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A REVIEW OF ASTRONOMY

EDITED BY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2006 May 12th at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

M. Rowan-Robinson, *President*
in the Chair

The President. We have just received notification of the death of one of our Associate members, Professor Marcello Rodono of Catania University, Italy. Professor Rodono died on 2005 October 23. He was made an Associate of the Society on 1991 March 8. I'd like to ask you all to stand for a moment and remember our Associate. [Audience stands in silence.] Thank you.

And now I have the very great pleasure to announce the award of the 2006 Gold Medal for Geophysics to Professor Stan Cowley. Stan Cowley has had a distinguished career in space-plasma physics, bringing clarity and order where there had been confusion and disagreement. He started his professional career as a student of Jim Dungey at Imperial College and worked there for many years until moving to Leicester, where he is now head of the Radio and Space Plasma Physics Group.

During the 1980s, Stan greatly advanced our understanding of the large-scale dynamics of coupling across the Earth's magnetopause. A key aspect of this work was Stan's demonstration that reconnection would lead to a distinctive mixing of magnetosheath (shocked solar wind) and magnetospheric plasma populations. In particular, Stan showed that ions flowing into the magnetosphere would occupy a D-shaped distribution with respect to velocity parallel and perpendicular to the magnetic field — and that this distribution could provide quantitative information on the reconnection régime. These distributions are now often referred to as 'Cowley-D distributions'. Stan's seminal 1982 paper on this work has been, and continues to be, widely cited, with a total of 328 citations recorded to 2005 November. It is testament to how far ahead of its time this theoretical paper was, and to Stan's ability to think with clarity, logic, and invention, that these predictions were published a full decade before observations revealed them to be of quite extraordinary accuracy and relevance. Another aspect of this work was Stan's pivotal rôle in understanding how the large-scale coupling of energy, mass, and momentum into Earth's magnetosphere would respond to asymmetries in the interplanetary magnetic field.

Stan's work in this area played a critical rôle in developing our modern understanding of how reconnection controls the large-scale dynamics of magnetopause processes. He showed how that understanding is a unifying framework for many magnetospheric phenomena and, crucially, how it provides quantitative as well as qualitative insights. Stan's work greatly enriched the physical evidence for magnetopause reconnection and thus helped to bring about its general acceptance by the worldwide STP community.

In recent years, Stan has extended those ideas to the magnetospheres of other planets, such as Saturn, both through his own work and through his leadership of the Leicester group. The results have taken our understanding of aurorae on the gas-giant planets to an entirely new level. This work has reinforced our understanding of reconnection as a universal process controlling the dynamics of Solar System and astrophysical plasmas.

Stan has an outstanding reputation as a communicator of physical concepts. His scientific presentations have long been characterized by careful preparation and attention to detail, in particular a very effective use of diagrams.

He is an outstanding supervisor of PhD students. There are a great many of Stan's students who have produced an excellent thesis and, based on the thorough and precise tuition they received from him, gone on to become successful scientists. Stan has also played important rôles serving the scientific community. He has served as an editor on a number of major journals — most importantly he was editor-in-chief of *Annales Geophysicae*, the leading European STP journal, from 1992 to 1999. He also received citations for the excellence of his reviewing from the American Geophysical Union (AGU). He has served on national and international scientific bodies, including PPARC and EISCAT Councils. He was awarded the RAS Chapman Medal in 1991 and the EGU Bartels Medal in 2005. He was elected an AGU Fellow in 1995.

In summary, Stan Cowley is awarded the RAS Gold Medal for his outstanding work in developing our understanding of reconnection as a unifying concept in magnetospheric physics, for his outstanding rôle as a communicator of physical ideas, and for his outstanding work in serving the scientific community. [Applause.]

It now gives me great pleasure to present the 2006 Gold Medal in Astronomy to Professor Simon White. One of the great astronomical achievements of the past 25 years has been the development of a new cosmological paradigm, the 'ΛCDM' model: cold dark matter (CDM) with a cosmological constant. What began as a speculative idea in the early 1980s has now achieved the status of a standard model, used routinely to interpret a plethora of data, from measurements of anisotropies in the cosmic microwave background to observations of galaxy evolution. Simon White, currently Director of the Max Planck Institute for Astrophysics in Garching, is prominent among those responsible for this remarkable achievement.

One of his key contributions has been to initiate and develop the use of simulations of the formation of structure, using so-called 'N-body calculations', where N started as a fairly small number of particles but now runs into many millions, culminating recently in the 'Millennium Simulation'. Early simulations clearly ruled out neutrinos as an important constituent of dark matter and already established the key features of the current CDM model of the Universe: the large-scale distribution of mass and the sequence of structure formation.

Simon has made many other important contributions to theoretical astrophysics. He has published more than 300 research papers in the refereed literature, and the influence of that body of work can be judged by the remarkable statistic of some 27000 citations, with 64 papers achieving more than 100 citations (including three with more than 1000 each). These impressive statistics tell only part of the story of his influence: his intellectual generosity is reflected by the fact that he is one of the most frequently acknowledged colleagues in the literature, by the long list of PhD students, and by his rôle as an editor of *Monthly Notices*.

Simon White's contributions to cosmology, galactic structure, galaxy evolution, and the nature and distribution of dark matter are among the most original, profound, and influential of the past 25 years. He is an outstanding candidate for the RAS Gold Medal. [Applause.]

Thirdly, it gives me great pleasure to award the 2006 Chapman Medal to Professor Steven Schwartz. [The citation for Professor Schwartz appeared in the report of the 2006 April meeting of the RAS (*The Observatory*, **126**, 319).]

The President. Now for the usual piece of house-keeping, as it were: new Fellows or long-standing Fellows who have not previously taken the opportunity to do so are warmly invited to sign the membership book after this meeting in the less-formal atmosphere of the drinks party, where I'll be very pleased to greet such Fellows, and formally welcome them to the Society. I hope that all Fellows will take advantage of this opportunity.

Also, on behalf of the Society I would like to congratulate Professor John Barrow of Cambridge University on winning the world's biggest cash award [laughter] — the annual 1·4-million-dollar Templeton Prize. [Applause.]

A Fellow. Is John buying the drinks afterwards? [Laughter.]

The President. That's the formal business finished. Now we will turn to the talks. The first talk is by our Gold Medallist, Professor Simon White, of the Max Planck Institute for Astrophysics, who will be talking about 'Simulating cosmic evolution in the new Millennium.'

Professor S. D. M. White. [No summary was received at the time of going to press. The speaker described the results of one of the most recent attempts to carry out a large-scale simulation of structure in the Universe — the Millennium Simulation. The aim of such simulations is to try to understand how present-day structure in the Universe can be formed from a set of initial conditions that are nearly uniform, with structure similar to that observed in the cosmic microwave background (CMB).

The Millennium Simulation incorporates some 10^{10} particles to represent the distribution of material in a region of the Universe about half a gigaparsec on a side (*i.e.*, about one tenth of the diameter of the observable Universe); the resolution of 5 kpc yields the equivalent of 10^{15} cells in three dimensions. The speaker emphasized how advances in the algorithms used, as well as in computer power, have made it possible to carry out such large simulations, in comparison to about 30 years ago when the earliest simulations incorporated just a few hundred particles.

The simulation was started with material distributed according to cosmological parameters adopted from the one-year *WMAP* results on the CMB: that is, it was assumed that the Universe is spatially flat and contains 25% dark matter, 5% baryonic matter, and 70% so-called 'dark energy'. Weak deviations from uniformity follow the statistical properties predicted by the simple inflationary models for the generation of structure from quantum fluctuations in the very early Universe. The distribution of particles representing the matter is followed and stored at 64 different time points within the simulation, from redshift 20 to the present day. The initial calculation assumed that only the dominant gravitational interactions are significant in driving the formation of structure; other physics, the processes leading to formation of galaxies for example, were added later, using the stored output of the evolutionary calculation. Some ten million galaxies were produced in the simulation region, many more than in even the most extensive 3-D observational surveys carried out so far.

The simulation can help us to understand which physical processes dominate the formation and evolution of galaxies: simulations of galaxy populations are required in order to be able to understand one's observational data on real galaxies. The processes explored include, for example, the effects of the supermassive black holes in the centres of galaxies, or how starburst activity is related to the galaxy environment and structure.

The speaker gave several examples of how the processes of galaxy formation and evolution can be tested by comparing the simulation results with real survey data. For example, it is possible to adjust the physics in the galaxy-formation modelling until the degree of clustering seen in the *2dF* Galaxy Redshift Survey is matched. Alternatively, different scenarios can be explored — either including or excluding certain formation physics — to test their effects on simulated galaxy populations, which can then be compared to observed populations. Indeed, an understanding of this physics is required in order to understand even the luminosity functions measured in galaxy surveys. Finally, the speaker demonstrated how the simulation can be used to trace the evolution of specific objects over time, from high redshift to the present day; for example, massive objects seen at high redshift, such as quasars, are found to end up in the centres of rich galaxy clusters today.]

The President. We're running a bit late, so I think we'll only have time to take one question.

Rev. G. Barber. Is there a problem with being able to simulate the formation of galaxies at very high redshift? The *Hubble* Ultra Deep Field is picking up some strange objects at high redshift.

Professor White. The simulations that I've been talking about treat the galaxies almost as points; they don't resolve any internal structure. If you take the particular model that I've shown you so far — effectively our first attempt — it actually has too many galaxies at high redshift when compared to the observations. So if we need to fix it, it's by making the galaxies form somewhat later. Also, I showed you a very-high-redshift object which was supposed to be a quasar — the black hole there was actually about an order of magnitude less massive than the very distant quasars seen in surveys such as the SDSS. That's something that doesn't appear to be working in the models very well; we don't appear to be making our black holes fast enough, and some different physics has to be put in to explain why they grow as fast as they do.

The President. Can you get very-high-mass galaxies at redshift 6? Is that possible? There are claims of very-high-mass galaxies at redshift 6, so do they appear in the model?

Professor White. If you examine the distribution function of the masses of galaxies, the most massive galaxies at redshift 6, according to this model, are about 5×10^{10} solar masses. I don't know if that is big enough or not.

The President. Thank you again for a very interesting talk. [Applause.] The next talk is by Professor Stan Cowley, our other Gold Medallist. He is going to talk about 'Aurorae of Earth and the planets'.

Professor S. W. H. Cowley. The aurorae that are observed in Earth's polar regions are certainly phenomena of outstanding natural beauty, but how are they formed, and why do we care scientifically? At the simplest level, aurorae are formed when energetic charged particles from the hot plasma regions of a planet's outer environment flow along the planet's magnetic field lines down into the cool atmosphere, and collide with the atmospheric neutral atoms. The atoms become electronically excited by the collisions, and subsequently de-excite with the emission of a photon, which is the light of the aurora. In the case of the Earth, the emission takes place at altitudes of $\sim$100 to $\sim$200 km. One important reason why we are interested scientifically is that the aurorae then provide an image of the plasma dynamics of the outer environment of the planet, projected along the magnetic field lines onto the two-dimensional TV screen that is the upper atmosphere. Direct *in-situ* observations of these outer environments using spacecraft remains vital to understanding their detailed physics, but auroral observations provide a unique global perspective.

In the case of the Earth, the outer environment is dominated by the interaction between the Earth's magnetic field and the solar wind. The nature of the interaction is complex, however, because it is mediated by an electromagnetic process at the magnetopause boundary of the Earth's field — magnetic reconnection — which depends on the direction and strength of the interplanetary magnetic field (IMF). When the IMF points south, opposite to the direction of the Earth's equatorial field, reconnection produces open flux tubes in the equatorial magnetopause which map from interplanetary space into the Earth's northern and southern polar regions. These flux tubes are then carried downstream by the solar wind flow and stretched into a long magnetic tail, from which they are subsequently released back to the Earth by reconnection in the tail. The latter is usually explosive in nature, forming a phenomenon known as a 'magnetospheric substorm'. The newly-closed field lines then flow back to the dayside boundary where the process can repeat, leading to a cyclic flow of field and plasma through the magnetosphere that is called the 'Dungey cycle', after its discoverer. Within this picture, aurorae are formed firstly on newly-opened dayside field lines as the solar wind pours in, before the source becomes switched off as the field lines are swept into the tail, and secondly on the nightside as field lines become closed again, heating and compressing the tail plasma. The hot nightside plasma, trapped on newly-closed flux tubes, is then transported round the Earth to the dayside in the Dungey cycle, producing a hot plasma torus around the Earth which maps into two rings around each pole.

Consequently, when we look at the Earth's aurorae from above, *e.g.*, in UV light from space-borne cameras, we find that it usually forms a continuous ring around each pole, the 'auroral oval', encircling the dark central region of open field lines mapping to the tail. The aurorae at high latitudes on the dayside of the Earth then contain signatures of the reconnection process at the magnetopause, while the aurorae by night contain signatures of the explosive dynamics of the tail. For example, when the IMF points to the south and open flux production is rapid, the dayside aurorae show signatures of pulsing on $\sim 5-10$-minute time scales, corresponding to reconnection bursts that form near noon, and propagate wave-like around the boundary. When the IMF points to the north, very different dayside auroral distributions are observed, indicative of high-latitude reconnection on the surface of the tail lobe. Auroral images from space can thus provide information on global plasma dynamics with good time resolution. Radar networks on the ground can similarly provide corresponding images of the Dungey-cycle flow projected along field lines into the ionosphere, so that the two together form a combination of great diagnostic power. Goals that have yet to be achieved in auroral studies include long-term continuous imaging that can follow the progress of major magnetic storms that can last for days, and systematic simultaneous imaging of aurorae in the Northern and Southern Hemispheres. To do this requires coordinated observations from two or more spacecraft, which remains a goal for the future.

Turning now to the outer planets, the polar aurorae at Jupiter shine with much greater power than at Earth, typically by a factor of about ten thousand. Recent UV images obtained by the *Hubble Space Telescope* show that they exhibit a very complex morphology. At lowest latitudes lie the aurorae at the footprints of the moons Io, Europa, and Ganymede, which orbit deep within Jupiter's magnetosphere. These are formed by the interaction of the moon and its atmosphere with the near-corotating magnetospheric plasma. The interaction slows the flow, and launches waves which propagate along the field lines to the planet's ionosphere, carrying electric currents that flow along the field. The existence of such currents can strongly enhance the aurorae, since currents that flow 'upwards' out of the ionosphere are carried by hot magnetospheric electrons flowing down the field lines, and if the current is strong enough these must be accelerated along the field by an electric field. This acceleration then strongly enhances the electron energy flux and hence the resulting auroral brightness in the upper atmosphere.

At higher Jovian latitudes a 'main auroral oval' then circles each of Jupiter's poles, but these do not map to the vicinity of the open tail field lines as they do at Earth, but instead map into the 'middle magnetosphere' at equatorial distances of $\sim 20-30$ Jupiter radii (the dayside boundary lies at $\sim 50-80$ radii). We at Leicester have suggested that the main oval is formed by the 'upward' field-aligned currents of the current system that enforces near-corotation of the magnetospheric plasma. The main plasma source is the moon Io, which produces about a tonne of sulphur and oxygen plasma per second from its sulphur-dioxide atmosphere, equivalent to the outgassing rate of an active comet. The plasma diffuses out through the magnetosphere producing a vast, spinning equatorial plasma disc, with near-corotation being maintained by the torque provided by ion–neutral collisions in the ionosphere, whose effect is communicated to the magnetospheric plasma by the magnetic field. The related current system associated with the field bending has 'upward' currents flowing in the inner part of the system, which are in the right place and of the right strength to explain Jupiter's 'main oval' aurorae. At even higher latitudes in Jupiter's polar region lie more mysterious auroral forms that map to the outer magnetosphere and the region of open field lines. Our theoretical models indicate that a ring of aurorae should lie around the boundary of the open field region within the main oval, and such a ring is often observed, though it is usually quite fuzzy in nature. Verification or otherwise of our suggested interpretations must await new *in-situ* data from the *Juno New Frontiers* Jupiter polar-orbiter space mission that should arrive in ~ 2015.

Our theoretical models also suggest a single-ring aurora for Saturn at the open-field-line boundary, since the currents associated with the corotation enforcement mechanism are much weaker in this case. *Hubble* UV images of Saturn indeed show a single auroral oval at about the right place and with about the right power. If this indeed is located at the boundary of open field lines (and some would disagree) then it should show a strong response to interplanetary conditions, like the Earth's aurorae do. However, the response cannot be exactly the same as at Earth, because the time scale for tail evolution leading to the explosive reconnection in substorms is very different, being a couple of hours at Earth, comparable to solar-wind time scales, but being a week at Saturn. Instead, *Hubble* data show that Saturn's aurorae respond strongly to the dynamic pressure of the solar wind, which generally varies strongly over the course of a $\sim$25-day solar rotation, a fact we have interpreted as being due to compression-induced tail reconnection, instead of the substorm-related tail reconnection that occurs at Earth. The response of Jupiter's aurorae to the solar wind has not been thoroughly investigated to date, though a large new allocation of *Hubble* time for these purposes has recently been announced for observations to be undertaken in 2007. Much new information on planetary aurorae is anticipated from these future studies.

Finally then, just a couple of words of thanks. Firstly, I would like to thank the RAS Council for the high honour of the award that has been given me today. Secondly, I would like to thank my wife, who is able to be here, and my family, for their support over the years, without which none of this would have been possible. Thirdly I'd like to thank my colleagues both at Leicester for the last ten years, and at Imperial before that time, for their stimulation and making my career such an interesting one. And fourthly, to one of my PhD students who is sitting here, and there may be legion elsewhere, I'd just like to point out that my PhD supervisor was a recipient of the Gold Medal — James Dungey, about 15 years ago — and indeed, his PhD supervisor was a recipient of the Gold Medal, namely, Fred Hoyle; and so to my one student who is sitting here: 'No pressure, eh?' [Laughter.]

