun-like star, 51 Pegasi b.

Further chapters cover the formation of planetary systems, examining the rôle of turbulence and magnetic fields in protoplanetary discs and how the gas-disc pressure gradients influence the movement of dust. This dust starts to coagulate into larger and larger planetesimals, resulting in a finale of truly colossal and potentially catastrophic collisions. If planet-formation theories are to be believed, the countless planetesimals collide and grow, and quickly form the cores of the giant planets and, more slowly, the main bulk of the rocky terrestrial planets. The growth rates of giant planet cores are determined by a delicate balance of various mechanisms, and are sometimes hard pushed to form cores within the lifetime of the gas disc. A gas disc is needed to provide the thick gaseous atmosphere of the gas giant, hence the need to form the cores quickly. The alternative method of giant-planet formation, whereby disc instabilities allow the rapid formation of giant planets, is briefly discussed, together with testable observational predictions that in future may constrain which formation mechanism is the most likely.

Theory predicts that hot-Jupiters are most likely to have formed beyond the 'ice-line', but then migrated inwards over a number of astronomical units into very small orbits. The migration mechanisms for planets of different mass and different migration speeds are detailed in turn.

Other aspects, including detection techniques, protoplanetary-disc destruction, and the properties of extrasolar planets, provide further depth to the book, each topic being worthy of a further paragraph in this review.

In summary, the book covers the main research areas one would expect, although caution should be applied given the natural evolution of research into planet formation since the book's publication. However, this should not detract from the usefulness of this publication as a concise reference and introduction to planet-formation research. — MARTIN ANDREWS.

Encyclopedia of the Solar System, 2nd Edition, edited by Lucy-Ann McFadden, Paul R. Weissman & Torrence V. Johnson (Academic Press/ Elsevier, Amsterdam), 2007. Pp. 966, 27 × 21 cm. Price $99·95 (about £50) (hardbound; ISBN 0 120 88589 1).

This is not, in format, really an encyclopaedia, where one expects alphabetized entries of very different lengths on topics that might include objects, people, concepts, and so forth, and a good deal of cross-referencing (Tombaugh to Pluto to dwarf planet, to pick an obvious example). It is, however, encyclopaedic, with 47 chapters of roughly equal length, beginning with the Solar System in general, its origins, and historical studies; continuing with the Sun, other individual entities, and classes, from Mercury to KBOs; and concluding with methods of study, dynamics, astrobiology, and extrasolar planets. Each chapter ends with a set of references, and there are a handful of appendices, a very extensive glossary, and an index not quite as up to date as at least some other portions of the volume.

The average epoch of the chapters is late 2006. An appendix discusses the 2006 August IAU resolution on Pluto, KBOs, and dwarf planets, but the Pluto chapter expresses no reservations about planethood, and "dwarf planet" does not

make the index. And there were about 150 exoplanets at the moment Michael Endl & William Cochran closed out their chapter. How easy is it to find things? Middling. I attempted to locate the oscillation of the obliquity of Mars and eventually found it indirectly, as a third-level entry (Mars, atmosphere; climate; Milankovich cycles).

Are there neat, unexpected things to be found? Absolutely! For instance, a colour photo of a daytime fireball from 1972, and a postage stamp showing a micrometeorite dust particle and Antarctic ice-core drilling (not both to the same scale), from *Terres Australes et Antarctiques Francaise*. (No, I hadn't heard of it either, not having collected stamps since about 1958.) David Leverington's discussion of the discovery of Neptune might best be described as tactful, with the contemporary evidence "currently being analyzed to establish the exact sequence of events." He is, perhaps not incidentally, British.

