THE OBSERVATORY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2012 March 9 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

R. L. DAVIES, *President*
in the Chair

The President. Our first speaker is Professor Xander Tielens from Leiden University, talking on 'Trickle-down astrochemistry: from PAHs to graphene to fullerenes and hydrocarbons.'

Professor A. G. G. M. Tielens. Over the last 20 years, we have discovered that we live in a molecular Universe: a Universe where molecules are abundant and widespread; a Universe with a rich organic inventory particularly in regions of star and planet formation; a Universe where the formation of stars and the evolution of galaxies is driven in many ways by the presence of molecules; a Universe where prebiotic interstellar molecules may represent the first steps towards life; a Universe where molecules can be used as 'dye' to trace important processes in the interstellar medium; a Universe where molecules provide unique information on the physical conditions of a wide variety of regions; and a Universe where molecules can work together to make species as complex as you and me.

From an astronomical perspective, this realization was driven, to a large extent, by the opening up of the infrared and sub-millimetre sky, both from space-based observatories such as the *Infrared Space Observatory* launched by the European Space Agency (ESA) in 1995 and the *Spitzer Space Telescope* by the National Aeronautics and Space Administration (NASA) in 2005. And the future looks bright with the *Herschel Space Observatory* — launched by ESA in 2009 — taking data, NASA's *Stratospheric Observatory For Infrared Astronomy* (*SOFIA*) just taking off, the *Atacama Large Millimeter Array* ready for early science, and NASA's *James Webb Space Telescope* on the horizon. In addition, progress in our understanding of the molecular Universe has been greatly aided by the close collaborations between astronomers, molecular physicists, physical chemists, molecular spectroscopists, surface scientists, solid-state physicists, quantum chemists, and astrochemists in a number of closely-knit networks both at the national level and also at the pan-national level.

The great quest of astrochemistry centres on understanding the organic inventory of space, the processes that drive it, and the implications of the presence of molecules for the evolution of the Universe. Here, I focus on the first two of these aspects. Over much of the 'history' of this field, the molecules considered were relatively simple — CH^+ and CH, for example — and these species were thought to form through binary reactions. The actual reaction pathway involved was not always understood — CH^+ comes to mind — but, adopting a (any) particular reaction stimulated a lot of insightful discussions on the implications for our understanding of the interstellar medium of the Milky Way and other galaxies. To stick to the CH^+ example, the relevant reaction between abundant C^+ and H_2 has a high barrier and CH^+ points towards the presence of warm gas. We now understand this to be in the form of a 'turbulent dissipation region'. In a way, astrochemistry built our view of the ISM, one atom at a time.

However, in more recent years, we have seen a shift in paradigm. First, we realized that the ISM is pervaded by rather complex molecules — polycyclic aromatic hydrocarbons (PAHs) — whose tell-tale vibrational signatures dominate the mid-infrared spectra of almost all objects in the Universe. Then, only some two years ago, we unambiguously identified the fullerene, C_{60}, from its unique infrared fingerprints in a peculiar object, the planetary nebula TC 1. Once we recognized these fingerprints, we realized that its spectral autograph is written all over the sky but generally covered by the much more prominent and much stronger bands of interstellar PAH molecules. Now, these molecules are so large and so complex — containing between 50 and 100 C atoms — that they cannot be formed atom-by-atom in the diffuse and harsh conditions of the interstellar medium. Rather, we think that these species are formed in the ejecta of stars — C-rich asymptotic-giant-branch (AGB) stars — that upon expanding, cool down, and this initiates a chemistry akin to that in sooty flames and car engines. In this way, fuel molecules — acetylene in this case — polymerize to benzene and then grow to ever-larger PAH species. These molecules can then cluster to larger units, which eventually coagulate and form submicron-sized soot grains. Models have been developed — based upon the extensive soot-chemistry literature dealing with automotive car-engine performance — that follow this chemistry in detail under conditions relevant for shocks traversing the pulsating atmospheres of AGB stars. Current versions of these models are very successful in growing large molecular species. This is of course again a bottom-up-chemistry approach, but once the ejecta mix into the interstellar medium, energetic processing by the rampant far-ultraviolet photons and cosmic-ray ions will break these species down to smaller species. This leads to a top-down chemistry where, given time or harsh conditions, molecular complexity 'trickles-down' into simpler species. This is a kind of chemistry that we had not suspected to be present and one that may lead to a rich and diverse organic inventory.