The President. It's not hereditary! Do we have any questions? Well, you've completely convinced us of the nature of aurorae.

Now it's a pleasure to welcome Professor Michael Werner from JPL to give the 2006 George Darwin Lecture. The title is 'The *Spitzer Space Telescope*: probing the Universe with infrared eyes.'

Professor M. Werner. [It is expected that a summary of this talk will appear in a forthcoming issue of *Astronomy & Geophysics*.]

The President. Thank you very much, Michael, for that wonderful talk about *Spitzer*. I think it's a heroic story of seeing it through to launch and its great success. Are there any questions?

Mr. M. F. Osmaston. Fairly early on in your lecture, you showed an image in which there are dark patches that you said were so opaque that they didn't radiate. Can you distinguish observationally between that inference and their being 'see-through' holes?

Professor Werner. That is a very good question. The question is, what is the nature of those dark patches? Remember that the picture was taken right in the plane of the Galaxy. It is very unlikely that you would have a hole that big due to absence of stars along that entire line of sight. Additionally, yet-longer-wavelength observations have shown that these dark clouds contain cold dust, so they're not empty, they're just very cold. It now appears to be the case that within these dark filaments, massive stars are forming, so at longer wavelengths than were used to make that image, you can actually see things going on in those dark filaments.

Rev. Barber. This is similar to a previous question. Is there an age problem in the early Universe at high redshift?

Professor Werner. Well, Simon is much better equipped to answer this question in detail. I think that the number and masses of the galaxies that we're finding at high redshift are certainly going to provide important constraints and challenges for the types of theories and simulations that Simon and his group are doing, so it's nice that the theory and the observations are proceeding together. We don't have enough data on the spectra of objects at higher redshifts to know when various substances might have formed, and it's hard to get those sorts of spectra. I can say that Richard Ellis and his student Dan Stark have just published a paper where they've taken one of these well-studied fields, and they were able to estimate the total stellar density at high redshift. Comparing that with what we think we know about star formation at earlier redshifts might be one way of addressing the kind of question you asked.

Mr. J. D. Shanklin. Spitzer has just released a spectacular image of Comet 73P/Schwassmann-Wachmann 3. One issue with that image, which also applies to some of those that you've shown today, is what is the angular scale?

Professor Werner. The angular size of the image is approximately 4×5 degrees. It is truly spectacular. It and other images from *Spitzer* can be viewed at the Spitzer Science Center website: http://sscws1.ipac.caltech.edu/Imagegallery/.

The President. With these redshift-6 galaxies, do you feel there is an ambiguity about the redshift? Could they actually be redshift 2·5 or something? There is an issue about which band drop you're seeing.

Professor Werner. Obviously, the only way really to be sure is if you have the spectroscopic redshift.

The President. The one I was thinking of allegedly has a mass of 2×10^{11} solar masses.

Professor Werner. I don't really know enough about that to add to the discussion. I do know that in the work by Richard Ellis that I talked about earlier, he had many spectroscopic redshifts at about a redshift of 5 which he then used. In any one case, obviously, with the spectroscopic redshift, the photometric redshift can be challenged.

The President. One more question.

Mr. M. Hepburn. Just a simple-minded question: how is it that there are infrared galaxies which are genuinely infrared? Is it that they formed very recently?

Professor Werner. The reason for that, we think, is that the infrared galaxies — that is, galaxies that radiate 95% of their energy in the infrared — tend to be associated with interacting systems. Naïvely, what happens is that you have two galaxies which collide and their interstellar material — the dust and gas which is in them — sinks down into the deep gravitational well which is created by having all these stars together in the same place. All that dust and gas suddenly turns into a whole mass of stars very quickly, but because of the fact that this whole mass of stars is dust-enshrouded, the energy that these stars radiate is absorbed by that dust and re-radiated in the infrared. So it's the result of an outburst of star-formation which is triggered by the interaction of two colliding galaxies which themselves are rich in dust and gas.

Mr. M. Hepburn. So it is, as it were, a recent thing?

Professor Werner. It doesn't occur only in the recent lifetime of the Universe, but the state that the galaxy is in is a very young stage. It hasn't been doing that for very long; it couldn't possibly be so prodigious as to generate that much energy for a very long time.

The President. Well, let's thank Michael Werner for his really excellent Darwin Lecture. [Applause.]

You are now invited to the usual drinks party over at the Society apartments, across the courtyard. You're all welcome; the contribution is one pound per head. It may be the last party we can hold in the RAS apartments for some considerable time because the whole building is being refurbished, starting in the summer. This is the last meeting of this season, and the next A&G meeting will be on Friday, October 13, so I wish you a pleasant summer.

DISCOVERY OF FLARE ACTIVITY IN GLIESE 157 B

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Photoelectric photometry has revealed flaring in Gliese 157 B, a faint companion to ADS 2894. Spectra of this red-dwarf star show chromospheric emission-line strengths indicative of a medium activity level for its spectral type. The absolute magnitude estimated from molecular band heads is uncertain, but not inconsistent with a spectroscopic binary as indicated previously by variable radial velocity.

Introduction

Gliese 157 B is a faint companion 11″ distant from ADS 2894 (= HD 24916 = BD −1° 565), which is 3·25 magnitudes brighter in V and 4 magnitudes brighter in U. Leonard[1] classified them as K4 and M2e dwarfs and discovered the emission lines of H I and Ca II in the faint component, with indications of variable line strengths[2]. Further low-dispersion spectroscopy has confirmed the emission nature[3] and has revealed variable radial velocity[4].

The stars are listed as a common-proper-motion pair ($\mu = 0''\cdot 23$/year in PA = 233°) in the *Hipparcos* catalogue with a parallax of $\pi = 0''\cdot 063 \pm 0''\cdot 002$. The separation has remained at 11″ for more than a century, but the position angle has decreased from 32° in 1877[5] to 15° in 2002. Taken at face value this suggests an orbital period of 2800 years, which is not inconsistent with the period of a circular orbit derived from the distance and separation and a mass of the primary slightly less than one solar mass. The *6th Washington Double Star Catalogue* lists a period of 3200 years based on data from Dommanget[6].

Gliese[5] lists $V = 11\cdot 48$ for the faint component, which implies $M_V = 10\cdot 48 \pm 0\cdot 07$.

Photometric flare monitoring

The large magnitude difference between the two visual components makes photoelectric flare monitoring of the pair in a wide diaphragm an exercise of little reward since only a major flare on the faint component would be detectable. A doubling of the brightness of the faint component due to a flare would increase the U magnitude of the system by only 0·03 magnitudes. A five-fold increase of the secondary would increase the system U magnitude by 0·1. Frequent small flares would remain undetectable due to the bright primary.

Direct flare monitoring of the faint component thus requires a very small diaphragm, excellent telescope tracking, and good seeing. There is a risk that scattered light from the bright primary will be added to the sky background when observing conditions are not perfectly photometric. Deviations from perfect telescope tracking in such conditions will introduce a variable brightness contribution in accordance with the slope of the scattered-light distribution some arcseconds away from the primary, notably at the nearest edge of the diaphragm.

We have monitored Gliese 157 B with a five-channel *UBVRI* photometer[7] on the 2·5-m *Nordic Optical Telescope* (*NOT*) on La Palma, using a diaphragm diameter corresponding to 5 arcseconds. The FWHM of the stellar seeing disc was always 1″ or better, as measured on occasional direct CCD images. A telescope autoguiding system was employed to ensure accurate tracking during each time series. An integration time of 3 seconds ensured about 1000 counts/observation in *U* and more than 4000 counts/observation in *B*.

Useful data were collected on four nights in 1990 August and two nights in 1991 January. Each time series lasted between 1 and 2 hours and were begun and ended by measurements of the sky background in several positions along the line connecting the two stars and in the direction perpendicular to it, at the distance of the secondary. Occasional sky-background measurements during each time series were made at a pre-programmed location perpendicular to the connecting line. These measurements were used to establish the brightness distribution of scattered light from the primary star, from which the sky background at the faint component could be determined. The observing log is shown in Table I.

TABLE I

U-filter flare monitoring of Gliese 157 B

Date (UT)	*Monitoring*	*Intervals (UT)*	*Total coverage (s)*
1990 August 27	04:42:05 – 04:54:04	04:57:49 – 05:07:32	
	05:11:10 – 05:21:03	05:24:41 – 05:34:34	2392
1990 August 28	04:31:50 – 04:38:57	04:40:04 – 04:44:39	
	04:48:23 – 04:57:49	05:01:27 – 05:09:12	
	05:10:31 – 05:15:49	05:19:56 – 05:28:08	
	05:31:46 – 05:32:52		2595
1990 August 29	04:41:34 – 04:51:17	04:54:54 – 05:05:43	
	05:09:21 – 05:17:40	05:21:24 – 05:29:40	
	05:33:18 – 05:40:05		2565
1990 August 31	03:36:08 – 03:51:42	03:55:20 – 03:58:21	
	04:02:37 – 04:14:39	04:18:20 – 04:30:36	
	04:34:21 – 04:48:18	04:51:55 – 05:02:39	
	05:06:17 – 05:15:56	05:19:36 – 05:31:11	5215
1991 January 05	22:30:40 – 22:46:12	22:49:50 – 23:03:12	
	23:06:50 – 23:19:20	23:22:58 – 23:37:03	
	23:40:41 – 23:51:26	23:55:04 – 24:00:00	
1991 January 06	00:00:00 – 00:05:32	00:09:10 – 00:18:41	
	00:22:19 – 00:31:32	00:35:10 – 00:44:28	
	00:48:06 – 00:56:23		6841
1991 January 07	22:23:24 – 22:23:08	22:36:46 – 22:46:26	
	22:52:37 – 23:02:04	23:05:42 – 23:13:42	
	23:17:20 – 23:25:02	23:28:40 – 23:36:00	
	23:39:38 – 23:47:51		3606

We detected five flares (in the *U* filter) during 6·4 hours of monitoring. The largest one (Fig. 1) was also seen in *B*, but not in *VRI*. Part of the flare rise was unobserved due to a sky-background measurement. Parameters characterizing flare time scales, amplitude, and energy are listed in Table II. The measurement precision in the *U* filter was 0·02 for the quiescent star so all flares exceeded the noise by a factor of 5 or more. The *U*-filter energy emitted by each flare was computed in the following way. The absolute *U* magnitude of Gliese 157 B was converted to a quiescent *U*-filter power of $L(U) = 8{\cdot}21 \times 10^{28}$ ergs s^{-1}, using the calibration of Moffett[8]. The relative energy of a flare (in units of seconds),

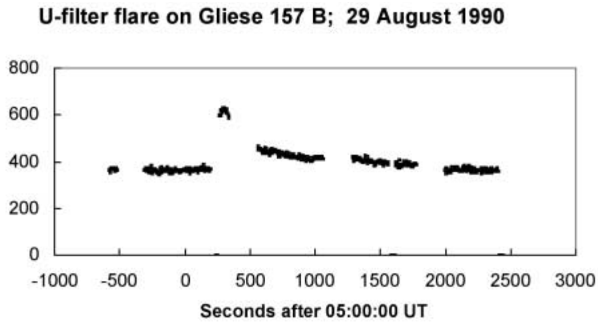

FIG. 1
Flare No. 2 (see Table II) on Gliese 157 B, observed on 1990 August 29

obtained by numerically integrating its light curve, was then multiplied with $L(U)$ to give the flare energy in ergs (Table II, last column). The result is an approximation since the colour change during a flare is not taken into account.

Gliese 157 B emitted $2 \cdot 6 \times 10^{31}$ ergs in *U*-filter flares during 23214 s of observations, *i.e.*, an average of $1 \cdot 1 \times 10^{27}$ ergs s^{-1}. Thus about 1% of its *U*-filter emission is due to flaring. This is less than the most active stars of similar spectral type[9].

TABLE II

U-filter flare characteristics for Gliese 157 B

No.	*Date (UT)*	*Flare max*	t_{rise} (s)	$t_{0.5}$ (s)	t_{dur} (s)	*Amplitude*	*Log energy (ergs)*
1	28·08·1990	05:23:30	30	30	180	0·10	29·69
2	29·08·1990	05:05:30	<100	163	1800	0·72	31·35
3	05·01·1991	22:51:09	9	3	190	0·24	29·61
4	06·01·1991	00:43:06	5	3	33	1·21	29·96
5	07·01·1991	22:30:44	17	64	150	0·23	30·14

Spectroscopy

A red spectrum (λλ 6200–7300 Å) of Gliese 157 B was obtained at UT 07:51–07:56 on 1990 October 4 with the modular spectrograph on the 2·5-m *Du Pont Telescope* at Las Campanas Observatory, Chile. A 1200 lines/mm grating (blazed at 7500 Å) and a CRAF CCD at the 85-mm camera focus yielded 1·2 Å/pixel and a spectral resolution (FWHM) of 2·8 Å, set by the entrance slit width. An excellent signal-to-noise ratio reveals individual photospheric absorption lines and numerous band heads of TiO and other molecules. Hα is prominent in emission and the measured equivalent width is 3·43 Å.

A blue spectrum (λλ 4500–5400 Å) of Gliese 157 B was obtained at UT 03:22–03:24 on 1991 October 16 with a low-dispersion spectrograph on the 2·5-m *Nordic Optical Telescope* on La Palma. The spectral resolution was about 5 Å. TiO band heads are prominent and Hβ is clearly seen in emission. The emission lines are slightly weaker than in AD Leo[10].

The strengths of TiO band heads (λλ 4760, 4950, and 7050 Å) were measured relative to nearby 'continuum' reference points as described in Pettersen

& Hawley[10]. Using their relationships with M_V, we estimate $M_V = 11 \cdot 4$, $11 \cdot 0$, and $11 \cdot 2$ from the TiO band heads at λλ 4760, 4950, and 7050 Å, respectively. Ca *H* 6385 Å yields $M_V = 11 \cdot 1$, while CaOH 6320 Å yields $M_V = 10 \cdot 6$. Application of these empirical relations may easily result in uncertainties of M_V of $\pm\, 0 \cdot 5$ magnitude or more, so the numbers above are not conclusive evidence that a difference exists between $M_V = 11 \cdot 1$ determined spectroscopically and $M_V = 10 \cdot 5$ derived from the *Hipparcos* parallax. The difference of $0 \cdot 6$ magnitude suggests, however, that Gliese 157 B may be a spectroscopic binary, in accordance with the variable radial velocity.

Summary

The precise autoguiding system of the *Nordic Optical Telescope* has allowed photometric monitoring of the faint component of Gliese 157 ($U = 14 \cdot 1$) only 11 arcseconds away from the $\Delta U \approx 4$ magnitudes brighter K4 V primary, when the seeing was about 1 arcsecond. Five flares were detected in the *U* filter. The largest flare was also detected in *B*, but not in *VRI*. This is the first time flaring has been reported for this star.

Spectra show prominent Hα and Hβ emission lines, slightly weaker than in the flare star AD Leo. The strength of TiO and other molecular band heads suggests an absolute magnitude somewhat fainter than that derived from the *Hipparcos* parallax value, although with considerable uncertainty. It is consistent with Gliese 157 B being a spectroscopic binary, as indicated by the variable radial velocity. Further observations are needed to clarify this question.

Acknowledgements

The red spectrum of Gliese 157 B was obtained by Suzanne Hawley as part of another observing programme on the *Du Pont Telescope* at Las Campanas Observatory. Travel funds from the Norwegian Research Council are gratefully acknowledged.

References

(1) F. C. Leonard, *PASP*, **56**, 38, 1944.
(2) F. C. Leonard, *PASP*, **56**, 85, 1944.
(3) A. H. Joy & O. C. Wilson, *ApJ*, **109**, 231, 1949; I. N. Shakhovskaya, *Izv. Krymskoj Astrofiz. Obs.*, **51**, 92, 1974.
(4) H. A. Abt, *ApJS*, **19**, 387, 1970.
(5) W. Gliese, *Veröff. Astron. Rechen-Institut Heidelberg*, no. 22, 1969.
(6) J. Dommanget, *Bull. R. Astr. Soc. Belgium*, **9**, 47, 1978.
(7) T. Korhonen, V. Piirola & A. Reiz, *The ESO Messenger*, 1984 December, p. 20.
(8) T. J. Moffett, *ApJS*, **29**, 1, 1974.
(9) B. R. Pettersen, in L. V. Mirzoyan *et al.* (eds.), *Flare Stars in Star Clusters, Associations and the Solar Vicinity* (Kluwer, Dordrecht), 1990, p. 49.
(10) B. R. Pettersen & S. Hawley, *A&A*, **217**, 187, 1989.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 191: HD 17310, HD 70645, AND HD 80731

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These three objects have been identified as members of the recently recognized class of γ Doradûs stars, which exhibit multi-periodic photometric variations that are thought to arise from non-radial pulsation. The particular objects treated here also prove to be spectroscopic binaries, for which we provide reliable orbits. The radial velocities exhibit unusually large residuals, in which some of the photometric periodicities can be traced. Some of the same periodicities are also demonstrated by the observed variations in the line profiles, which are quantified here simply in terms of the line-widths.