Have I used this book? Indeed, almost immediately upon picking it up, because a colleague had just asked what fraction of all missions to Mars had failed. About half, I hazarded, but, in the spirit of the staircase, I have now checked in the Appendix that lists all known Solar System missions from *Pioneer 1* in 1958 (a lunar fly-by) to launches scheduled for the next few years. The answer (counting orbiters and their landers separately) is 20 failures and 18 successes — about half. You will most definitely find the volume useful if you teach Solar System courses without its being your primary research topic, a common occurrence, at least in the USA. Indeed, if viewed in terms of amortization, you might well find the book worth buying.

Conflict of interest statements: Senior Editor McFadden is a former co-author and 'sun maven' Markus J. Aschwanden a current one. I trust them implicitly. My copy of the *Encyclopedia* is a review copy, but one originally sent to another journal. — VIRGINIA TRIMBLE.

Galaxy Evolution Across the Hubble Time, edited by F. Combes & J. Palouš (Cambridge University Press), 2007. Pp. 448, 25·5 × 18 cm. Price £62 (hardbound; ISBN 0 521 86344 9).

Among the very many parallel activities at the IAU General Assembly held in Prague, 2006, was this meeting on galaxy evolution. I attended some of the talks, in spite of the innumerable parallel distractions. Rather interesting many of them were, too. Galaxy evolution is in a phase of astonishingly rapid development, thanks to the current plethora of survey projects using 8-m-class telescopes, superb instruments, decent software, and *HST* imaging. Things are getting even better with the various UV and IR satellite studies, reducing the biasses. I remember the comparable meeting at the Sydney IAU GA, which was dominated by noisy defence of inadequate models. All those models are known to be grossly inadequate (as many suspected at the time), and the subject has moved on impressively. There are somewhat over 200 papers in this volume giving a snapshot of that progress.

The meeting structure was very traditional, rather than based on the structure of the subject. It starts with 'building blocks': a quaint concept, of some value when stars, gas, dark matter, and dynamics are deemed too messy. This is followed by environment and interactions, which again is rather historical. Perhaps galaxies really did 'form', and then 'interact', but the papers here demonstrate that the reality was more complex. This modular view continues with 'Star formation and feedback', the 'feedback' aspect of that reflecting the interest of most 'galaxy' astronomers in star formation: very, very difficult to quantify, and

essentially of only statistical and time-averaged interest. Finally, to high redshifts, or the 'early Universe' as it is termed here. Things are exciting here. We know that the most massive galaxies are old today, and were already in place and massive early on — the exact opposite of all predictions. We know now, too, that the massive red galaxies are the norm, not the Lyman-break galaxies which were the focus of so much excitement a few years ago, when people learned to find them. So, exciting and fast-moving times. This book is a snapshot of an interlude in that progress, when hundreds of astronomers stopped doing research to write overly-brief articles, on subjects which were frequently already outdated at that time. Why the IAU bothers to publish these things is beyond me. Clearly the publishers are happy to keep taking our research funds as our libraries buy them. I propose a campaign to boycott conference books. Let's spend our time doing astronomy, and writing serious papers. They might even get read and cited, which these articles won't be. — GERRY GILMORE.

AGN Variability from X-Rays to Radio Waves (ASP Conference Series, Vol. 360), edited by C. M. Gaskell *et al.* (Astronomical Society of the Pacific, San Francisco), 2006. Pp. 292, 23·5 × 15·5 cm. Price $77 (about £38) (hardbound; ISBN 1 583 81228 8).

Having been largely absent from the field for a number of years, it was a pleasure to be able to give more of an outsider's perspective on progress made in our current understanding of active galactic nuclei. This book highlights work presented at a workshop on AGN variability held at the Crimean Astrophysical Observatory, an institute with a long-standing history in AGN-variability studies, and one whose original optical-variability studies paved the way to a new understanding of AGN and laid the foundations for much of the work presented here.