Spitzer and *Herschel* studies of the reflection nebula NGC 7023 have now provided the first glimpse of the importance of this top-down chemistry. The infrared spectrograph on board the *Spitzer Space Telescope* has spectroscopically mapped the photodissociation region (PDR) associated with this reflection nebula, and the spectra are dominated by the bands of PAH molecules at 6·2, 7·7, 8·6, and 11·3 microns. The spectra also reveal the 18·9-micron emission band due to C_{60}, which is very weak but clearly present. This band becomes particularly prominent close to the illuminating star. The *PACS* instrument on the *Herschel Space Observatory* has, in the meantime, studied the emission due to classical-sized dust grains. The combination of *Spitzer* and *Herschel* data allows us to put the abundances of these different components on an absolute scale. The results show that far from the star (> 35″), some 20% of the elemental carbon is locked up in large PAH molecules, but upon approaching the star (~ 10″), the PAH abundance decreases to about 1% of the carbon. At the same time, the abundance of C_{60} increases from about 10^{-5} to about 10^{-4} of the elemental carbon when approaching the star.

These results have been interpreted in terms of a top-down model driven by photolysis. Upon absorption of a far-ultraviolet photon, the PAH molecule is highly excited and most of the time cools down through IR-photon emission — the IR emission features — but there is a finite possibility for unimolecular dissociation. The weakest link will then go first and that is the C–H bond. Far away from the star, this process is not happening very often and the loss of H is balanced by reactions with atomic H. However, the H balance shifts towards rapid H loss as the PAH approaches the star when the PDR evaporates. Depending on their size, PAHs will be completely stripped of peripheral H at a given distance; *e.g.*, the PAH is transformed into graphene. At that point carbon loss from the skeleton kicks in and the graphene sheet may break down to smaller flats, rings, chains, and carbon radicals. The loss of carbon from graphene may also initiate an isomerization process that converts it into cages and fullerenes, and there are laboratory studies supporting this scenario. So, the picture that emerges now from the observations of NGC 7023 is one of competition of trickle-down chemistry — feeding small carbon radicals into the gas phase — with isomerization and the formation of highly stable fullerene molecules. The implications of this for the organic inventory of the interstellar medium have not yet been evaluated. However, we do note that IR spectra of the planet-forming discs around young stellar objects show clear evidence for a rapid chemical evolution of PAH molecules driven by the stellar radiation field, and we realize that in many respects the conditions in the habitable zones of these discs are much more extreme than those in the PDR of NGC 7023.

Mr. M. F. Osmaston. Do you envisage any other atom, apart from hydrogen, acting as a catalyst in any of these transformations or structural processes?

Professor Tielens. No, the only thing is these PAH structures that you start off with. And it's largely aromatic hydrocarbons. Once you lose the hydrogen, you're locked with the carbon. Some laboratory studies support the idea that if you excite these graphenes, they start to curl up into fullerenes.

Mr. Osmaston. The reason I ask is that if there were some atom which was germane to the formation of these species, then you could concentrate on looking for that, as an indicator.

Professor Tielens. That would be a very interesting idea.

Dr. G. Q. G. Stanley. Looking at the PAH abundance with distance from the central star, are you able to determine whether these migrate? It's a complex model, I know, but are you seeing the PAHs formed at that particular distance?