Introduction

The characters of a few stars that showed small photometric variations with multiple periodicities of the order of one day — longer than typical δ Scuti variations — gradually became apparent in the late years of the last century. As recently as 1999 Kaye *et al.*[1] defined a new class of variables, having γ Doradûs as the type star, to accommodate such objects, whose photometric instability has been attributed to high-order gravity-mode pulsations, in which the motions are mainly tangential (rather than radial, as in the case of δ Scuti pulsations which have typical periods of the order of 0·1 day). The periods are in the range 0·3–3 days; the pulsations are likely to affect the line profiles, more particularly in the wings of the lines, but since they are largely non-radial and slower than in the δ Scuti case their effects on stellar radial velocities are likely to be more muted.

In the same year as the new class was recognized, Handler[2] presented a list of membership candidates, identified from a comprehensive search of the *Hipparcos* 'epoch photometry'; the list contained 70 entries, of which 46 were considered to be 'prime candidates'. Many, but not all, of those that have been investigated have proved to be spectroscopic binaries. Paper 187[3] in this series gave orbits for two of them; in an introductory section it referred to the observational history (salient parts of which were published in this *Magazine*), of γ Dor itself, and to the recognition[4,5] in 9 Aur, a non-binary member of the class, of a sub-set of the photometric periods in the star's radial velocities and line-profile variations. One of the present authors was also responsible for the radial-velocity measurements that led to a double-lined orbit[6] for HD 221866 and the tentative identification of the secondary component in that system as a γ Dor star.

The observational histories of the three stars that form the subject of this paper, all of which are of *HD* type F0, run extremely parallel with one another, because (apart from some *uvby*Hβ photometry, not referenced here) it is only since their appearance in Handler's list[2] of 'prime γ Dor candidates' that any interest has been taken in them. Even since then, there have been only three papers — by Martin, Bossi & Zerbi[7] in 2003, Mathias *et al.*[8] in 2004, and Henry, Fekel & Henry[9] in 2005 — that have shed much light on them; all three stars feature in the last one[9], but the other two do not include HD 17310.

The latter star, however, does feature in a few papers that are not concerned with the others. It was among a large number of stars observed for radial velocity by Grenier *et al.*[10], who found a mean of $-21 \cdot 4 \pm 3 \cdot 6$ km s^{-1} from three 80-Å mm^{-1} spectrograms, the uncertainties of the results being such that the plate-to-plate discrepancies did not suggest real variability; they classified the spectrum as F2 IV–V. Then Koen & Eyer[11] identified periods* in the *Hipparcos* photometry; and Nordström *et al.*[12] gave basic data about the star in their survey of F and G dwarfs, but they did not measure any radial velocities for it. HD 70645 is mentioned in one 'extra' paper, in which Topka *et al.*[13] remarked that it is within a field surveyed by the *Einstein* X-ray satellite, but no X-rays from it were detected. HD 80731 was observed twice by Moore & Paddock[14] long ago with the Lick 36-inch refractor and a prismatic spectrograph giving 75 Å mm^{-1} at Hγ ; they listed a spectral type of F0 V and a mean radial velocity of $+4$ km s^{-1} with a 'probable error' of $1 \cdot 7$ km s^{-1}, so the binary nature of the object was not discovered.

All three stars feature in the *Hipparcos* survey. For HD 17310, the *Hipparcos* catalogue preferred to give ground-based values of V and $(B-V)$, $7^{\mathrm{m}} \cdot 76$ and $0^{\mathrm{m}} \cdot 378$, respectively, to its own measurements, but we have not been able to discover whence it obtained them. The V magnitude was flagged as variable, but no period was found; Handler[2] and Koen & Eyer[11], however, thought that they saw a period of $2 \cdot 0296$ days in the *Hipparcos* photometry. The parallax, $0'' \cdot 00914 \pm 0'' \cdot 00114$, leads to a distance modulus of $5^{\mathrm{m}} \cdot 2 \pm 0^{\mathrm{m}} \cdot 3$ and thus to an absolute magnitude of about $+2^{\mathrm{m}} \cdot 6$. HD 70645 is attributed a *Hipparcos*-based mean V magnitude of $8 \cdot 12$, appearing to vary with a period (also noted by Handler) of $0 \cdot 82488$ days, and a ground-based $(B-V)$ of $0^{\mathrm{m}} \cdot 344$. The parallax of $0'' \cdot 00755 \pm 0'' \cdot 00087$ yields a distance modulus of $5^{\mathrm{m}} \cdot 6 \pm 0^{\mathrm{m}} \cdot 3$, implying $M_V \sim 2^{\mathrm{m}} \cdot 5$. HD 80731 is listed with ground-based magnitudes of $V = 8^{\mathrm{m}} \cdot 46$, $(B-V) = 0^{\mathrm{m}} \cdot 345$, the former variable in a period of $1 \cdot 11556$ days (again confirmed by Handler), and with a parallax of $0'' \cdot 00677 \pm 0'' \cdot 00103$, leading to $m–M = 5^{\mathrm{m}} \cdot 85 \pm 0^{\mathrm{m}} \cdot 3$ and thus to $M_V \sim 2^{\mathrm{m}} \cdot 6$. The three stars are all seen to have just the colour indices and absolute magnitudes that would be expected for early-F dwarfs.

We next give a brief synopsis of what the three post-Handler papers[7–9] have discovered about the stars. Martin *et al.*[7] obtained fresh photometric data on eight stars, including HD 70645 and HD 80731, on the five useable nights during a single 14-night observing run on the 90-cm telescope in the Sierra Nevada; the number of observations per star was only about 50. They also re-investigated the *Hipparcos* photometry with a computer program that they considered to be superior to other people's. For HD 70645, Martin *et al.*† did not confirm the $0 \cdot 825$-day period that both *Hipparcos* and Handler thought to exist in the *Hipparcos* photometry, but instead found periods of $0 \cdot 792$ and $1 \cdot 297$ days; their own data indicated $1 \cdot 14$ and $0 \cdot 690$ days. For HD 80731 they confirmed

*In this paper we usually refer to periods rather than frequencies, inverting where necessary the numbers quoted from other authors.

†It may save other readers of Martin *et al.*'s paper[7] some time and thought if we mention that where the caption of the all-important Table 5 refers to the 'first column' it means columns 1–6; the 'second column' is really columns 7 and 8, and the 'third column' is columns 9–11. The expression 'semi-column' means a colon.

the *Hipparcos*/Handler periodicity of 1·1156 days in the *Hipparcos* photometry, and found an additional one of 0·745 days. Their own measures were considered to indicate possible periods of 7·00, 2·23, and 1·401 days, but it is difficult to believe that periods of such lengths could be reliably identified on the basis of only five nights' data.

Mathias *et al.*[8] obtained repeated spectra of a number of γ Dor candidates, including HD 70645 and HD 80731, with the *Aurelie*[15] spectrograph on the Haute-Provence 1·52-m telescope, mainly to look for line-profile variations that would corroborate the γ Dor natures of the stars concerned. They concentrated attention on just two ionic lines in the blue part of the spectrum. Over a total interval of a little more than a year they obtained ten spectra of HD 70645 and 11 of HD 80731, finding line-profile variations to be "evident" in both cases and discovering the binary natures of both stars. They derived orbits for them both; that of HD 70645 is in principle correct, but that of HD 80731 is completely mistaken, having a period of 13·572 ± 0·011 days, whereas we shall show below that the true value is 10·674 days. Unfortunately they did not publish their radial velocities, so we cannot take them into account in our own orbital solutions. We note that we have already found[3] in Mathias *et al.*'s paper[8] another mistaken period, that of HD 100215; without the data in front of us we cannot see exactly how the errors arose, but in all cases the number of velocities was very small upon which to base orbits. Mean $v \sin i$ values of 11 and 13 km s^{-1} were listed for HD 70645 and HD 80731, respectively.

Henry, Fekel & Henry[9] observed, in the course of a year's campaign with an automated 0·4-m telescope at the Fairborn Observatory, all three of the stars discussed in the present paper. They obtained much more satisfactory photometric coverage than either *Hipparcos* (very bad temporal distribution of the data points, but of course the photometry was only a by-product of the principal objective) or Martin *et al.*[7] (very small data set). For HD 70645 and HD 80731 they had a total of more than 400 measurements in both *B* and *V*, obtained on about 250 nights in one season, so the derived periodicities ought to be entirely reliable. Martin *et al.*'s rejection of the *Hipparcos*- and Handler-derived period of 0·825 days for HD 70645 from the *Hipparcos* photometry in favour of 0·792 days was corroborated, and the Martin primary period of 1·14 days was confirmed. The Henry *et al.* periods for HD 70645, in descending order of amplitude, were 1·1032, 0·7929, 0·8593, 1·2405, and 1·1461 days, all of them found in both the *V* and the *B* data and all having uncertainties typically of 2 in the fourth decimal place. In the case of HD 80731, Henry *et al.* confirmed the 1·1156-day period that all of the previous investigations had found in the *Hipparcos* photmetry, but not the periods proposed by Martin *et al.* from their own data. The Henry *et al.* periods, in order, were 1·1159, 1·2783, 1·5154, and 0·7623 days.

Henry *et al.*[9] also obtained spectroscopy in the red ($\lambda \sim 6400$ Å) with the Kitt Peak coudé-feed system. They classified the stars, finding both HD 70645 and HD 80731 to be of type F1 (and they knew them to be main-sequence objects from the *Hipparcos* parallaxes), and they gave $v \sin i$ values of 11 and 14 km s^{-1}, respectively. They measured (and tabulated, so we are able to utilize them) three radial velocities for HD 70645 and seven for HD 80731. They commented that two of their velocities of HD 70645 are consonant with Mathias *et al.*'s orbit, but that the third showed a residual of about 10 km s^{-1}, so the orbit must require some revision; and they saw that their velocities of HD 80731 were *not* consistent with the Mathias *et al.* orbit.

We have left till last our reference to the work of Henry *et al.*[9] on the third of the stars discussed in the present paper, HD 17310, simply because their paper is the only one that deals with it. The paper[9] lists as many as eleven radial velocities, with a range of over 40 km s^{-1}, and gives a spectral type of F2 and a projected rotational velocity of 10 km s^{-1}. Three photometric periods were established from more than 200 measurements in both V and B; they were 2·138, 1·825, and 2·452 days, with uncertainties near 0·001. The 2·0296-day period derived from the *Hipparcos* photometry by both Handler[2] and Koen & Eyer[11] was not confirmed.

Henry *et al.* performed a period search on their radial velocities of HD 17310 in an effort to identify the orbital period. The observational 'window function' was far from ideal, because the measurements were made during just four observing runs, in which the star was observed on one night and on three, two, and five consecutive nights, respectively. The best period formally was 0·9653 days, but the authors[9] did not trust it. "Instead," (they said) "we prefer periods in the 20–30 day range, the best of which is 27·793 days." We are able to commend both their instinct and their conclusion, as we shall show below that that period is correct. Their preferred period is a 1-day^{-1} alias of the short one; expressed as frequencies, they are 0·03598 and 1·03595 day^{-1}, respectively.

New radial velocities and orbits

The paper[9] by Henry, Fekel & Henry, which is entitled *11 New γ Doradus Stars*, was published in mid-2005 and caught the attention of one of the present authors, who found particular interest in a column in Table I where the $v \sin i$ values were given for the 11 stars. Three of the values — those assigned to the stars that we are discussing now — were from 10 to 14 km s^{-1}, whereas the others ranged from 38 to 150 km s^{-1}. Stars that rotate rapidly are difficult or impossible to measure for radial velocity with the *Coravel* at the Cambridge 36-inch telescope, but when a short investigation of the literature had revealed that the three γ Dor stars that rotated slowly lacked reliable orbits those objects were placed on the *Coravel* observing programme.

HD 17310 is very unfavourably placed, at a declination of nearly −7° in Eridanus, on the border by Cetus, about 3° north-preceding the fourth-magnitude star η Eri. Strictly speaking it ought not to be observed with the Cambridge telescope, whose coudé beam is increasingly vignetted by the telescope structure below −5° declination, but the observer persuaded himself that the vignetting at −7° was not so great as to be likely to produce errors as bad as those that could be expected from other sources. Observations were necessarily confined to the vicinity of the meridian, so the observing season was short and yielded only 11 measurements.

HD 70645 and HD 80731, in contrast, are at high declinations (68° and 62° respectively), quite close together in the north-preceding corner of Ursa Major. Preliminary orbits were established very quickly, and for a time thereafter the radial velocities were measured only where they would serve to fill gaps in the phase distribution. Later, when it became apparent that the residuals from the orbits might yield (or at least exhibit) some of the pulsational periodicities, a measurement was made on each fine night regardless of orbital phasing. The two stars, though easily circumpolar as seen from Cambridge, cannot be observed more than about six hours from upper culmination because structures associated with the northward-going coudé focus (and indeed the *Coravel* instrument itself) occupy the northern part of the dome of the 36-inch reflector. The total numbers of new radial velocities are 44 for HD 70645 and 54 for HD 80731.

Although the data are (unusually, for this series of papers) confined to a single observing season, by reason of their continuity and compact distribution in time they lend themselves tolerably well to the investigation of short periods superimposed upon the orbital variation. The likelihood that pulsational instabilities would be traceable in the radial velocities is indicated by substantial variations in the profiles of the cross-correlation dips from which the velocities are determined. That is illustrated by Fig. 1, which compares the dips given by HD 80731 on different occasions. The S/N ratios achievable for radial-velocity traces of the stars concerned are not usually adequate to delineate with confidence any real asymmetries that may be present, but the overall widths of the line profiles certainly change from one occasion to another. The widths are characterized numerically here as if they were projected rotational velocities, $v \sin i$, but our use of that expression is to be regarded merely as a name for the line-width parameter that is routinely calculated for each radial-velocity trace by the *Coravel* reduction software *as if* the broadening of the spectral lines, beyond the minimum width given by other stars, were due simply to rotation of the stars as solid bodies. The values are quantized in $^1/_2$-km s^{-1} steps, owing to the manner in which they are calculated[16].

Straightforward orbital solutions of the radial-velocity data give orbits that are quite satisfactory but are characterized by unusually large residuals, of the order of 1·5 km s^{-1} or so — two if not three times as large as might be expected from the character of the data. We show below that pulsational periods can be traced in the residuals. We can try to model the residuals by sine waves, by regarding the residuals as radial velocities in their own right and solving them with a program that derives circular orbits from such data. If there were only one short period, it would perhaps be appropriate to treat the raw radial-velocity measurements with the orbit program that solves simultaneously the outer and inner orbits of single-lined triple systems. That, however, manages to improve slightly the fit to the short-period, low-amplitude 'inner orbit' by making slight changes to the 'outer' — in this case, the only true — orbit. Not only would such changes not be likely to suit more than one periodicity among

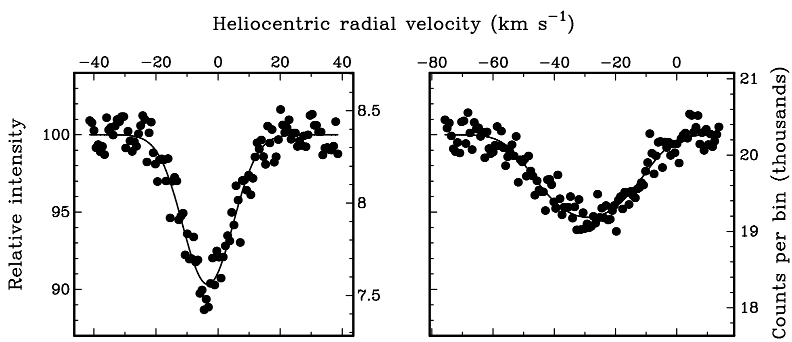

FIG. 1

Radial-velocity traces of HD 80731, obtained with the Cambridge *Coravel* on 2006 May 9 (left) and June 3, illustrating the variability of the 'dip' profile.

the pulsational 'orbits' but, as the number of data points increases, the scope for adjusting the true orbit to accommodate residuals arising from pulsation decreases until in the limit of an indefinitely large number of data it would vanish altogether. We conclude that the proper procedure is first to derive the actual orbit by a straightforward application of the single-line orbit-solving program, and then to use the resulting set of residuals as the dataset to be investigated for evidence of pulsational periodicities. In the sections below, we discuss the stars out of conventional right-ascension sequence in order to treat the two comparatively well-observed ones first.

It was only as our observations accumulated, and we realized that the velocity residuals were not random but exhibited one or more periods associated with the γ Dor pulsations, that concern arose as to whether the quality of the data would be adequate to support an analysis of pulsations whose amplitudes would be very much smaller than those of the orbits that we initially set out to determine. Most of the later observations, therefore, were integrated to more generous levels, usually >10 000 counts per bin, than most of the earlier ones, which were nearer 5000. In analyzing the final datasets, we experimented with flagging them (*a*) by temporal halves, and alternatively (*b*) by the count levels. There proved not to be significant differences between any of the divisions thus made: the conclusion to be drawn from the exercise seems to be that observational error is *either* not the principal contributor to the velocity residuals (the analysis of which is therefore valid), *or* is not significantly reduced by approximately doubling the integrations (which is difficult to believe). It also appears, therefore, that our concern over the data quality was misplaced, and that the extra time spent on many of the later integrations may largely have been wasted!

HD 70645

The Cambridge radial-velocity measurements began in 2005 November, soon after the star was first observable on the dawn meridian, and continued until it was beyond reach in the north-west at dusk at the beginning of the following June. Forty-four observations were made of it; they are listed in Table I, together with the three velocities published by Henry *et al.*[9] and the phases and residuals obtained from a solution performed as for a normal single-lined binary star. All the velocities were given equal weight. Initially the Cambridge measurements were solved alone, and gave the period with a standard error of 0·0022 days. Then the published data were brought in to the solution, producing negligible changes to the elements but (by increasing the time base from 200 to 1200 days) reducing the standard error of the period to 0·0008 days, a worthwhile improvement. The solution is illustrated in Fig. 2 and the orbital elements are set out in the informal table below.