Variability has long been considered the key to understanding these exotic sources, simply because their spatial extent (sub milliarcsecond) remains far beyond the reach of current facilities. Despite a significant investment in time, much remains to be learnt. Most progress has been made in understanding the relationship between the optical and X-ray continuum variability, though even here the picture is not always a simple one. Power-density spectra suggest that AGN operate like Galactic black-hole candidates (GBHC), broad-line objects being analogues to GBHCs in the low–hard state and narrow-line objects analogues to GBHCs in the high–soft state, a useful property which allows an alternative estimate of black-hole mass to be derived from a simple scaling of their break-frequencies. The origin of the continuum variability is most likely a combination of disc instabilities (outside-in) wherein optical variations appear to lead X-ray variations on long-timescales, and irradiation (inside-out) in which a variable X-ray source irradiates and drives variations in the cooler outer regions of the disc on shorter timescales. This section has a number of thought-provoking presentations (see, *e.g.*, McHardy, Uttley, Papadakis, and de Vries) and it is clear that the majority of these studies will benefit hugely from continued long-term multi-wavelength monitoring of AGN.

Since the early intensive monitoring campaigns in the late 1980s, measuring the continuum–broad-emission-line time delays, or reverberation mapping, has enjoyed considerable success, most recently in the area of black-hole-mass estimation. Indeed, the derived empirical relationships, once calibrated for high-redshift, high-luminosity objects, should enable huge advances in black-

hole-mass demographics and their cosmic evolution with time. Perhaps, a little disappointingly, the original design goal for these experiments has yet to be realized, and the nature of the geometry (spherical *versus* disc) and kinematics (though generally accepted as gravity dominated) of the broad-emission-line region remains tantalizingly elusive. However, all is not lost: much progress has been made in understanding the rare, radio-loud, double-peaked emitters (see contributions by Eracleous and Pronik), which clearly point to flattened disc-like geometries for the Balmer lines, and whose observed variations point to dynamical causes, likely candidates including rotating eccentric discs, hotspots, or spiral density fluctuations, to name a few. How these relate to the more normal reverberation-driven line variations seen in the classical Seyfert 1 galaxies and quasars (see contributions by Peterson and Sergeev) is unclear.

As for beamed sources, the jet-disc connection is still under investigation (see, *e.g.*, contributions by Fidelis, Jorstad, and Efimov) and requires huge investments of observing time at multiple wavelengths from radio to gamma rays. It is very likely that the launch of *GLAST* in 2007–2008 will completely re-invigorate this field.

To whom would I recommend this book? Certainly to anyone who has an innate interest in accretion-powered objects whose central cores lie in the staggering million- to several-billion solar-mass range. It is an excellent starting point for incoming graduate-level students. — MIKE GOAD.

Planetary Landers and Entry Probes, by A. J. Ball, J. R. C. Garry, R. D. Lorenz & V. V. Kerzhanovich (Cambridge University Press), 2007. Pp. 340, 25·5 × 18 cm. Price £70/$130 (hardbound; ISBN 0 521 82002 2).

Until the mid-20th Century humanity was earthbound, able only to stare at the heavens and wonder about the true nature of the Moon and planets. Then, in 1959, came a momentous event — the launch of a spacecraft which was able to reach the Moon and impact its surface. Within a few years, automated craft were soft-landing on our celestial neighbour and venturing forth to explore the other terrestrial planets.

Today, almost 50 years after the dramatic impact of *Luna 2*, robotic ambassadors have not only touched down on the Moon and returned samples of lunar regolith, but they have landed on Venus, Mars, Titan, and two near-Earth asteroids. Roving vehicles have also wandered across the rugged landscapes of the Moon and Mars, while an instrumented probe has conducted a suicidal mission to explore the deep atmosphere of Jupiter and balloons have negotiated the high-speed winds of Venus.

As the preface states, this volume seeks to provide "a concise but broad overview of the engineering, science and flight history of planetary landers and atmospheric probes." In this, it certainly succeeds. Written for an academic readership, the book is divided into three complementary sections. The first part summarizes the major engineering issues related to the development of landers, atmospheric-entry probes, and surface penetrators. This is reinforced by a second section which contains some key technical data on each major mission, followed by seven case studies of spacecraft which have faced an unusual technical challenge in their design or mission. It is interesting to note that this latter section includes the *Deep Space 2* Mars Microprobes, which were lost before they could return any data, and *Rosetta*'s *Philae* lander, which is still seven years away from reaching its destination.