Professor Tielens. Well, the picture that you have here is that there is a central star, which has been formed in a molecular cloud, and is just eroding the molecular cloud. And there is an atomic flow of gas from the photodissociation-region surface, which in flowing away has created an inner cavity that is of much lower density than the molecular cloud around it. And the time-scale, of the order of 10^5 years, is one that I think is relevant for that kind of process; but we don't see specific evidence in our spectra that this process is happening

Dr. D. McNally. Are we getting any nearer with this wonderful chemistry to identifying the classical diffuse interstellar features in the optical?

Professor Tielens. Can I cry here? [Laughter.] No, let me be honest here. I do not think that PAHs are the answer to that problem. You have these diffuse interstellar bands arising from transitions that occur in species which have electronic transitions in the visible; they could be large PAHs, but unfortunately in large PAHs the first electronic transition is really very weak, so it would be very difficult to do this; and the second transition couples with lower-lying electrons so the bands get very broad. Those bands should be there, but they will be very difficult to detect. They're certainly not the diffuse interstellar bands and we should be looking for them.

Professor M. Rowan-Robinson. You've convinced us that PAHs are formed in the atmospheres of red-giant stars; you've given us the argument that they're destroyed on the time-scale of a few hundred million years; and you've suggested that graphite being destroyed could be the way to rebuilding them instantly in interstellar clouds. But is there any observational evidence for the formation of PAHs in clouds?

Professor Tielens. No, only for the destruction! We are very good at destroying things! [Laughter.]

Professor Rowan-Robinson. So it's a theoretical argument that needs to be made — there's no actual direct evidence?

Professor Tielens. Let me put the argument the other way around: it is very difficult to make something big in the interstellar medium. The abundance of big molecules that we think are formed locally through ion–molecule chemistry is very small. It is just too difficult to put these things together. And that's why I like to start and take something big, take a sledgehammer, and break it down to graphene, to PAHs, and then work with that. Can we expect to find this kind of signature in the future? Yes, I think that we could start looking for the signatures of the small hydrocarbons, and we could start to see, perhaps with *ALMA*, what the structure is of these small hydrocarbons, in the photo-dissociation regions, and whether there is a chemical process that we can identify that way.

The President. I think we must move on. Thank you very much. [Applause.]

Our next speaker is Professor Mike Kendall from the University of Bristol. Mike is a Vice-President of the Society, and he's going to tell us about 'Continental rifting in Africa: insights from the core to the crust'.

Professor M. Kendall. The rifting of continents and subsequent formation of ocean basins is a fundamental component of plate tectonics, yet the mechanism for break-up is poorly understood. The rupture of continental plates occurs by a combination of mechanical deformation and magma intrusion, but the available driving forces have been estimated to be as much as an order of magnitude smaller than those required to rupture thick continental lithosphere. The East Africa Rift System (EARS) is an ideal place to study rifting; it captures the initiation of a rift in the south through to incipient oceanic spreading in north-eastern Ethiopia — Afar. Recent seismic experiments in Ethiopia are offering unprecedented resolution of the crust and mantle structure beneath this area of continental rifting, as well as the on-going tectonic processes that characterize its development.

Conventional ideas of rifting appeal to distant plate-boundary processes (*e.g.*, subduction) to provide the driving forces to break and rift thick, cold, continental crust. This leads to a model of plate stretching where the deformation is distributed over a wide area. In contrast, recent models that include the effects of magma injection into the lithosphere show how the magma serves considerably to weaken the plate and localize the deformation.

These end-member models provide clear hypotheses that can be tested using seismic methods.

A series of seismic experiments over the past decade has led to the deployment of over 150 seismometers in Ethiopia, in regions varying from fertile rift-valley lakes to the harsh environment of the Afar depression. The resulting data have provided high-resolution images of the velocity structure, seismic-discontinuity structure, and seismic anisotropy beneath the region. They have also led to a much better understanding of seismicity in the region, which is helping with hazard assessments.