$P = 8 \cdot 4402 \pm 0 \cdot 0008$ days	$(T)_{10} = \mathrm{MJD}\ 53764 \cdot 26 \pm 0 \cdot 21$
$\gamma = +14 \cdot 53 \pm 0 \cdot 28$ km s^{-1}	$a_1 \sin i = 3 \cdot 82 \pm 0 \cdot 05$ Gm
$K = 33 \cdot 1 \pm 0 \cdot 4$ km s^{-1}	$f(m) = 0 \cdot 0314 \pm 0 \cdot 0011\ M_\odot$
$e = 0 \cdot 077 \pm 0 \cdot 012$	
$\omega = 66 \pm 9$ degrees	R.m.s. residual = $1 \cdot 72$ km s^{-1}

Unfortunately the potential pulsational periods cannot be determined accurately enough for the cycle count back to the published observations to be secure, so from this point onwards the investigation is limited to the Cambridge

TABLE I

Radial-velocity observations of HD 70645

Date (UT)			*MJD*	*Velocity* km s^{-1}	*Phase*	*(O – C)* km s^{-1}	*v sin i* km s^{-1}
2003	Mar.	10·279*	52708·279	+44·4	$\overline{116}$·887	–2·3	
	Apr.	30·159*	759·159	+44·7	$\overline{110}$·915	+0·8	
2004	Sept.	26·505*	53274·505	+34·7	$\overline{49}$·974	+0·3	
2005	Nov.	14·178	53688·178	+31·2	0·986	–0·7	13
		19·176	693·176	+17·5	1·578	+1·6	11·5
		25·182	699·182	–18·4	2·290	–0·9	12
		30·183	704·183	+45·6	·882	–1·5	11·5
	Dec.	15·131	719·131	+26·9	4·653	–2·4	12
		17·172	721·172	+47·9	·895	+1·9	12
		18·119	722·119	+29·7	5·007	+2·5	12
2006	Jan.	26·016	53761·016	+22·4	9·616	–0·3	13·5
	Feb.	15·991	781·991	+3·7	12·101	–1·5	11
		16·905	782·905	–12·6	·209	+0·6	10·5
		17·998	783·998	–15·9	·339	+0·4	12
		18·867	784·867	–7·7	·442	–1·2	9·5
		20·887	786·887	+35·4	·681	+1·4	14
	Mar.	1·920	795·920	+41·1	13·751	–2·5	10·5
		4·927	798·927	+3·2	14·108	–0·5	16
		6·006	800·006	–18·6	·236	–3·1	11·5
		6·909	800·909	–15·6	·343	+0·5	14
		24·918	818·918	–4·5	16·476	–3·0	11·5
	Apr.	3·994	828·994	+33·5	17·670	+1·4	12
		4·938	829·938	+44·0	·782	–2·4	11
		6·057	831·057	+41·5	·915	–2·5	7·5
		8·962	833·962	–16·3	18·259	+0·5	13·5
		10·915	835·915	+3·5	·490	+2·9	11·5
		12·022	837·022	+21·4	·621	–2·3	15·5
		14·872	839·872	+37·9	·959	+0·7	10
		25·915	850·915	–17·6	20·267	–0·5	9·5
		27·898	852·898	+1·1	·502	–1·5	15·5
		29·854	854·854	+42·7	·734	+1·2	11·5
	May	1·947	856·947	+31·5	·982	–1·2	11
		2·974	857·974	+4·7	21·104	+0·1	10
		5·970	860·970	–6·1	·459	–2·0	14
		9·866	864·866	+42·8	·920	–0·5	12
		10·892	865·892	+19·4	22·042	+0·3	12
		11·901	866·901	–5·0	·161	+1·6	14
		15·928	870·928	+27·5	·638	+0·8	11
		16·868	871·868	+43·6	·750	+0·2	12·5
		18·876	873·876	+31·3	·988	–0·2	11·5
		21·885	876·885	–14·0	23·344	+2·0	13
		23·886	878·886	+19·3	·581	+2·9	13·5
		29·893	884·893	–16·1	24·293	+1·4	10
		30·896	885·896	–8·9	·412	+1·3	11·5
		31·896	886·896	+6·8	·530	–0·6	15·5
	June	2·893	888·893	+47·6	·767	+2·5	12
		3·893	889·893	+50·8	·885	+4·0	13·5

*Observation published by Henry *et al.*[9].
All others observed with the Cambridge *Coravel*.

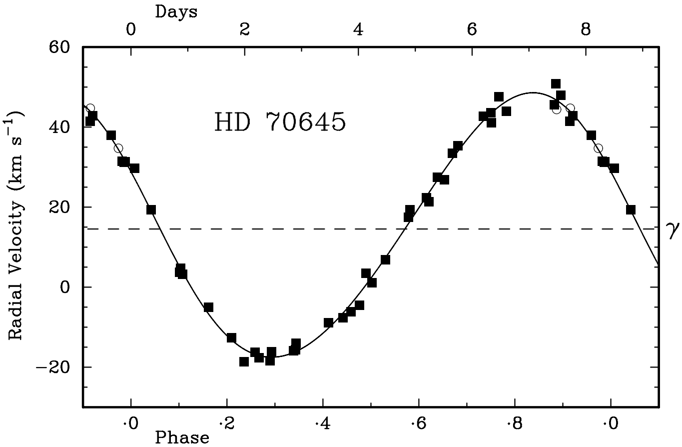

FIG. 2

The observed radial velocities of HD 70645 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Cambridge observations are represented by the filled squares; those published by Henry *et al.*[9] are plotted as open circles. All were given equal weight in the solution of the orbit.

measures. A column has been added to Table I to give the apparent $v \sin i$ value determined individually from each observation.

We have treated the velocity residuals, with their corresponding observational epochs, as an autonomous dataset, to be examined for pulsational periodicities as explained at the end of the section above. Equally, we regarded the line-widths as constituting a parallel dataset meriting an analogous examination. Rather than choosing whether to test for the presence of periods already proposed by others, or instead to make an independent search for periodicities, we decided to adopt first the one strategy and then the other. It could be argued that the photometric periods found by Henry *et al.* come from such a rich database that their validity in the magnitude data is practically guaranteed, so all we need to do is to test for their presence in the radial velocities and the line-widths; but it would be a pity to overlook other periods, that might be more conspicuous in radial velocities or in line-widths than in brightness, simply by neglect of an unprejudiced search of our own data. At the same time we need to be careful not to fall into the error, of which we have sometimes[18,19] suspected others, of placing too much reliance on short periods that may be mathematically present in sparse data strings.

Our procedure for assessing the significance of possible periods, whether taken from the literature or found by ourselves, was as follows. We set up the datasets as if for single-lined solutions of circular orbits, with the period to be tested, a nominal amplitude of 1 km s^{-1}, and with the epoch set at that of the largest positive (residual) velocity or the largest line-width. If the solution then ran and converged, that result was taken as qualitative evidence in favour of the existence of the relevant period in the data. If it did not, we ran a 'plot-only solution', in which we did not ask the computer to improve the elements that we had supplied but simply to plot the solution as it stood; that would enable us to see from the plot whether there appeared to be a significant variation with the relevant period but not with the phasing implied by our inevitably crude guess. Any apparent variation could be followed up by re-running an optimized solution with an appropriately adjusted initial epoch. Where no evidence of a systematic phase-related variation could be seen in a 'plot-only solution' and the computer could not be persuaded to pull in to any solution and improve on it, we concluded that no significant periodicity existed. We feel quite secure in doing that, since (as we proceed to show) several of the results where there *did* appear to be *some* evidence of phase dependence, and where the computer *did* grasp the solution and improve on it, have turned out to be without statistical significance.

The method that we have selected for quantifying significance is to compare, in the light of the F test, the sums of the squares of the residuals from the solutions obtained with and without the prospective period. We consider first the radial-velocity case. The 'without' sum is always the same, being just the sum of the squares of the residuals that are given in Table I for the 44 Cambridge observations and that form the data set that we are testing for periodicities. That sum is 132·24 (km s^{-1})^2. In solving those data for a circular 'orbit' we attach optimal values to four independent variables, *viz.*, period, epoch, amplitude, and γ-velocity. (Although, from the manner in which they were obtained, the velocities that constitute the dataset must have a mean of zero, it does not follow that the γ-velocity of an optimized pulsational 'orbit' derived from them will be exactly zero.) Especially if the imposed or resulting period is a significant one, the sum of squares of the new set of residuals will be reduced. The amount of the reduction will be assignable to the four degrees of freedom represented by the four fitted variables, while the remaining sum is to be laid at the door of the other 40 degrees of freedom; the significance of the reduction is found by taking the ratio of the mean-squares per degree of freedom between the four and the 40 and comparing it with tabular values of $F_{4,40}$ for various levels of significance.

We clarify the procedure by an initial 'worked example' based on the most significant pulsational period that we have found for HD 70645, *viz.*, the 0·792-

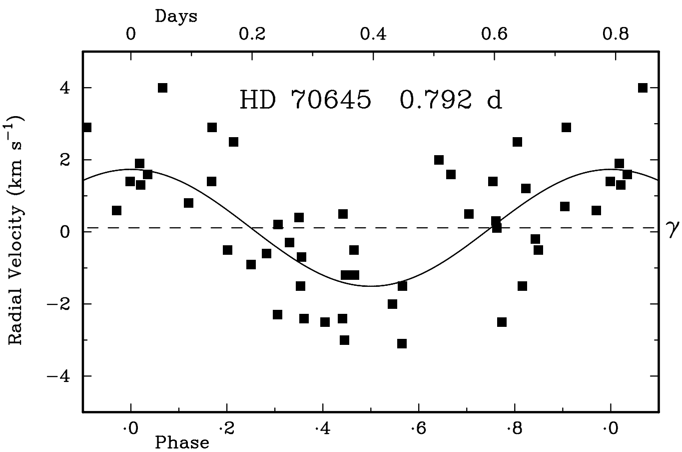

FIG. 3

Illustrating the most convincing pulsational period detected in the orbital radial-velocity residuals of HD 70645. The data points are the times of observation and the velocity residuals tabulated for the Cambridge observations in the fifth column of Table I. The Henry *et al.* velocities cannot usefully be plotted, because the pulsational period is not determined well enough to maintain phases back to previous seasons.

day one found first by Martin *et al.*[7] and corroborated by Henry *et al.*[9]. The computer pulls into a solution with a period of 0·7919 ± 0·0003 days and an amplitude of 1·62 ± 0·31 km s^{-1} (which at >5σ looks promising) and yields a sum of squares of 78·81 (km s^{-1})^2 for the 44 residuals, which represent the 40 degrees of freedom left after we used four in fitting the four variables. Thus the 40 degrees cost 78·81/40 = 1·97 (km s^{-1})^2 each. The four degrees represented by the variables cost (132·24 – 78·81), or 53·43 (km s^{-1})^2, *i.e.* 13·36 per degree, so we obtain $F_{4,40}$ = 13·36/1·97 = 6·80. The tabular values[17] of $F_{4,40}$ for various degrees of significance are as follows: 10% 2·09, 5% 2·61, 2·50% 3·13, 1% 3·83, 0·5% 4·37, 0·1% 5·70. Our value is therefore comfortably beyond even the 0·1% value of F, and it follows that the period is to all intents and purposes certainly present in the data. The plot of the fitted sine-wave and the velocities to which it is fitted (the residuals from the orbit derived above and plotted in Fig. 2) are shown in Fig. 3.

We have been through all of the periods found by Henry *et al.* in the same way, and present the results very succinctly in Table II. The successive lines of the table give the successive quantities specified in our illustration of the procedure above, as follows:

(a) Period (days) given by Henry *et al.*[9];
(b) Period (days) found in our velocities, with its standard error in units of the last decimal place in brackets;
(c) Amplitude (km s^{-1}) found in our velocities, with its standard error similarly;
(d) Sum of squares of the velocities ((km s^{-1})^2) before the period is fitted;
(e) Sum of squares after the period is fitted, followed by that quantity divided by 40 (the number of degrees of freedom that it represents), so the second number is the mean square per degree of freedom;
(f) (d) minus (e), the remaining portion of the sum of squares, attributable to the four degrees of freedom represented by the fitted period, and the same quantity divided by four to give the mean square per degree;
(g) the ratio of the mean squares in (e) and (f) immediately above, = $F_{4,40}$; and finally
(h) the significance of that F ratio (n. s. = 'not significant').

The ensuing lines (b1) to (h1) will be explained shortly.

TABLE II

Significances of periods in the radial- and rotational-velocity data on HD 70645

(a)	0·7929		0·8593		1·1032		1·2405	
(b)	0·7919	(3)	0·8606	(5)	1·1049	(8)	1·2428	(16)
(c)	1·62	(31)	1·35	(34)	1·17	(37)	0·93	(37)
(d)	132·24		132·24		132·24		132·24	
(e)	78·81	1·97	95·03	2·38	105·99	2·65	113·52	2·84
(f)	53·43	13·36	37·21	9·30	26·25	6·56	18·72	4·68
(g)		6·80		3·91		2·48		1·64
(h)	0·1%		1%		10%		n. s.	
(b1)	0·7927	(5)	0·8594	(9)	1·1018	(10)	1·2475	(16)
(c1)	1·26	(35)	0·84	(38)	0·99	(38)	0·9	(4)
(d1)	134·94		134·94		134·94		134·94	
(e1)	100·90	2·52	120·48	3·01	114·37	2·86	120·26	3·01
(f1)	34·04	8·51	14·46	3·61	20·57	5·14	14·68	3·67
(g1)		3·38		1·20		1·79		1·22
(h1)	2½%		n. s.		n. s.		n. s.	

It is to be noticed that the order of the periods listed in Table II with progressively decreasing significance is not the same as the order of the photometric amplitudes found by Henry *et al.*, which is 2, 3, 1, 4 for the successive columns in our table; the uncertainties in the photometric amplitudes, however, are large enough in relation to the amplitudes themselves to mean that the ordering of the photometric periods is not really determinate. Henry *et al.*'s fifth period is omitted from our table because it did not produce a plot that looked at all significant, and the sum of squares fell only to about 125, so there is no evidence for its presence at all.

An analysis can be made of the significance of the various periods in the $v \sin i$ data in exactly the same fashion as for the radial velocities. The mean $v \sin i$ is 12·16 km s^{-1}, and the r.m.s. spread of the individual values is 1·75 km s^{-1}, the mean square being therefore $(1 \cdot 75)^2$ or 3·07, and the sum of squares 44 times that, 134·94 (km s^{-1})^2 (coincidentally very close to that of the radial velocities); that total is apportioned between the four degrees of freedom represented by the fitted sine-wave and the remaining 40 degrees, exactly as in the case of the radial velocities, so we have simply added to Table II another set of lines corresponding precisely with the first set, labelled (b1) to (h1) and pertaining to the $v \sin i$ data.

We point out that potential periodicities may lack statistical significance but nevertheless be present in the data. That may be suggested in some cases by the simple fact that the attempt to compute a solution with a given period does actually produce convergence, and does so at a period that is close to the suggested one. If the process is initiated with an arbitrary period, it tends either to diverge or to pull into a period that is not plausibly similar to the one under trial.

The final results of our analysis, seen in lines (h) and (h1), are that three of the Henry *et al.* photometric periods are traceable in the radial velocities, with diminishing degrees of significance, but only one is significant in the rotational velocities. It is the same period that is much the most significant one in the radial velocities that is also traceable in the rotational ones. As a general comment on the results of Table II and the analogous tables to follow for the other two stars, we remark that the significances that are found from the F test are smaller than might be anticipated from a comparison of the amplitudes in lines (c) and (c1) with their respective standard errors. Although we cannot offer any mathematical reason for the apparent discrepancy in significances, we understand that it is well known to period-search experts that ratios less than 4 for K to $\sigma(K)$ are not usually significant, notwithstanding that in a 'normal distribution' a significance of 1% is reached at a ratio of 2·58.