This nicely designed book, complete with specially commissioned line drawings, is recommended as a valuable addition to the technical literature about the challenges that face engineers and scientists who seek to explore alien worlds with automated spacecraft. However, anyone seeking a detailed history of planetary landers and their successes or failures will have to look elsewhere. Unfortunately, the mathematical content of the first section and the rather exorbitant retail price are likely to limit the readership. — PETER BOND.

The Spitzer Space Telescope: New Views of the Cosmos (ASP Conference Series, Vol. 357), edited by L. Armus & W. T. Reach (Astronomical Society of the Pacific, San Francisco), 2006. Pp. 317, 23·5 × 15·5 cm. Price $77 (about £38) (hardbound; ISBN 1 583 81225 3).

The meeting reported in these proceedings took place in Pasadena in 2004 November 9 to 12, just over one year after the satellite was launched (in 2003 August). There have been many refereed scientific publications using *Spitzer* data since then, starting with the special *Astrophysical Journal Supplement* of 2004 September 1, so the value of this book is limited. It is a snapshot of the progress at a certain point in the history of the satellite. The book is also, naturally, very *Spitzer*-centred with minimal cross-referencing to other data, less so than in refereed publications. However, there are some tantalizing glimpses of the work in progress, but all too often the analysis had not progressed far enough for certainty, and several projects had yet to receive any data, so their articles contained only the hopes for the future. This type of meeting can often be a showcase for gems which would not get space elsewhere; for example 'IRIS: A new generation of IRAS maps' particularly appealed to me. (Twenty years after the end of *IRAS* and they are still finding new ways to 'destripe' the data scans — wonderful!) Other gems included the *Keck* observations of M dwarfs, and the report on the 17-micron feature in the article by Draine on the 'Physics of interstellar matter'. You need to do your own data mining with care to find the gems when around half the contributions are limited to two pages. It is a useful guide as to what to look out for in the various topic areas, but the earliest results from any satellite (particularly in conference proceedings) are subject to revision, so you do need to check the refereed literature to know whether they stood the test of time, calibration, and peer-review. — HELEN WALKER.

The Amateur Astronomer's Introduction to the Celestial Sphere, by W. Millar (Cambridge University Press), 2007. Pp. 299, 24·5 × 18·5 cm. Price £24·99/$40 (paperback; ISBN 0 521 67123 X).

This book covers co-ordinate systems, stars, the rotation and revolution of the Earth, the motion of the Moon, and eclipses. There is little mathematics beyond addition and subtraction. Multiplication, division, and the trigonometric functions occur only rarely. There are a great number of black-on-white line diagrams together with a few grey-scale half-tones. Cambridge University Press provide a web page for the book (www.cambridge.org/9780521671231) that contains larger, coloured versions of the figures.

The main star chart covers 24 hours of right ascension, extending over four pages, and ± 60° of declination. It has a limiting magnitude around 6 and a scale of 0·73° per mm on the equator. However, there is no allowance for convergence of the meridians so the right-ascension scale differs from the declination scale by a factor of two on the northern and southern borders.

Co-ordinate systems are treated at a very simple level; *e.g.*, the reader is reminded that a right angle is 90°. The material continues by easy stages through terrestrial co-ordinates, with definitions of 'great circle', 'small circle', and 'meridian', and then on to celestial co-ordinates including the horizon, equatorial, and ecliptic systems, with diagrams for both hemispheres.

The relationship between stars, constellations, and asterisms is described together with the outlines of stellar nomenclature, apparent magnitude, and double and variable stars. English readers will be surprised to learn that the Great Bear is known in England as "The Great Plow", and further surprised to see it as a mirror image (Fig. 2.16). The author also confuses Herschel's relationship between magnitude and intensity with that of Pogson.