Numerous lines of evidence have led to arguments that a mantle plume must lie beneath Ethiopia, but its structure and connection to the lower mantle have been unclear. Large-scale global tomographic models show a large, low-velocity anomaly seated below Africa, which rises from the core–mantle boundary beneath southern Africa and crosses the 660-km mantle discontinuity beneath Kenya. This so-called 'superplume' leads to the African 'superswell' and it is most probably thermo-chemical in origin. However, its connection with the uppermost mantle and rifting in Ethiopia has been unclear. In a series of papers, Bastow and co-workers have shown that there is no clear evidence for a single diapiric plume beneath Ethiopia. Instead, the rift valley is underlain by a long vertical curtain of low P-wave (V_P) and S-wave (V_S) velocities. Discrete and more-focussed upwellings punctuate the lithosphere at depths above 100 km. The travel times of seismic phases recorded at seismic stations in the region show the slowest residuals in the world, suggesting that the lithosphere is riddled with partial melt.

The receiver-function method uses seismic phase conversions (*e.g.*, P-wave to S-wave conversions) at interfaces to map the structure of seismic discontinuities. It is most commonly used to map the thickness of the crust and its V_P/V_S ratio. Recent results show an abrupt thinning of the crust at the flanks of the rift. The crust varies from well over 40 km in thickness beneath the Ethiopian plateau, to less than 15 km beneath northern Afar. Similarly, V_P/V_S ratios show sharp variations at the rift boundary and suggest high degrees of partial melt exist throughout much of the crust beneath the Afar region, where V_P/V_S approaches 2·3.

Plate deformation, particularly at their boundaries, produces strain-enhanced crystal alignment and increased melt production within the upper mantle, both of which can cause seismic anisotropy (directional variations in seismic velocities). The perhaps least-ambiguous indicator of anisotropy is the observation of two independent and orthogonally polarized shear waves (*i.e.*, shear-wave splitting or birefringence). Using a combination of core-transiting shear phases (*e.g.*, SKS), surface waves, and local earthquakes, we have shown that the anisotropy in the upper 100 km (*i.e.*, lithospheric depths) beneath the rift valley is best explained by dyke-induced faulting and orientated melt inclusions. The anisotropy at deeper mantle depths is due to the preferred alignment of olivine in mantle rock, which is a result of the northeasterly flow of mantle material associated with the deeper superplume.

The driving forces of rifting in Africa come from a number of sources. Distant forces, such as those associated with plate subduction, are probably second order in influence — especially as mid-ocean ridges surround much of the continent. The African superplume provides the pronounced anomalous topography of Africa and leads to a significant amount of gravitational potential energy (GPE). Deviatoric stresses associated with lateral variations in GPE will work to restore the continent back to its equipotential surface, and will therefore provide a force for rifting. Another plausible mechanism is traction associated with mantle flow at the base of the lithosphere. The density-driven flow associated with the superplume will also exert significant deviatoric stresses on the plate. Nevertheless, even when all combined, the available forces for rifting amagmatic, cold, thick continental lithosphere are most likely insufficient. However, our seismic observations have shown the tell-tale signs of magma injection into the lithosphere and have shown highly focussed strain at the rift margins. Much less force is required to break apart lithosphere that is heavily intruded with magma.

Overall, the consensus emerging from Ethiopia is that focussed magma intrusion becomes an important factor in the accommodation of strain, well before the onset of sea-floor spreading in a new ocean basin. Upwellings, which most probably originate from a deeper and larger super plume in the lower mantle, thermally erode the lithosphere along sites of pre-existing weaknesses or topographic highs. Decompression melting leads to magmatism and dyke injection that weakens the lithosphere enough for rifting and the strain appears to be localized to plate boundaries, rather than the wider zones that characterize early mechanical deformation. In many ways the scenery in the mantle beneath Ethiopia is as spectacular as the scenery that captures the transition from the Ethiopian rift-valley lakes to the Danakil depression in Afar. The challenge now is to use what we have learned in the Horn of Africa to understand better the processes that shaped the rifted margins elsewhere on Earth, and indeed other planets, over geological time.

The President. Thank you very much! Are there any questions?