HD 80731

Just as in the case of HD 70645, radial-velocity measurements with the Cambridge *Coravel* began in 2005 November and continued until the observing season closed in the following June, and (again like HD 70645) it was observed with increased assiduity towards the end of the season in order to improve the chances of documenting pulsational periods. The Cambridge measurements number 54; they are set out in Table III, along with the seven velocities published by Henry *et al.*[9] as well as with the phases and residuals that stem from a normal single-lined orbital solution, and also with the '$v \sin i$' values for each of the observations. A solution based on the Cambridge observations alone gave a period of 10·678 ± 0·004 days; the inclusion of six out of the seven

TABLE III

Radial-velocity observations of HD 80731

Date (UT)			*MJD*	*Velocity* km s^{-1}	*Phase*	*(O−C)* km s^{-1}	*v sin i* km s^{-1}
2003	Mar.	8·307*	52706·307	−8·7	$\overline{93}$·987	−1·1	
		9·283*	707·283	+17·2	$\overline{92}$·079	−0·8	
		10·314*	708·314	+11·6	·175	−9·0	
	May	1·258*	760·258	+12·4	$\overline{87}$·041	+2·0	
2004	Apr.	24·202*	53119·202	−9·2	$\overline{54}$·668	+2·3	
		25·192*	120·192	−18·7	·761	−0·4	
		28·215*	123·215	+11·0	$\overline{53}$·044	−0·1	
2005	Nov.	19·213	53693·213	+0·7	0·443	−3·4	15
		25·191	699·191	−2·6	1·003	−0·4	16·5
		30·193	704·193	+0·9	·471	−1·3	14
	Dec.	15·148	719·148	−24·8	2·872	−0·6	17·5
		17·177	721·177	+15·9	3·062	+0·6	12
		18·131	722·131	+17·7	·152	−3·6	13·5
		26·946	730·946	−11·8	·978	−1·0	14·5
		28·022	732·022	+19·3	4·078	+1·4	12
2006	Jan.	26·007	53761·007	−20·3	6·794	+0·2	14·5
		27·242	762·242	−22·5	·909	+0·9	11·5
	Feb.	15·997	781·997	−16·4	8·760	+1·8	14·5
		16·919	782·919	−23·9	·847	−0·4	18·5
		18·009	784·009	−16·8	·949	+1·6	19·5
		18·876	784·876	+5·7	9·030	−1·4	14·5
		20·896	786·896	+17·4	·219	−1·2	10·5
	Mar.	1·035	795·035	−8·4	·982	+1·1	13·5
		1·931	795·931	+15·8	10·066	−0·1	11·5
		3·042	797·042	+21·1	·170	+0·3	14·5
		3·865	797·865	+17·1	·247	+0·1	18
		4·936	798·936	+13·0	·347	+2·5	16
		6·016	800·016	+5·4	·448	+1·6	9·5
		6·917	800·917	+0·5	·533	+2·5	14
		22·921	816·921	+10·1	12·032	+2·4	15
	Apr.	4·002	829·002	+22·2	13·164	+1·2	13·5
		5·053	830·053	+17·6	·262	+1·5	13·5
		6·068	831·068	+9·7	·357	−0·2	15
		8·957	833·957	−9·6	·628	−1·0	17
		10·933	835·933	−23·8	·813	−2·0	13
		12·029	837·029	−23·5	·916	−0·5	12
		14·880	839·880	+21·7	14·183	+1·3	20
		25·925	850·925	+19·7	15·217	+1·0	13
		27·912	852·912	+6·5	·404	−0·3	16
	May	1·961	856·961	−19·9	·783	−0·1	12
		2·964	857·964	−22·4	·877	+1·9	15
		5·996	860·996	+21·9	16·161	+0·8	14
		9·901	864·901	−2·9	·527	−1·3	9·5
		10·915	865·915	−6·0	·622	+2·2	13
		11·915	866·915	−13·2	·715	+1·8	12
		15·941	870·941	+20·1	17·093	+0·6	21
		16·969	871·969	+20·0	·189	−0·1	18·5
		18·915	873·915	+7·0	·371	−1·9	13
		21·913	876·913	−13·2	·652	−2·9	15·5
		26·943	881·943	+21·8	18·123	+0·6	14·5
		29·921	884·921	+8·9	·402	+2·0	16
		30·929	885·929	+0·3	·497	−0·2	17
		31·908	886·908	−6·1	·588	−0·3	16

TABLE III (*concluded*)

Date (UT)		*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*	*v sin i km s⁻¹*
2006 June	2·910	53888·910	–19·4	18·776	–0·1	19
	3·917	889·917	–27·1	·870	–2·9	23·5
	5·914	891·914	+10·2	19·057	–4·1	17
	8·925	894·925	+9·5	·340	–1·6	12·5
	9·923	895·923	+2·9	·433	–1·9	14·5
	10·926	896·926	–1·8	·527	–0·2	11
	11·917	897·917	–7·4	·620	+0·6	17
	12·920	898·920	–14·3	·714	+0·5	15

*Observation published by Henry *et al.*[9].
All others observed with the Cambridge *Coravel*.

Henry *et al.*[9] measures did not change the elements significantly but reduced the standard error of the period to 0·0004 days. Among the published measurements, the third one has such an extreme residual (9 km s^{-1}, more than twice as great as any other) that it seems to be beyond any combination of pulsational velocities plus normal accidental eror, so it may be suspected of some sort of qualitative error and has therefore been omitted from the solution. The orbit has the elements given below and is plotted in Fig. 4.

P = 10·6744 ± 0·0004 days	$(T)_4$ = MJD 53731·19 ± 0·05
γ = –0·78 ± 0·22 km s^{-1}	$a_1 \sin i$ = 3·08 ± 0·05 Gm
K = 22·82 ± 0·33 km s^{-1}	$f(m)$ = 0·0103 ± 0·0005 $M_{\odot}$
e = 0·392 ± 0·012	
ω = 265·7 ± 2·3 degrees	R.m.s. residual = 1·57 km s^{-1}

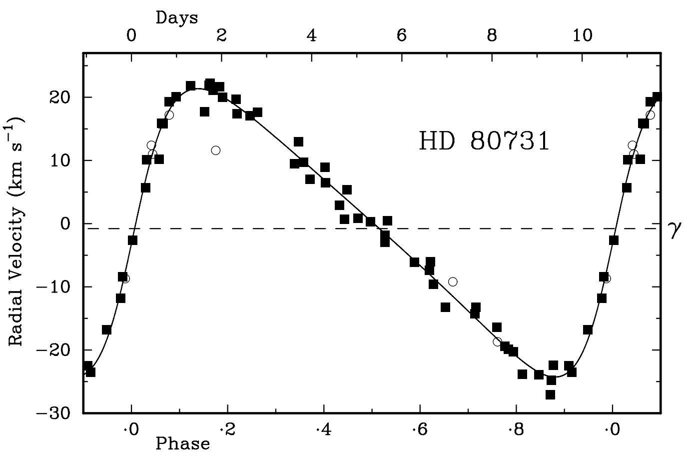

FIG. 4

As Fig. 2, but for HD 80731. The errant open-circle point below the maximum of the velocity curve was omitted from the solution of the orbit.

To investigate the presence of pulsational periods we have followed exactly the same procedure for HD 80731 as for HD 70645, so we can proceed immediately to present the results, which are shown in Table IV. The first three periods given in line (a) are those of Henry *et al.*[9], and the fourth is one of those proposed by Martin *et al.*[7]. As in Table II, the first section (as far as line (h)) refers to pulsations seen in the radial-velocity residuals, while the second section (lines (b1) – (h1)) refers to those seen in the rotational velocities. The third section (lines (b2) to (h2)) gives information about two additional periods identified by ourselves in the rotational velocities (clearly line (a) does not apply there). Opportunity is taken to use the spare space in that section to include brief reminders of the significance (described in full immediately before Table II) of the successive lines.

TABLE IV

Significances of periods in the radial- and rotational-velocity data on HD 80731

(a)	1·1159		1·2783		1·5154		2·23	
(b)	1·1159	(9)	no solution		1·5157	(22)	2·236	(4)
(c)	1·00	(32)			0·91	(28)	1·05	(28)
(d)	137·1				137·1		137·1	
(e)	113·9	2·28			112·5	2·25	106·0	2·12
(f)	23·2	5·80			24·6	6·15	31·1	7·77
(g)		2·55				2·73		3·67
(h)	~5%				5%		2½%	
(b1)	1·1147	(7)	1·2774	(14)	1·5137	(25)		
(c1)	2·3	(5)	1·6	(5)	1·4	(6)		
(d1)	432·1		432·1		432·1			
(e1)	282·1	5·64	357·9	7·16	385·6	7·71		
(f1)	150·0	37·50	74·2	18·55	46·5	11·62		
(g1)		6·65		2·59		1·51		
(h1)	0·1%		5%		n. s.			
(b2)	0·8210	(5)	1·1617	(7)	Period and (in brackets) its standard error			
(c2)	1·9	(4)	2·2	(5)	Pulsational amplitude and its standard error			
(d2)	432·1		432·1		Sums of squares, apportioned between:			
(e2)	314·3	6·29	328·5	6·57	from 50 degrees of freedom, and per degree			
(f2)	117·8	29·45	103·6	25·90	from 4 degrees (pulsation), and per degree			
(g2)		4·69		3·95	$F_{4,50}$ (quotient of the above two lines)			
(h2)	0·5%		1%		Significance of the F ratio above			

HD 17310

Although the first Cambridge radial-velocity measurement was made in 2005 September, it was not till late November that routine measurements began, and after the observer was absent for much of 2006 January the observing season was practically at its close. There are only 11 Cambridge measurements, listed in Table V, to add to the same number published by Henry *et al.*[9]. The Cambridge data are, however, better distributed in time, and when solved by themselves for the orbital elements they yield an unambiguous period of 27·67 ± 0·22 days, very similar to the best (but not uniquely determined) value of 27·793 days favoured by Henry *et al.* The precision of the Cambridge period is plenty good enough to extrapolate back to the Henry *et al.* epochs without any possible error in the cycle count, so the two sets of velocities can be solved together.

The joint solution does, however, throw up problems that were mercifully lacking in the cases of the other two stars. For them the data from the two sources seemed to agree well both in zero-point and in the sizes of the residuals from the orbits, so neither a zero-point shift nor unequal weighting was called for. In the present case, a straightforward solution with equal weights shows fairly serious disparities both in zero-point and in residuals. The means of the residuals from the two sources differ by 1·62 ± 1·16 km s^{-1}, Cambridge being more positive, while the mean squares (the variances) are 3·81 and 10·82 (km s^{-1})^2 for Cambridge and Henry *et al.*, respectively, a difference of a factor of 2·85. With six elements fitted to 22 equally weighted observations, we could consider that each source has eight degrees of freedom; the factor that we have found exceeds the 10% point of $F_{8,8}$, which is 2·54, so we have seen fit to attribute half-weight to the published velocities. The weighted variances then turn out to be 2·93 and 6·05 (km s^{-1})^2, a ratio still as high as 2·06, but no longer very significant; we would have to go a lot further to equalize them, but we do not care to do that, particularly in the light of the apparent quasi-equality in the cases of the other stars. We could also worry about the zero-points, which in the revised (weighted) solution differ by 1·84 ± 1·15 km s^{-1}, or 1·60σ, for which the probability according to the 'normal distribution' is about 11%. Not wishing to tamper too much with an already minimal dataset, we decided *not* to make any adjustment to the relative zero-points. On the basis, then, of no interference with the observed velocities apart from half-weighting the published ones, we obtain the orbit that is plotted in Fig. 5 and whose elements are:

P = 27·819 ± 0·022 days	$(T)_{-5}$ = MJD 53485·4 ± 1·2
γ = +25·8 ± 0·7 km s^{-1}	$a_1 \sin i$ = 9·0 ± 0·4 Gm
K = 24·0 ± 1·0 km s^{-1}	$f(m)$ = 0·038 ± 0·005 $M_\odot$
e = 0·19 ± 0·04	
ω = 125 ± 15 degrees	R.m.s. residual = 2·1 km s^{-1}

For the purposes of searching for pulsational effects, potentially of multiple modes that are all of short periods and small amplitudes, our data are woefully few. The three periodicities tabulated by Henry *et al.*[9] and the one identified in

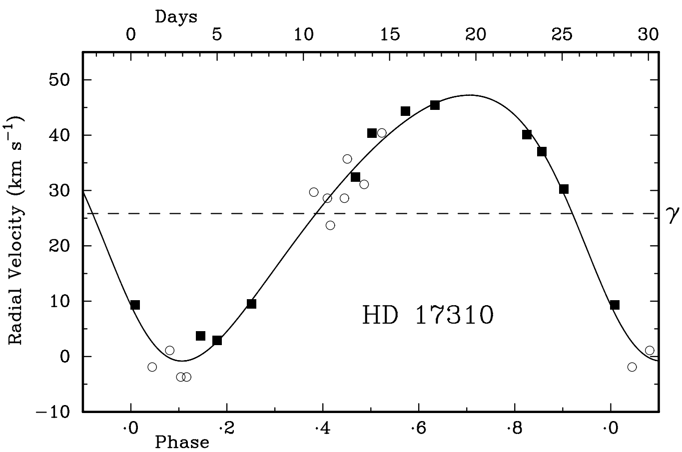

FIG. 5

As Fig. 2, but for HD 17310; open-circle points were half-weighted.

TABLE V

Radial-velocity observations of HD 17310

The sources of the observations are as follows:
2002–2004 — published by Henry et al.[9]*; 2005/2006 — Cambridge Coravel*

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	$(O-C)$ $km\ s^{-1}$	$v \sin i$ $km\ s^{-1}$
2002 Sept. 25·411	52542·411	−3·7	$\overline{39}$·104	−2·9	
2003 Sept. 20·408	52902·408	−1·9	$\overline{26}$·044	−4·5	
21·425	903·425	+1·1	·081	+1·4	
22·402	904·402	−3·7	·116	−2·9	
Oct. 28·379	940·379	+28·6	$\overline{25}$·409	+0·2	
29·369	941·369	+28·6	·445	−3·4	
2004 Sept. 25·427	53273·427	+29·7	$\overline{13}$·381	+4·4	
26·385	274·385	+23·7	·416	−5·4	
27·371	275·371	+35·7	·451	+3·1	
28·344	276·344	+31·1	·486	−4·8	
29·370	277·370	+40·4	·523	+1·4	
2005 Sept. 29·092	53642·092	+45·4	0·633	−0·3	9
Nov. 29·949	703·949	+37·0	2·857	−0·2	4·5
Dec. 8·937	712·937	+2·9	3·180	+0·2	11
10·921	714·921	+9·5	·251	−0·6	11
16·940	720·940	+32·4	·468	−1·8	11·5
17·917	721·917	+40·4	·503	+3·0	6·5
19·858	723·858	+44·3	·572	+1·7	9
26·893	730·893	+40·1	·825	−1·1	12·5
2006 Jan. 4·795	53739·795	+3·7	4·145	+3·4	9·5
25·836	760·836	+30·3	·902	+0·8	8·5
28·814	763·814	+9·3	5·009	+1·6	13

the *Hipparcos* 'epoch photometry' by Koen & Eyer[11], however, are all near 2 days (not 1 day, as in the cases of HD 70645 and HD 80731), and that circumstance makes it more plausible to search the whole run of 22 velocities for the relevant periods. There are gaps of about one year each, or 180 cycles, in the data set, and the Henry *et al.* periods being tested have uncertainties between one and two thousandths of a day, so it looks as if the phasing error after a year is only of the order of 0·3 days and there should be little chance of getting out of phase by whole cycles.

We did first test the various periods against the Cambridge data alone, but since we used up six degrees of freedom by determining the basic orbit from the 11 observations, by the time we had fitted another 'orbit' (circular, so using four degrees of freedom) to the observations there could be said to be almost nothing left — with one more variable one could in principle fit *all* the velocities exactly! To do so, however, one would need to solve the two orbits simultaneously rather than *seriatim* as in our tests. Having determined the orbit of the spectroscopic binary, we could possibly regard the residuals as constituting a fresh data source, notwithstanding that those residuals will have been reduced (*i.e.*, the information in which we are then interested will have been diluted) by some accommodation of the pulsational velocities by the orbital solution. The upshot of the investigation, in any case, was that we found nothing significant at any of Henry *et al.*'s three periods, but there was a remarkably large signal at the Koen & Eyer period of 2·0296 days. Indeed, a periodicity very close to 2 days is conspicuous in the data of Table V just upon inspection — the violent reversal of the signs of residuals between alternate days gives it away — and a period of 1·966 days, that gave an even more dramatic signal than the Koen & Eyer period, was noticed before any period-search program was brought to bear. The search program identified a still more potent period at 0·6618 days. The actual statistical significances of the various periods are very doubtful owing to the scarcity of data, and comment is withheld until we have presented an analysis of the complete dataset including the Henry *et al.* velocities.

Before going on to do that, however, we may refer to the '$v \sin i$' data for HD 17310, of which there are just the 11 Cambridge values. Their mean is 9·6 ± 0·8 km s^{-1}, and the sum of the squares of the deviations from that value is about 65 (km s^{-1})^2. We can state the results of our trials quite briefly. The three Henry *et al.* periods did not reduce the sum of squares to any great extent, but the periods of 2·0296, 1·966, and 0·6618 days all produced sums of squares reduced to near 20 (km s^{-1})^2. Since the rotational-velocity numbers were not utilized in the determination of the binary-star orbit, the 11 values could reasonably be regarded as independent data and therefore as possessing jointly 11 degrees of freedom, of which four are used up in fitting any pulsational 'orbit'. So, in exact analogy with the treatment described before the presentation of Table II for HD 70645, we may say that the sum of squares remaining after the derivation of a pulsational periodicity is associated with seven degrees of freedom, while the reduction from the original sum represents the cost of the four degrees used in the fit. In that case, the three periods that caused reductions of about 45 and left sums of about 20 (km s^{-1})^2 gave values of $F_{4,7}$ of about (45/4)/(20/7), ~ 4, which is nearly the 5% point (4·12). Thus, in view of the fact that we were not trying to find fresh periods

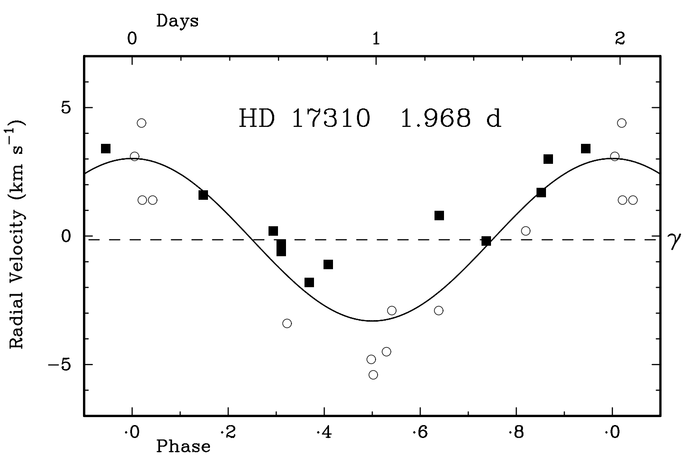

FIG. 6

Illustrating one of the apparent periods noticed in the radial-velocity residuals from the orbit of HD 17310 but (it seems) not in the photometry. The period was first noticed in the Cambridge observations alone (the filled squares); if it does not manifest any underlying reality it is amazing that it should have been reinforced as cogently as it obviously *is* by the inclusion of the altogether independent Henry *et al.* velocities (the open circles).

but were merely making individual tests of ones that had been proposed on the basis of quite independent data, there are grounds for cautious optimism in thinking that those periods may be discernible in the rotational velocities. Conversely, the likelihood of the existence of the periods in the rotational velocities provides some support for their presence in the radial ones.