There is a clear description of the change in meridian altitude of the Sun, day length, and the cause of the seasons. Time follows in its various guises, solar time (mean and apparent), sidereal, and ephemeris. Historically, as time was more precisely defined and measured, it became necessary to develop clocks of increasing accuracy.

The book includes a chapter on the motion of the Moon, its phases, and the calendar; and another on solar and lunar eclipses. Each chapter ends with questions and review problems, and the book concludes with observational projects and appendices with additional mathematical material, data, and a glossary. — DEREK JONES.

Steve O'Meara's Herschel 400 Observing Guide, by S. O'Meara (Cambridge University Press), 2007. Pp. 370, 28 × 22·5 cm. Price £35/$65 (hardbound; ISBN 0 521 85893 3).

Amateur deep-sky observers in the late 1970s were short of lists of target objects to look for after the well-known Messier list. In 1976 a group of amateur astronomers decided to create a list of the finest deep-sky objects out of the 2500 discovered by William and Caroline Herschel that should be visible in medium-sized telescopes. After a lot of filtering, a list of 400 objects was decided upon and an observing guide was published and then adopted by the Astronomical League (AL) in the United States; the AL awards a pin and certificate to anyone who completes the list. The original guide was a fairly primitive affair and it is perhaps a surprise that another guide has taken so long to come out. In fact, like buses, a second one is also due, in late 2007. Stephen O'Meara is well known for his columns in both *Sky & Telescope* and *Astronomy* magazines as well as his previous three books on deep-sky observing. The Herschel guide is a bit different from his previous ones as, due to the larger number of objects presented, there are only short descriptions of each one along with an image from the DSS.

The book starts with a short introduction to deep-sky observing and then the meat of the book is divided into four sections that cover when to observe the objects by season. Each group of objects is accompanied by a star chart. I am not sure of the purpose of these as I doubt they will be detailed enough to find the objects, and just give a rough idea of where they are. It is also unclear to me that anyone would take a book this expensive into the field to use as a star chart. Each object has an accompanying image from the DSS as well as a brief description of the object as seen through his 100-mm refractor, along with O'Meara's notes. As usual these observations are made from 7000 feet up and will not represent what the vast majority of normal observers will see. The book ends with a check list that you can fill in as you observe the objects. Again I am not sure that anyone

would actually use this as most deep-sky observers will fill in their own logbooks, especially as if they wanted to gain the AL pin they would have to send it in for verification.

So for whom is this book written? Well, it is a far better (and more expensive) guide to the Herschel objects than the one available from the AL. It is well presented and I found few important errors. I think it provides a better set of challenges than the Caldwell list and is to be recommended to observers looking for an organized project with medium-sized telescopes after completing the Messier list. It does not provide the detailed history for each object that O'Meara's previous books did and as such will not be dipped into so much unless you are starting the H400 challenge. — OWEN BRAZELL.

OTHER BOOKS RECEIVED

Isolated Neutron Stars: From the Surface to the Interior, edited by S. Zane, R. Turolla & D. Page (Springer, Heidelberg), 2007. Pp. 660, 28·5 × 21·5 cm. Price £115·50/$219/€149·95 (hardbound; ISBN 978 1 402 05997 1).

This weighty tome contains the proceedings of a conference at University College London in 2006 April. It reports both theoretical work and multi-wavelength observations on a wide range of objects from pulsars to magnetars, giving an up-to-date perspective on isolated neutron stars. Librarians should note, however, that the papers are reprinted from *Astrophysics and Space Science*, Vol. **308**, nos. 1–4, 2007.

Here and There

 EARLY KNIGHT

… Sir John Flamsteed, the first Astronomer Royal … — *Astronomy Now*, 2007 May, p. 41.