We next extend the investigation of periodicities in the orbital radial-velocity residuals to the complete dataset, including the Henry *et al.* velocities. The results are presented in exactly the same way as for the other two stars, in Table VI below. In the first part of the table we test the four periods (three from Henry *et al.* and one from Koen & Eyer) that have been identified photometrically, and then give the results from the other two periods that seemed so significant in the Cambridge radial-velocity data and gained some support from the rotational velocities. The figure for the sum of squares of the 'raw' orbital-velocity residuals, appearing throughout in lines (d) and (d1), is seen to be 98·51 (km s^{-1})^2. The 1% point of $F_{4,18}$ that is very nearly reached by two of the periods in the first section is 4·58. The 0·1% point is 7·46, so both the values in the second section of the table are far beyond that. Even the highest significance that we have seen tabulated for $F_{4,18}$, 0·05%, is 'only' 8·47. The periods quoted in line (a1) are those found first, when the Cambridge velocities were considered alone, and are otherwise unsupported. The 1·968-day period is illustrated in Fig. 6.

TABLE VI

Significances of periods in the radial-velocity data on HD 17310

(a)	2·137		1·825		2·451		2·0296	
(b)	2·1360	(7)	1·8220	(4)	2·4510	(10)	2·0292	(4)
(c)	1·8	(7)	2·4	(6)	1·9	(7)	2·6	(6)
(d)	98·51		98·51		98·51		98·51	
(e)	71·57	3·97	49·40	2·74	68·93	3·83	49·77	2·76
(f)	26·94	6·73	49·11	12·28	29·58	7·39	48·74	12·18
(g)		1·70		4·49		1·93		4·41
(h)	n. s.		almost 1%		n. s.		almost 1%	
(a1)	1·9650	(26)	0·6617	(2)	Period being tested and its standard error			
(b1)	1·9683	(3)	0·66173	(3)	Period found and its standard error			
(c1)	2·9	(4)	3·3	(4)	Pulsational amplitude and its standard error			
(d1)	98·51		98·51		Sum of squares, apportioned between:			
(e1)	24·65	1·36	21·27	1·18	from 18 degrees of freedom, and per degree			
(f1)	73·86	18·46	77·24	19·31	from 4 degrees (pulsation), and per degree			
(g1)		13·6		16·3	$F_{4,18}$ (quotient of the above two lines)			
(h1)	0·1%		0·1%		Significance of the F ratio above			

Discussion

We have gone some way towards demonstrating, by a formal (if elementary) statistical analysis, that certain periods, mostly already recognized in photometric datasets that are much richer than our kinematic ones, are present in the radial and quasi-rotational velocities that we have measured for the three γ Dor stars. There remain questions, however, as to how far the statistical results should be trusted.

We have already indicated an inclination towards trusting them where we are simply testing already-defined periods for their presence in our data. In such cases we are not searching a sparse data string for a short period, a procedure that we *know*[18] can lead to 'false positives'. If the test calculation immediately converges and gives a period that is, within the joint uncertainties of itself and of the trial period, the same as the one being tested, there are grounds for thinking that the result is secure. Misgivings start to creep in, however, when we consider the results of multiple periodicities identified in the same dataset. If we look at row (f) of Table II, for example, we see that the sum of contributions listed as being made by the four tested periods to the total sum of squares is more than that whole total! A greater excess of the individual contributions over the whole total is seen in row (f) of Table VI. It could, however, be argued that we should not include contributions from periods that have turned out not to be significant. If we pretend for a moment to be really naïve operators, we could imagine ourselves trying any number of periods at random, and most of them would yield a 'solution' that was better than nothing, in the sense that it would produce *some* reduction in the sum of squares; but it would be nonsensical to add up all the reductions and say that we had thereby accounted for all and more of the apparent raggedness of our velocities. Clearly some consideration ought to be given to the *total* number of degrees of freedom used in fitting multiple periods to the same data, but we are unable to suggest how to do that in a constructive fashion.

A more extreme situation than those already mentioned is the one referred to in the paragraph next but one before Table VI above, where each of three periods is apparently found to be responsible for more than two-thirds of the total sum of squares! Two of those periods, however, have found no support from photometry and might be dismissed as mere idiosyncrasies in the very small Cambridge dataset, especially as they result from doing just what we have warned against[18,19], *viz.*, searching a data string for periods short in comparison with the mean interval between observations. But in that case why would they be overwhelmingly reinforced when the dataset in which they were first noticed was expanded to include the published velocities? Row (f1) in Table VI appears to show that each of the two 'new' periods accounts for three-quarters of the total variance!

We can see that at least part of the answer is that there is really only one period: the two new ones are 1-day^{-1} aliases of one another (although not within their joint formal uncertainties). Labelling 1·9683 days as P_1 and 0·66173 days as P_2, we find the corresponding frequencies to be $\nu_1 = 0{\cdot}5081$ and $\nu_2 = 1{\cdot}5112$ day^{-1}, respectively. Moreover, the Koen & Eyer period of 2·0296 days (P_3) inverts to — in fact it was actually given by those authors as — a frequency of 0·4927 day^{-1} (ν_3), which is seen to be very closely the 1-day^{-1} complement of ν_1. The close numerical relationships between all three of the periods that seem to be so powerfully present in the small dataset of HD 17310 radial velocities warns us of the likelihood that at most one of the three periods can be real, the others being mere mathematical artefacts. When plotted *modulo* the three periods in turn, the *Hipparcos* 'epoch photometry' seems unrelated to P_2, but at least to a subjective view its phase-dependence on P_1 is scarcely less convincing than that on P_3, which itself inspires little confidence; the Henry *et al.* periods are even less visible in the *Hipparcos* photometry.

Clearly we cannot claim to have the last word, let alone the greatest wisdom, on these matters, which would become clearer, even in the absence of fresh insight or inspiration, if we could bring to bear a much greater quantity of data. What we *can* claim in this paper is to have established the spectroscopic orbits of the three stars; in descending order of certainty we believe also that we can trust the demonstration of two of the already-known photometric periods in the radial velocities of HD 70645, and probably also in HD 80731, and we think that we have traced the dominant radial-velocity period in each of those stars in the line-width parameter too. It furthermore seems likely, from our very parsimonious data, that at any rate two of the four photometric periods that have been identified in HD 17310 are present in the radial velocities; one of them appears also to be present in the line-widths. Those widths, as well as the radial velocities, are also represented extraordinarily well by either of two periods that are aliases of one another and of one of the photometric ones, but we are not able to adjudicate on the reality of those periods.

As far as our observations (or those of Mathias *et al.*[8]) are concerned, all three of the systems with which we are concerned are single-lined. We have not noticed secondary dips in any of the radial-velocity traces, although we regret having omitted to make a specific search for them by taking long integrations at the appropriate velocity ranges near the nodes of any of the orbits. We can say only that the secondaries are probably at least two magnitudes fainter than the primaries. None of the mass functions is particularly large: those of HD 70645 and HD 17310 are both between 0·03 and 0·04 $M_{\odot}$, while that of HD 80731 is only 0·01. For an early-F star whose own mass may be estimated at 1·6 $M_{\odot}$, a mass function of 0·04 $M_{\odot}$ requires the secondary to have a minimum mass of about 0·55 $M_{\odot}$, corresponding to a spectral type not much earlier than M0 V and an absolute magnitude about six magnitudes fainter than that of the primary. If the orbital inclination is far from 90°, however, the secondary may be more massive than the minimum value, to any extent, though statistically inclinations are high.

In their study of 59 potential γ Dor stars whose candidatures were mostly based on the *Hipparcos* photometry, Mathias *et al.*[8] were able, in a very few cases, to identify the main *Hipparcos* frequency in their radial-velocity curves. For those cases, they deduced ratios between the radial-velocity and photometric amplitudes in the range 35 to 96 km s^{-1} per magnitude. We can perform the same exercise for the three stars whose radial velocities we have analyzed, all of which have periods in common with the photometric ones found by Henry *et al.*[9]. For HD 70645, we find ratios of radial velocities to *B*- and *V*-band signals between 56 and 81, and 74 and 110 km s^{-1} per magnitude, respectively. The corresponding numbers are 33 to 95 and 42 to 107, respectively, for HD 80731, while for HD 17310, which has particularly low photometric amplitudes and suspiciously high radial-velocity ones, the ratios are all very large, between 170 and 430. We suppose that the observed ratios will be of significance for modellers of the γ Dor phenomenon.

Stars in binary systems with short orbital periods often have synchronized rotations. (They often have circular orbits, too, but since the time-scale for circularization is much longer than that for capture of the rotation[20,21], the non-zero orbital eccentricities of the three stars with which we are concerned here does not necessarily imply that the rotations are not synchronized.) We have seen in the introductory section of this paper that all three stars have colours and luminosities appropriate to early-F dwarfs, so they must also have normal radii of about 0·9 Gm. The pseudo-synchronous[22] rotation periods appropriate to the periods and orbital eccentricities of the three stars are about 23, 8·2, and 5·2 days, corresponding to equatorial rotational speeds of about 3, 8, and 13 km s^{-1} for HD 17310, HD 70645, and HD 80631, respectively. The variability of the observed line-widths of all three stars demonstrates that those widths are not to be interpreted purely in terms of rotation; we do not know whether the *minimum* width observed for each is or is not still largely increased from the value set mainly by rotation, but it must represent an upper limit to the rotational velocity. The minimum observed value is very likely to have been minimized partly by accidental observational error; allowing subjectively for such an effect, we might say that the minimal values for the three stars are about 6, 9, and 10 km s^{-1}, respectively. Comparison with the values calculated on the basis of pseudo-synchronism leads to the conclusions that HD 17310 and HD 70645 are either rotating faster than synchronism or else their minimum line-widths still owe something to pulsation, whereas HD 80731 is either rotating more slowly than synchronism or, if synchronized, has an orbital inclination no greater than about 50°.

References

(1) A. B. Kaye *et al.*, *PASP*, **111**, 840, 1999.
(2) G. Handler, *MNRAS*, **309**, L19, 1999.
(3) R. F. Griffin, *The Observatory*, **126**, 119, 2006 (Paper 187).
(4) K. Krisciunas *et al.*, *MNRAS*, **273**, 662, 1995.
(5) F. M. Zerbi *et al.*, *MNRAS*, **290**, 401, 1997.
(6) A. B. Kaye, R. O. Gray & R. F. Griffin, *PASP*, **116**, 558, 2004.
(7) S. Martin, M. Bossi & F. M. Zerbi, *A&A*, **401**, 1077, 2003.
(8) P. Mathias *et al.*, *A&A*, **417**, 189, 2004.
(9) G. W. Henry, F. C. Fekel & S. M. Henry, *AJ*, **129**, 2815, 2005.
(10) S. Grenier *et al.*, *A&AS*, **137**, 451, 1999.
(11) [Announced by] C. Koen & L. Eyer, *MNRAS*, **331**, 45, 2002.
(12) [Announced by] B. Nordström *et al.*, *A&A*, **418**, 989, 2004.
(13) K. Topka *et al.*, *ApJ*, **259**, 677, 1982.
(14) J. H. Moore & G. F. Paddock, *ApJ*, **112**, 48, 1950.
(15) D. Gillet *et al.*, *A&A*, **108**, 181, 1994.
(16) R. F. Griffin, R. P. Church & C. A. Tout, *New Astr.*, **11**, 431, 2006. (See Appendix.)
(17) *e.g.*, D. V. Lindley & W. F. Scott, *New Cambridge Elementary Statistical Tables* (CUP), 1984, pp. 50–54.
(18) C. L. Morbey & R. F. Griffin, *ApJ*, **317**, 343, 1987.
(19) R. F. Griffin, *The Observatory*, **126**, 1, 2006 (Paper 186).
(20) J.-P. Zahn, *A&A*, **57**, 383, 1977; **220**, 112, 1989.
(21) J. L. Tassoul, *ApJ*, **324**, L71, 1988; **358**, 196, 1990.
(22) P. Hut, *A&A*, **99**, 126, 1981.

CORRESPONDENCE

To the Editors of 'The Observatory'

False Dawn on Mercury?

According to an item entitled "False Dawn" in the *Here and There* section of the April issue of *The Observatory* (**126**, 148, 2006), "Mercury is the only planet where the Sun rises twice a day". Some readers may have had a quiet chuckle at this 'howler', but in fact the author who wrote the statement can have the last laugh, for indeed the Sun *does* rise twice a day on Mercury, and Mercury is indeed the only planet in the Solar System where this happens. The phenomenon is described well in the book by Strom[1].

The sidereal rotation period of Mercury on its axis is 58·65 (terrestrial mean solar) days, which corresponds to an angular speed of 6·139 degrees per (terrestrial mean solar) day. Apart from a small dynamical libration of amplitude only a few arc-minutes, this rotation speed is almost uniform throughout the hermean year.

On the other hand, because of the large eccentricity of its orbit, the orbital motion of Mercury varies greatly between perihelion and aphelion. It varies, of course, according to Kepler's second law, which conserves angular momentum, so that $r^2\omega$ is constant around the orbit (r = heliocentric distance; ω = angular speed). The sidereal orbital period of Mercury is 87·969 days, which corresponds to a mean angular orbital speed of 4·092 degrees per day. For most of the orbit, the angular motion around the Sun is slower than its angular motion around its axis. At aphelion, the orbital angular speed is only $4{\cdot}092/(1 + e)^2 = 2{\cdot}815$ degrees per day (e = orbital eccentricity) and indeed during most of the orbit the sidereal orbital angular speed is slower than the sidereal rotation (spin) angular speed. During that time, as on Earth, the Sun moves during the day from east to west across the sky.

For a brief period around perihelion, however, Mercury is moving around the Sun faster than it is rotating about its axis, reaching an orbital angular speed of $4{\cdot}092/(1 - e)^2 = 6{\cdot}485$ degrees per day at perihelion, which is slightly faster than the rotation speed. Consequently, when Mercury is near perihelion, the Sun appears to move from west to east. A summary of these speeds may be helpful. All angular speeds in the table below are sidereal.

Orbital angular speed at aphelion	= 2·815 degrees per day
Mean orbital angular speed	= 4·092 degrees per day
Spin angular speed	= 6·139 degrees per day
Orbital angular speed at perihelion	= 6·485 degrees per day

The mean orbital angular speed is exactly two-thirds of the spin angular speed. As a remarkable consequence, the length of the hermean day is two hermean years! That is, the length of a hermean solar day is 175·9 terrestrial mean solar days.

It is natural now to ask for what true anomaly, v, is the orbital angular speed of Mercury equal to the spin speed, for at that point the Sun is stationary in Mercury's sky. It is not difficult to show that the answer is given by

$$\cos v = \frac{\sqrt{3}\ (1-e^2)\ \sqrt{2}}{\sqrt{2}e}$$

or

$$v = \pm 32^\circ{\cdot}7.$$

This corresponds to mean anomalies of

$$M = \pm 32^\circ{\cdot}3,$$

which means that the Sun travels from west to east for a fraction 32·3/360 of a hermean year, which is 0·0449 of a hermean day, or 7·9 terrestrial days.

The apparent motion of the Sun across the sky during a hermean day depends on the longitude of the observer, but an observer situated at a longitude such that sunrise occurs near perihelion will see the Sun start to rise. (This observer would be at a hermographic longitude of ± 90°, since the hermographic zero longitude is the subsolar point at the first perihelion passage of 1950.) Just after the lower limb has cleared the horizon, the Sun reverses its motion and starts to set again, disappearing briefly below the horizon. The motion reverses again and the Sun rises for a second time. The same phenomena in reverse occur at sunset.

Thus, as stated in the original article, "Mercury is the only planet where the Sun rises twice a day".

For an observer 90° away, the Sun rises only once — but at noon the Sun moves a little way past the meridian, reverses its direction for a short while, and then proceeds once more towards the west.

Yours faithfully,
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(1) R. G. Strom, *Mercury: The Elusive Planet* (Smithsonian Institution Press, Washington), 1987.

REVIEWS

Observing the Deep Sky: An Astronomer's Companion, by D. Bushnall (Crowood, Marlborough), 2005. Pp. 175, 23·5 × 16·5 cm. Price £14·99 (paperback; ISBN 1 861 26765 1).

Amongst amateur astronomers, the popularity of observing deep-sky objects has never been greater. Telescopes have got larger, better, and cheaper, eyepiece quality has improved, and dedicated nebular filters are now part of most amateurs' accessory kit. A big contributor to the growth in interest has been the advent of electronic 'GoTo' telescope mounts. These mounts have sold in huge numbers over recent years and enable their owners to point their 'scopes to any one of thousands of deep-sky objects just by a few keypad clicks. This then removes the time-consuming task of checking the location of targets in star charts before hunting them down by star-hopping or other laborious methods.

As well as hardware improvements, there has also been an explosion in information available to those wishing to explore the deep sky — magazine articles, detailed star atlases, as well as superb CD-based planetarium software, showing the positions of many tens of thousands of deep-sky objects. Several excellent guide books exist detailing constellation by constellation what there is to see, but few books are dedicated to the peripherals of deep-sky observing. *Observing the Deep Sky: An Astronomer's Companion* attempts to address this deficiency.

The book has been written by the director of the deep-sky section of the Society for Popular Astronomy. It has chapters on choosing and maintaining your telescope and what accessories to buy for it for observing the deep sky;

how to find deep-sky objects, including choice of star atlases and software; how to sketch what you see; different types of deep-sky object; and a chapter on battling the effects of light pollution. The final two sections of the book, representing approximately half the total pages, are devoted to a review of the brighter and more interesting deep-sky objects and the more interesting binary stars that can be seen in smaller telescopes.

Although the choice of chapter topics is good, for a book dedicated to observing the deep sky it unfortunately suffers from a serious lack of in-depth detail. Although it may be directed towards those just starting to get into the deep sky in a more serious way, it only barely attains the level of detail that would be found in a few chapters of larger astronomy books of a much more general nature. The first half of the book, pertaining to the background on observing the deep sky, is filled with numerous figures that help to illustrate various points for the author but just don't leave enough room for the meat of the text.

Given that this is a volume generally about the visual observation of the deep sky, I would like to have seen much more on how to get the best out of your eyes at the eyepiece. Detailed information is missing about the use of averted vision, such as where the most light-sensitive area of vision is located, and there is no mention of the position of the eye's blind spot. No mention is made either of the use of motion to detect large faint nebulosity, or the use of high magnifications to improve the visibility of faint low-contrast detail or to resolve globular clusters. In fact, the information on how the eye works is contained in the first two pages of a chapter entitled 'The eye and binoculars'.

I found the structure of the book a bit confusing in places. 'GoTo' mounts are not mentioned under mounts but under finding deep-sky objects; nebular filters are discussed under light pollution rather than under telescope accessories. For me the best chapter of the book was on deep-sky drawing, in which the author obviously has much experience, but again the chapter was too short.

The back of the book states that the book is lavishly illustrated; however, although there are numerous illustrations, these are all in black and white. This is hardly lavish and in the modern era of publishing this would be a disappointment to many readers. Far too many of these figures are also, unfortunately, inaccurate or badly labelled, and this is second major weakness of the book. For example, just in the first chapter, Figure 1·1 has the caption the wrong way round, Figure 1·2 is not the Milky Way from Cygnus to Sagittarius but is only Sagittarius, and Figure 1·4, "a naked eye view of the Orion Nebula", shows stars well below naked-eye visibility. Printed sections of star maps are often confusing, with scale or orientations not being well defined. Most of the errors in the book were in the illustrations and figures but some were in the general text; for example, larger reflecting telescopes do not have 18 screws for collimation, although they may have an 18-point support system.

The second half of the book, giving details of what to find in the sky, is, as with the first half, too cursory for a book dedicated to the deep sky. There are descriptions of only just over 200 deep-sky objects with sketches of 26 of these. This means that constellations overflowing with deep-sky objects, like Virgo, only have five objects listed. I would like to have seen drawings of deep-sky objects through different-sized telescopes, but almost all were through either 11- or 8½-inch reflectors. I would also like to have seen a scale on these drawings.

All in all I find it hard to recommend this book, which contains just too many errors and not enough solid detail. — MARTIN LEWIS.

General Relativity: An Introduction for Physicists, by M. P. Hobson, G. P. Efstathiou & A. N. Lasenby (Cambridge University Press), 2005. Pp. 574, 25·5 × 18 cm. Price £40/$70 (hardbound; ISBN 0 521 82951 8).

General Relativity (GR) is one of the treasures of physics, and this book is a fine introduction and exposition of many of the theory's features. Aimed at advanced undergraduates and postgraduate students, it succeeds in explaining clearly the theory from basic principles.

The book starts with an account of special relativity, introducing fundamental concepts such as inertial frames, spacetime, Lorentz transformations, and light-cones. This is followed by the introduction of the necessary mathematical and geometric concepts for GR, including how to describe curves and surfaces on manifolds, the metric, geodesics, and tensor fields. Tensors in particular are explained very well in a coordinate-free fashion as a means of mapping vectors to scalars.

Before launching into GR itself, the authors go on to describe electromagnetism in a relativistic context. A beautiful approach is taken: the authors show that a consistent theory of electromagnetism can be derived from the simple supposition that there is a force (technically, a pure 4-force) which depends linearly on (4-) velocity and charge, plus a few appeals to simplicity. In the course of this account, the electromagnetic-field tensor and current density are introduced, and the electromagnetic-field equations are derived. These act as a welcome dry run for the reader in understanding the more complicated gravitational equivalents still to come. At this stage, GR is tackled in earnest. Gravity is accounted for as a manifestation of spacetime curvature, and the gravitational-field equations are constructed. The possibility of a cosmological constant, which leads to a universe with accelerating expansion, is discussed, as are intriguing alternative relativistic theories of gravity.

Now physical implications of the theory are explored in detail. The Schwarzschild geometry, associated with spherically symmetric matter distributions, is explained, and this leads to calculation of the gravitational redshift and trajectories of particles in Schwarzschild spacetime. Appropriately, experimental evidence for General Relativity is now considered, including the precession of planetary orbits, deflection of light by the Sun, and the gravitational redshift of spectral lines in accretion discs.

My only criticism of the book arises at this point: it would have been very valuable to have more material included (at this point or elsewhere) about the many applications of gravitational lensing. Lensing directly probes the metric of spacetime in many contexts, from microlensing of stars to weak lensing of the large-scale structure of the Universe, and is therefore one of the most widely used effects associated with General Relativity; however, here attention is restricted to bending of light near the Sun.

The authors turn then to Schwarzschild black holes. Fascinating issues, such as the formation of black holes and tidal forces near a black hole, are well covered here. Even more interesting is the introduction of Kruskal coordinates, which afford a clear discussion of white holes and wormholes, including the dynamics of the wormhole structure. The Hawking effect is also discussed at a basic level using simple quantum arguments. Other solutions to GR are considered, including the spacetime in a stellar interior and the Reissner-Nordström geometry for spherically symmetric charged-mass distributions. Most significantly, the Kerr geometry appropriate for rotating bodies is discussed; here the authors outline the approach to finding this solution, without going into the formidable derivation in full detail. There is an excellent account of the structure of the Kerr black hole and the Penrose process which allows energy extraction from the rotation of the black hole.

The authors now turn to cosmological applications of GR, which are ably explained. The Friedmann–Robertson–Walker geometry, so central to cosmological models, is described; clear explanations are given for phenomena such as cosmological redshift, the expansion of the Universe, and the need for several different measures of cosmological distance. This leads on to a detailed description of the evolution of matter, radiation, and scale in the Universe. The cosmological models described so far can't explain the reason for our spacetime having so little curvature, and how patterns in the early Universe's structures appear to be far too coordinated. A possible explanation for these puzzles is rather fully given in terms of inflationary cosmology — the concept that there was a dramatic phase of accelerated expansion in the early Universe. The authors show how a scalar field can evolve in GR to act as the instigator of inflation, and the way that large-scale structure in the Universe can be seeded by quantum perturbations in inflation is explained.

The book then proceeds to look at linearized GR, where the gravitational fields are weak. This affords a study of gravitational waves, examining how such waves will act on free particles, how they can be generated, and to what extent they communicate energy away from sources. The authors also present the exciting current approaches to detecting gravitational waves. To conclude, in the final chapter a description is given of how to derive GR using a variational principle; this is an approach beloved of theoretical physicists, as it allows symmetries in a theory to be clearly seen.

The book includes over 300 exercises, which are well chosen to stretch the reader without being far too difficult. Illustrations pepper the text, usually contributing significantly to understanding. I strongly recommend this book for a very wide range of readers. Advanced undergraduates will obtain a good first understanding of GR; postgraduates will find it a useful reference book, and will no doubt learn a great deal that they have not fully covered at undergraduate level. Researchers and lecturers will also find it an invaluable book, not only for recommending to students, but also for obtaining significant new insights themselves. — David Bacon.

Ancient Astronomy: An Encyclopaedia of Cosmology and Myth, by Clive Ruggles (ABC-CLIO, Santa Barbara), 2005. Pp. 518, 26·1 × 18·4 cm. Price £55 (hardbound; ISBN 1 851 09477 6).

Where do you start when it comes to an appreciation of the astronomical culture and artefacts of our distant ancestors? Well there are few better places than this new encyclopaedia by Clive Ruggles, the professor of archaeoastronomy at the University of Leicester. This book contains over 200 entries, starting with aboriginal astronomy, ending with zenith tubes, and passing topics such as the Ring of Brodgar, Celtic calendars, Inuit cosmology, Minoan temples, Nasca lines, precession, sky bears, solstitial alignments, and Yekuana roundhouses on the way. Each entry is two to three pages long and is enhanced by a short section listing references and suggestions for further reading. Care is also taken with cross referencing. Unlike many encyclopaedias, which are multi-authored, here Ruggles has written everything, so all the entries are of a consistent standard.

Ancient Astronomy transports the reader back to a time when humanity's knowledge bank was meagre and the approach was holistic. The modern western conceptualization of our environmental landscape is too easily divided into land, sea, and sky; and today, in the vast majority of cases, the latter is unknown and mainly ignored. In the distant past all aspects of the environment were probably inextricably linked into an overall world view. Sun, Moon, planets, and stars were vital components of life, acting as clock, calendar, compass, light source, astrological guide, and seasonal marker. Our lives were governed by the sky much more then. What happened there could not be ignored. And its rhythmic regularity and predictable nature was a refreshing bedrock in an otherwise fickle and uncertain existence.

Two things greatly impressed me when reading *Ancient Astronomy*. One was the common sense of the author. The other was the care taken in explaining difficult concepts. Archaeoastronomy and the related subject of ethnoastronomy are intellectual pursuits greatly loved by the enthusiast. Too often we find the predilections and preferences of our modern mindset being foisted on our forefathers. Many proponents are too keen to fit unjustified astronomical explanations to poorly understood archaeological phenomena. Too often we are entertained by the mathematically adept but anthropologically naïve. Ruggles insists that the fair assessment of data is vital. A scientific and statistically valid approach is paramount. To quote the author, many suggestions "do not withstand close scrutiny". *Ancient Astronomy* is a first-class introduction to this fascinating subject. — David W. Hughes.

The Star Guide, 2nd Edition, by R. Kerrod (A. & C. Black, London), 2006. Pp. 160 + Planisphere, 25 × 25 cm. Price £14·99 (hardbound; ISBN 0 713 67612 4).

This is the second edition of a book published by Headline in 1993 with the title *The Illustrated Guide to the Night Sky* (reviewed **115**, 108, 1995). The present edition is subtitled "Learn how to read the night sky star by star". The method adopted is to start with ten prominent constellations well spread over the sky, north and south: And, Cas, Cen, Cyg, Ori, Sgr, Sco, Tau, UMa, and Vir. At any time three or four of them can be recognized and then other constellations identified between them.

At the heart of the book are the twelve monthly sections, comprising an opening each, with two additional openings for the north and south celestial poles. Each month starts with a map of the heavens covering four hours of right ascension and $\pm \sim 50°$ of declination showing stars, nebulae, clusters, and galaxies. The Milky Way is shown stippled. Each map is supplemented by two small-scale hemispherical maps, reaching to magnitude 4·5, for observers looking south from the Northern Hemisphere (latitude about $+45°$) and looking north from the Southern Hemisphere (latitude about $-25°$), as seen at 23 hours local time. There are notes on the more interesting objects in each constellation and coloured pictures, many from the *Hubble Space Telescope*. Interspersed with the monthly maps are openings devoted to larger-scale maps of the ten most prominent constellations listed above.

To aid in understanding the maps there is a convenient set of cross-references to the beginning of the book where stars at different ages, clusters, nebulae, and galaxies are explained. The graphics are particularly clear and well designed. After the star maps come explanatory sections on the Sun, Moon, eclipses, planets, satellites, meteors, and comets.

The key to star magnitudes shows a consistent error on all the charts. There are two different circles, both labelled 5·0, where the smaller is intended to be 6·0. This is a trifling problem on the ten large-scale constellation maps, which reach to magnitude 6·5, but more confusing on the monthly maps which show stars only as faint as magnitude 5·5, while the key extends to 6·5.

A 23-cm planisphere for latitude +52° is included, which, like the monthly star maps, shows the ecliptic. There is no further help in finding the planets on a particular date. This is a substantial defect as planets frequently break up the patterns of the constellations and confuse attempts at star identification by beginners.

The book is printed on high-quality, glossy paper which enhances the many fine colour pictures and should prove a benefit to observers who consult it outdoors on damp evenings. — DEREK JONES.

The Cosmic Century: A History of Astrophysics and Cosmology, by Malcolm S. Longair (Cambridge University Press), 2006. Pp. 545, 25·5 × 18 cm. Price £35/$60 (hardbound; ISBN 0 521 47436 1).

You do not often read a book and think "Gosh, this will change things". Sifting through the library of astronomical history over the last hundred years or so this might have been said of *A Popular History of Astronomy during the Nineteenth Century* by Agnes M. Clerke (Adam & Charles Black, Edinburgh, 1885), *Astronomy of the 20th Century* by Otto Struve and Velta Zebergs (The Macmillan Company, New York, 1962), and *Cosmic Discovery* by Martin Harwit (The Harvester Press, Brighton, 1981), but of little else. I predict that Longair's *The Cosmic Century* will be added to this trio. It is fresh, authoritative, thorough, and insightful. It approaches the subject from a different angle. We are not confronted by the historian, philosopher, or sociologist pontificating about what they think astronomers were up to. We are presented with the views of someone who appreciates what it is like to be at the back end of a large telescope gazing at a mysterious object, or confronted with the physical interpretation of a tricky data set. We are getting an insider's view, and the understanding and appreciation of the scientific methodology leaps from every page.

The reader quickly realizes that Longair is a fan of history. He is convinced that today's researchers into astrophysics and cosmology will benefit hugely by studying how advances were made in the past. The history of these sciences provides a real physical insight into the intellectual infrastructure.

The Cosmic Century starts with the breakthrough in astrophysics produced by the measurement of stellar distances and the interpretation of stellar spectra. We then read how physicists were welcomed into the subject and how they revealed why stars radiate and how they evolve. Then, looking back to the period between 1900 and 1939, we are shown how the imperfect knowledge of our galactic home was transformed into a Universe consisting of a multitude of galaxies, expanding under the influence of General Relativity. The mid-20th Century then witnessed the huge extension of the wavelength window, the optical astronomer being joined by investigators of radio, infra-red, UV, X-ray, and gamma-ray emissions. Longair then considers the importance of the exotics. Black holes, supernovae, active galactic nuclei, and gamma-ray bursters all vie for attention. Finally we are treated to the history of cosmology, replete with steady states, inflation, the Hubble constant, density parameters, structure, microwave backgrounds, and dark matter.

This book is superbly written, well referenced, fully illustrated, and beautifully produced. It will become a classic. Buy it, read it, and improve yourself. — DAVID W. HUGHES.

Death Rays, Jet Packs, Stunts & Supercars: The Fantastic Physics of Film's Most Celebrated Secret Agent, by Barry Parker (Johns Hopkins University Press, Baltimore), 2005. Pp. 288, 19·5 × 15 cm. Price $25 (about £14) (hardbound; ISBN 0 801 88248 6).

Hollywood is famous for stretching the laws of physics to, and sometimes beyond, breaking point. In this book, Barry Parker sets out to examine just how much the life of Agent 007 — aka James Bond — deviates from physical reality. In a sequence of films packed with sophisticated gadgets, electrifying chases, and world-threatening catastrophes, there is no shortage of material for analysis, and Parker exploits the possibilities well. The book is well structured, with separate chapters to deal with stunts, gadgets, cars and chases, amongst others. He also devotes an entire chapter to 'Bond in Space', in which he discusses the film *Moonraker* and its foundation in physical fact.

Parker's own passion for the Bond films is clear, and he is sometimes a little over-indulgent. His personal rankings of Bond films, Bond cars, and Bond actors are unlikely to be of interest for all but the most die-hard fan, though his introductory chapter 'Bond for Beginners', with brief summaries of key scenes in each film, is useful for readers that haven't seen all twenty films. His physical explanations of Bond phenomena are interesting and insightful, particularly the chapter on 'Bond in Space', in which Parker discusses orbits and rocket trajectories. He is unafraid of stating physical formulae and these are well explained when included, but the symbols with which he represents quantities are not always standard and can sometimes be confusing for students of physics. One particular example is his use of the letter 'O' to represent the object distance in a discussion on lenses, where 'O' could easily be confused with zero.

The chapter on cars is largely statistics, and therefore probably has a limited readership, but the rest of the chapters contain good and fascinating science. As advertised on the flyleaf, Parker reveals whether the laser in *Goldfinger* could actually have cut Bond in half, and whether or not a 360-degree barrel roll is possible in an ordinary car, these being only two aspects of Bond physics that Parker examines. For anyone moderately interested in both James Bond and physics, this is an entertaining and relatively easy read. — JOANNA BARSTOW.

Chaos and Complexity in Astrophysics, by O. Regev (Cambridge University Press), 2006. Pp. 455, 25·5 × 18 cm. Price £45 (hardbound; ISBN 0 521 85534 9).