AND EDITORS TOO

It is requested that teh author examines the proof with the utmost care — instructions to authors, on the inside back page of *PASJ*, **59**, Nos. 2 and 3, 2007.

ALL OVER BAR THE SHOUTING

Most distant star clusters found — *Astronomy*, 2007 May, p. 24.

A FIELD PROJECT

The formation of an eccentric gap in a gas disc by a plant in an eccentric orbit. — *MNRAS*, **378**, contents page (for p. 966), 2007.

NOT QUITE YET

The two bodies were also found to be rotating around their own axes at the same speed as they orbit each other, as the Earth and Moon are tidally locked together. — *A&G*, **48**, 3.8, 2007.

SO KEPLER *WAS* ON THE RIGHT TRACK

US$20 million for South African astrologers — *Sawubona* (in-flight magazine for South African Airways), 2007 July, p. 77.

PLATE 3.

The first of two remarkable naked-eye comets to grace the sky during 2007, Comet McNaught was discovered in 2006 August by Rob McNaught at Siding Spring. It rose to prominence early in 2007 January as an easily seen object in the western twilight sky, and the image generously supplied by Roger Johansen from his observatory in Hammerfest, Norway — "the northernmost town in the world" — accords well with what was spotted serendipitously by the Managing Editor from his bedroom window.

PLATE 4.

'Astronomy Picture of the Day' presented this superb image of Comet Holmes taken by Ivan Eder in Hungary (see http://eder.csillagaszat.hu/en.htm) on 2007 November 10. First discovered on 1892 November 6 by Edwin Holmes and announced in these pages (**15**, 441), this periodic comet ($P = 6 \cdot 9$ years) quite unexpectedly (and thus far inexplicably) brightened a million-fold on 2007 October 24 to become an easy naked-eye object in Perseus.

Advice to Contributors

The Observatory magazine is an independent journal, owned and managed by its Editors (although the views expressed in published contributions are not necessarily shared by them). The Editors are therefore free to accept, at their discretion, original material of general interest to astronomers which might be difficult to accommodate within the more restricted remit of most other journals. Published contributions usually take one of the following forms: summaries of meetings; papers and short contributions (often printed as *Notes from Observatories*); correspondence; reviews; or thesis abstracts.

All papers and *Notes* are subject to peer review by the normal refereeing process. Other material may be reviewed solely by the Editors, in order to expedite processing. The nominal publication date is the first day of the month shown on the cover of a given issue, which will normally contain material accepted no later than four months before that date. There are no page charges. Authors of papers, *Notes*, correspondence, and meeting summaries are provided with 25 free reprints if required; additional reprints may be purchased.

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and for books:

(No.) Authors, [in Editors (eds.),] Title (Publisher, Place), year[, page].

where the bracketed items are required only when citing an article in a book. Authors are listed with initials followed by surname; where there are four or more authors only the first author '*et al*.' is listed. For example:

(1) G. H. Darwin, *The Observatory*, **1**, 13, 1877.
(2) D. Mihalas, *Stellar Atmospheres (2nd Edn.)* (Freeman, San Francisco), 1978.
(3) R. Kudritzki *et al*., in C. Leitherer *et al*. (eds.), *Massive Stars in Starbursts* (Cambridge University Press), 1991, p. 59.

Journals are identified with the system of terse abbreviations used (with minor modifications) in this *Magazine* for many years, and adopted in the other major journals by 1993 (see recent issues or, *e.g.*, *MNRAS*, **206**, 1, 1993; *ApJ*, **402**, i, 1993; *A&A*, **267**, A5, 1993; *A&A Abstracts*, §**001**).

UNITS & NOMENCLATURE: Authors may use whichever units they wish, within reason, but the Editors encourage the use of SI where appropriate. They also endorse IAU recommendations in respect of nomenclature of astronomical objects (see *A&AS*, **52**, no. 4, 1983; **64**, 329, 1986; and **68**, 75, 1987).

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