There are countless books on dynamical systems, chaos, nonlinear dynamics, and so on, but this is the best for the all-round astrophysicist. It is not a straight-laced textbook or a how-to manual, but a good-natured guidebook to the literature. It does expect of the reader at least a graduate level of sophistication. If you read it you are unlikely to learn how to solve that problem that has had you stumped for the last six months, but you may well hit upon an idea for making progress, along with the right entry point to the specialist literature. At any rate you will end up much better educated, learning lots of facts and insights into a wide range of topics from Liapounov indicators to the theory of turbulence.

Of course, in a book that ranges so widely, there are bound to be points with which experts will find fault. One inconsequential and light-hearted example must suffice. I once had a student who thought that the Heaviside function was so called because it was light on one side and heavy on the other. Maybe that student was the author (or copy-editor) of this book, or maybe the "Heavyside" function on p. 108 is something else entirely.

In the introductory chapters the astrophysics is well integrated with the mathematics. Then they part company for a while, as we learn the jargon and results of dynamical systems, partial differential equations, time-series analysis, and so on. Finally come several chapters reviewing a number of selected research topics in astrophysics where these approaches have been most fruitful. Without eschewing deep results, the book is as readable as a novel, and like any decent novel, deserves to be read from cover to cover, though probably not at one sitting. — DOUGLAS C. HEGGIE.

US Spacesuits, by K. S. Thomas & H. J. McMann (Springer, Heidelberg), 2005. Pp. 415, 24 × 17 cm. Price £22/$39·95/€32·95 (paperback; ISBN 0 387 27919 9).

In his introduction, astronaut and spacewalker Storey Musgrave describes this book as "historical, massively comprehensive, precise, informative, relevant and readable." I completely agree: everything you ever wanted to know about US spacesuits is here, well illustrated, well set out and, for such a specialist topic, quite readable too. Strongly recommended for die-hard spaceflight enthusiasts, historians, or aerospace engineers with a professional interest. However, probably just a bit too intense for the general reader with only a passing interest in space travel. — JOHN DAVIES.

Future Directions in High Resolution Astronomy, (ASP Conference Series, Vol. 340), edited by J. D. Romney & M. J. Reid (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 661, 23·5 × 15·5 cm. Price $77 (about £44) (hardbound; ISBN 1 583 81207 5).

This volume contains the papers presented at a meeting that celebrated the 10th birthday of the *VLBA*. As the title suggests, there are some other topics considered as well, but the majority of the contributions discuss the many different topics that have been the subject of *VLBA* observing over its prolific lifetime so far. There are contributions relating to a wide range of astrophysical problems, from protostars and masers in the Galaxy, astrometry and apparent proper motion of the Galactic centre, microquasars, then further on to extragalactic radio supernova remnants, accretion discs, and the powerful jets in AGN. Perhaps the analysis of the motions of the sub-parsec-scale water-vapour masers in the disc around the nucleus of NGC 4258 is the most impressive and elegant of this great variety. There are, however, some 140 papers to choose from in this compendium if you want to find another favourite. Who would have thought, back in the early days of radio astronomy, when the struggle was to obtain a resolution of an arcminute, that working at radio wavelengths would result in mapping at resolutions better than a milli-arcsec?

There is still much to do, as listed in Roger Blandford's introduction, for the *VLBA* (or its competitors; but this meeting was in New Mexico). This will be a useful volume for many astronomers. — GUY POOLEY.

Mathematical Methods for Physics and Engineering: A Comprehensive Guide, 3rd Edition, by K. F. Riley, M. P. Hobson & S. J. Bence (Cambridge University Press), 2006. Pp. 1333, 25·5 × 18 cm. Price £70/$160 (hardbound; ISBN 0 521 86153 5), £35/$80 (paperback; ISBN 0 521 67971 0).
Student Solution Manual for Mathematical Methods for Physics and Engineering, 3rd Edition, by K. F. Riley & M. P. Hobson (Cambridge University Press), 2006. Pp. 534, 25·5 × 18 cm. Price £13·99/$27·99 (paperback; ISBN 0 521 67973 7). Also sold as a two-volume set, price £45 (ISBN 0 521 68339 4).

This doorstop of a book supplies all that anyone could wish to know about mathematical methods at undergraduate level. The text has been gradually maturing since the first edition in 1998, and the frequent reprintings and two new editions since then demonstrate its popularity. This edition adds chapters giving a systematic treatment of special functions, practical uses of complex-variable techniques, and quantum operators.

The biggest change in the current edition is the addition of a student solution manual for the odd-numbered exercises in the book (numbering more than 400). The solutions here are more exhaustive than would be expected of a good student, but deliberately aim at further instruction. They are particularly readable and clear, and systematically fill out intermediate algebraic steps that often baffle students. The manual does make the book particularly useful. As it is separately bound, conscientious students can make genuine attempts at the questions before checking the answers, and even those who succumb to natural curiosity will gain some profit from reading the manual without this desirable prelude.

The main drawback of the book is its sheer weight: students will think twice about moving it around, although I suppose this will reduce the number of unwelcome requests to borrow it. And it offers one more highly attractive feature: for those instructors a little worried about their ability to solve the even-numbered exercises, there is a password-protected website where you can register to get the solutions.

Well worth it, I should have thought. — Andrew King.

Water and the Search for Life on Mars, by D. M. Harland (Springer, Heidelberg), 2005. Pp. 256, 24 × 17 cm. Price £16·50/$29·95/€24·95 (paperback; ISBN 0 387 26020 X).

This book tackles a subject that is highly popular and that has fascinated scientists, the press, and public for more than a century. The book is organized as an historical review of observations and theories about Mars from telescopic observation, followed by a chronological description of Mars exploration from space probes. The historical section is full of fascinating information, with many stories and anecdotes that will be unfamiliar to all but specialists and that give a detailed background as to the state of knowledge of Mars up to the start of the space race and how it was obtained. With a solid historical background established, the book moves on to a description, mission by mission, of the exploration of Mars by NASA, the Soviet Union/Russia, and Europe, both the successes and the many failures (although, curiously, the failed Japanese mission to Mars is not mentioned). Again, there is a wealth of detail and many interesting anecdotes.

Logically enough, the second half of the book is dedicated to the *Spirit* and *Opportunity* rovers on Mars and their exploration of the planet. Here, though, the book seems to lose its way somewhat and is converted into a travelogue: moved *x* metres; visited rock A; bored a hole *y* mm deep; went to next rock. The detail is impressive and the traverse of the rovers on Mars is exquisitely documented, but there is little of the passion and excitement about the exploration and the quotes from scientists seem to have been taken from statements at press conferences rather than inside information or conversations that would properly convey the emotions of the moment. As the story progresses there is a strong sense of an opportunity missed. It would have been nice to see less detailed description and more analysis of what it all means (the *Viking* section is nicely rounded off with some timely analysis and explanation of the possible explanations of the life-science results). Given the title of the book, it would also have been nice to see a section at the end summarizing the evidence found by *Spirit* and *Opportunity* for the existence of past liquid water.

A final, slightly annoying detail is the fact that the editing of the book is somewhat uneven at times, including one editorial oversight in the first few pages that rather sets the tone for the rest of the book. — MARK KIDGER.

14th European Workshop on White Dwarfs (ASP Conference Series, Vol. 334), edited by D. Koester & S. Moehler (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 666, 23 × 15·5 cm. Price $77 (about £44) (hardbound; ISBN 1 583 81197 9).

The European Workshop on white dwarfs is currently the most important meeting on white dwarfs and related objects. This can be appreciated by the wealth of contributions as well as the diversity of topics discussed in these proceedings. Not only are white dwarfs being studied from the perspective of understanding their structure and evolution, they are also being used as tools to investigate a larger scope of astronomical questions, such as galactic properties and cosmology.

These proceedings are divided into six large headings, encompassing (*i*) white-dwarf structure, evolution, and galactic distribution, (*ii*) large surveys, (*iii*) atmospheres, abundances, and magnetic fields, (*iv*) white-dwarf progenitors, (*v*) binary systems, and last but not least, (*vi*) variable white dwarfs and progenitors. It is easy to see that such a spectrum of topics can cater to a variety of interests. Indeed, from theoretical modelling to observational discoveries, if the field of white dwarfs interests you, something is bound to draw your attention. Moreover, with the anticipated data release of the Sloan Digital Sky Survey, we are treated to a first glimpse of things to come. Results stemming from this endeavour will undoubtedly have a strong impact. Most notably, the number of known white dwarfs has doubled in one go, and this will inevitably stimulate many areas of research.

In terms of appraising this work, I feel it is a good reference for anyone working in the field. It provides an excellent review of on-going work in this domain and certainly presents exciting results that can inspire future work. The only downside is that these proceedings may become outdated fairly quickly when one considers that these meetings occur every two years. Some basic background is definitely useful as the reader may come across rather technical terminology. However, references are given and should guide the reader to more thorough discussions of these topics. Thus, whether you are looking to update your knowledge fully on white dwarfs, or wish to examine a specific facet of this area, or are simply curious about this ever-growing field, this is definitely a good place to start. — Caroline Pereira.

Compact Stellar X-Ray Sources, edited by W. H. G. Lewin & M. van der Klis (Cambridge University Press), 2006. Pp. 690, 25·5 × 18 cm. Price £100/$175 (hardbound; ISBN 0 521 82659 4).

As part of the illustrious Cambridge Astrophysics Series, this volume has a hard set of acts to follow. A previous volume dealt with X-ray binaries, but now the subject has been expanded to include every type of compact stellar X-ray source. Even ignoring galaxy-sized monsters feeding off their environment, the cosmic zoo of X-ray sources is still vast. Rather than try and review everything in one go, the editors have wisely chosen a set of authors each of whom takes on a particular topic. The result is a set of review articles, long enough for sufficient detail but not so long as to lose the reader in a mountain of references.

Each article is typically around 40 pages long, leading to a sizeable book, which it should be given the price. I'm not entirely clear what drove the order in which the articles appear: why, for example, is Andrew King's nice review of accretion near the end? Nevertheless, the topics are well chosen and fairly distinct, providing an extremely useful summary of current research. Things that go bang in the night (or the day) are my current interest, so I found the articles on transients and gamma-ray bursts of particular interest even though the latter suffers from being written just before the results from the *Swift* mission became available. What is clear from many of the articles is how essential it is to combine temporal and spectral information. We are still limited in getting large area, good spectral resolution, flexible scheduling, and wide bandpass all at the same time. That's not too much to ask, is it? If the space agencies are wondering why they should be planning now to replace *XMM–Newton*, *Chandra*, and *RXTE*, they should read this book.

My only quibble, apart from the price, is the almost complete lack of colour. Otherwise a good buy for libraries and essential background reading for students and their supervisors. — Paul O'Brien.

Ten Worlds: Everything That Orbits the Sun, by K. Croswell (Boyds Mill Press, Honesdale, Pennsylvania), 2006. Pp. 56, 31 × 24 cm. Price $19·95 (about £11) (hardbound; ISBN 1 590 78423 5).

Ten Worlds is an engaging survey of the Solar System for readers of all ages, combining the latest astronomical images (from, *e.g., SOHO* and *Cassini*) with a detailed overview of the Sun, planets, and major moons. The writing level is appropriate for young teenagers, but the scientific content is rich and will interest and surprise older readers too: *e.g.*, "Sometimes people say the Sun is just an average star. But this claim is wrong. The Sun is actually far above average. Most stars give off much less light than the Sun."; or, "It probably rains methane on Titan, just as it rains water on Earth."

With his clear, accessible explanations, Croswell helps young readers grasp complex ideas and information, though some of the more advanced concepts (such as carbon dating or thermonuclear reactions) might have benefited from an accompanying picture or diagram. Croswell's inclusion of charts and discussions of asteroids, meteors, and star-forming clouds nicely provide a more textured vision of the Solar System. Two pages are dedicated to the controversy regarding 2003 UB313 (Eris, 'the tenth planet'), for which the book shows an artist's rendition. His discussion of the ambiguity in the definition of a planet is an excellent introduction to the complexities, conversations, and disagreements that crop up in the process of doing scientific research.

As a non-textbook resource, *Ten Worlds* does a wonderful job of introducing children to the Solar System, and to the idea that science is not just about learning 'facts', but a process of discovery for students and scientists alike. Almost everyone will learn something new from this book. The high picture quality makes *Ten Worlds* suitable even for toddlers, who will enjoy associating names with the colourful glossy images, if they do not manage to tear them first. Many budding young astronomers are sure to be inspired. — A. MAHDAVI.

Stargazers' Almanac 2007 (Hawthorn Press, Stroud), 2006. Pp. 32, 30 × 42 cm. Price £12·99 (ISBN 1 903 45867 9).

Just in time for Christmas, the *Stargazers' Almanac* is a beautifully illustrated calendar to keep the astronomer — and anyone else with an interest in the night sky — on the ball throughout 2007. The basic layout is essentially as described in the review for the 2006 edition (see **126**, 59), but with all the new information for the coming year and all the descriptive passages fully refreshed. The 'specials' section at the end features methods of telling the time — by using the stars at night and by means of sundials during the day; and to make it happen, instructions are given for constructing a star nocturnal and a sundial. (And if you don't want to cut up a nice calendar to make these 'clocks', you can download the plans from a website.) One of the other 'specials' concentrates on the northern circumpolar sky, while the Campaign for Dark Skies reiterates its valuable message on the inside back cover. Go on, get one or two as presents! — DAVID STICKLAND.

OTHER BOOKS RECEIVED

New Cosmological Data and the Values of the Fundamental Parameters (IAU Symposium No. 201), edited by A. Lasenby & A. Wilkinson (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 544, 23·5 × 15·5 cm. Price $95 (about £53) (hardbound; ISBN 1 583 81212 1).

This volume reports the proceedings of a conference held in conjunction with the IAU General Assembly in Manchester in 2000 August. The delay in publication probably ensures that it won't be regarded as a necessity for cutting-edge research, but it may find use as an archival record of the state of the art at the turn of the century. It contains a number of reviews, with work on the cosmic microwave background looming large, and a host of poster papers from what was evidently a well-attended meeting.

Quark–Gluon Plasma, by K. Yagi, T. Hatsuda & Y. Miake (Cambridge University Press), 2005. Pp. 446, 25·5 × 18 cm. Price £80/$140 (hardbound; ISBN 0 521 56108 6).

Quark–gluon plasma is considered in this monograph to be the primordial matter at the time of the Big Bang, which later undergoes transition into hadronic particles. This text for graduate students and researchers considers such quantum chromodynamic phase transitions, and other properties of the plasma, in cosmological and astrophysical contexts.

Nuclear Superfluidity: Pairing in Finite Systems, by D. M. Brink & R. A. Broglia (Cambridge University Press), 2005. Pp. 378, 25·5 × 18 cm. Price £80/$140 (hardbound; ISBN 0 521 39540 2).

A monograph devoted to pair correlations in nuclei, this book covers superconductivity in metals and superfluidity in ^{3}He and thus has application to neutron stars. This modern text is aimed at researchers and students in experimental and theoretical nuclear physics.

THESIS ABSTRACT

Studies of OH and Methanol Masers in Regions of Massive-Star Formation

By Lisa Harvey-Smith

Phase-referenced observations of OH 4·7-GHz masers in 13 regions of massive-star formation were carried out using *MERLIN*. Masers were detected in ten of the regions and the flux-weighted mean positions and velocities of masers were determined. These were compared with published positions and velocities of 1·7-GHz OH masers. Where two lines coincide to within 30 AU and 1 km sec^{-1}, it is suggested that the masers are propagating through the same column of gas. Incidents of co-propagation can help to constrain models of maser pumping and hence determine the physical conditions within the region. There were five OH 4765-MHz masers thought to be co-propagating with OH 1665- or 1720-MHz masers. In one region, W3(OH), *MERLIN* detected a vast, low-brightness, OH-maser filament that stretches 2200 AU across the face of the H II region and has a systematic velocity gradient.

Phase-referenced observations were carried out on W3(OH) using the new *MERLIN* 6-GHz receivers. Forty methanol 6668-MHz masers were found and several co-propagating maser regions were identified. The methanol masers formed extended arcs and a large-scale analogue to the OH filament. The extended OH and methanol anti-correlate in position, suggesting a change in conditions along the filament. It is likely that the maser arcs and filaments delineate shocks. The velocities of methanol masers in W3(OH) suggest a large-scale rotating disc, and groups of masers to the north of the region and the OH filament appear to suggest that the region may also be expanding. — *University of Manchester; accepted 2005 December*.

The full thesis is available electronically at: http://www.jive.nl/~harvey/thesis.ps.

Here and There

VERY UNUSUAL

Venus rises an hour before dawn and Mercury will make unusual appearances in the second half of [February] about 10 degrees above the southern horizon, at about 4 pm. — *The Daily Telegraph*, 2006 February 6, February Night Sky.

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.

LAYOUT: The general format evident in this issue should be followed. ALL MATERIAL MUST BE DOUBLE SPACED. Unnecessary vertical spreading of mathematical material should be avoided (*e.g.*, by use of the solidus or negative exponents). Tables should be numbered with roman numerals, and be provided with a brief title. Diagrams should be numbered with arabic numerals, and have a caption which should, if possible, be intelligible without reference to the main body of the text. Lettering should be large enough to remain clear after reduction to the page width of the *Magazine*; figures in 'landscape' format are preferable to 'portrait' where possible.

REFERENCES: Authors are requested to pay particular attention to the reference style of the *Magazine*. References are quoted in the text by superscript numbers, starting at 1 and running sequentially in order of first appearance; at the end of the text, those references are identified by the number, in parentheses. The format for journals is:
(No.) Authors, journal, volume, page, year.
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**).

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