Dr. R. T. Holme. You have described a huge superplume structure coming up in a straight line, a few hundred metres wide, over a long distance. So there is a high degree of organization within a very thin structure?

Professor Kendall. Yes, you start with a structure that is 1000 km across at the core–mantle boundary. And then by the time it gets to the surface it's 100 km. But it organizes itself as it starts to encounter the lithosphere–asthenosphere boundary: there is a permeability barrier, and everything gets focussed towards where the rifting is occurring.

Dr. Holme. Which is pushing which?

Professor Kendall. The forces are associated with the density-driven flow from below, so it's the combination of the gravitational potential energy, the fact that it's perched high, and the tractions on the base of the lithosphere — those working in concert are the primary driving forces, I think. That's still a bit of a contentious issue.

Dr. Holme. But then, to control where it's coming out at the surface — is that an addition?

Professor Kendall. There are a lot of good arguments for that being where there is a pre-existing weakness, where there have been previous sutures. It looks like Africa, or Gondwanaland, as it was when all the continents were together, has opened and closed a few times in this area, just as the Atlantic has opened and closed at least three times — it always opens in the same spot. It looks like Africa has done that before too. And so there is a pre-existing weakness that runs down the centre of Africa.

Mr. Osmaston. One point on dynamic topography: you need to put into your sums the fact that the garnet-peridotite–spinel-peridotite phase change produces 50 times more volume increase per joule than by thermal expansivity. And that particular phase change is going to happen in these circumstances.

Professor Kendall. Yes, definitely, there is a whole line of research just in getting the sums right for the gravitational potential energy, I agree.

Professor R. Kennicutt. You mentioned this is the one place where you can effectively study ocean-floor spreading above the surface. How far can what you are learning be generalized?

Professor Kendall. That's a good question: when you've got only one place, it's hard to say if it fits everything. It's quite slow what's happening there, so it's probably more akin to the mid-Atlantic as opposed to the East-Pacific rise. The East-Pacific rise is moving apart very, very quickly, and you get quite a different style of volcanism and structure. So I'd say there is probably a good caveat: this is probably more like what we see at slow spreading centres, perhaps even the Gakkel which runs across the North Pole, which is a very enigmatic mid-ocean-ridge segment.

Mr. M. Hepburn. Is it not true that Africa is the only vast continental plate which is more or less stationary, with respect to everything underneath; and isn't that quite a good reason that there is more heat building up?

Professor Kendall. Yes, except that you would get some heat build-up, because you're not actually moving that much, but on the other hand there is this huge anomaly underneath. There are two on this planet — the other one sits under the South Pacific, and gives rise to what is called the superswell in the southern Pacific. There is a lot of other auxiliary evidence that these superplumes have been around for at least the last 500 million years. It looks like where Africa has moved over it, its dynamic topography has reflected that. I think it was some 150 million years ago, it was more centred over the southern part of Africa, and that's why India started to drift away from Africa.

The President. Let's thank Mike again. [Applause.]

It is time to move on to this year's Eddington Lecture. The Eddington Lecture is jointly organized by the University of Cambridge and the Royal Astronomical Society, which means that the Eddington Lecturer has to give the lecture twice! I'm particularly pleased to have Professor Julianne Dalcanton here from the University of Washington.

Some two or three years ago, the *Hubble Space Telescope* started to get concerned about its legacy — it only has a finite life, of course — and there was an opportunity to make applications for what were called Multi-Cycle Treasury programmes; and one of the only three, I think, successful PIs was Professor Dalcanton, and I'm pretty sure we'll hear a little bit about this in her Eddington Lecture: 'Galaxies viewed as collections of individual stars'.

Professor J. Dalcanton. [It is expected that a summary of this talk will appear in *Astronomy & Geophysics*.]

The President. It is a fantastic survey, data, and a wonderful talk; thank you! But you didn't mention binary stars anywhere. So surely, in these images you've showed us, there are lots of binary stars?

Professor Dalcanton. Absolutely! And one interesting fact is that for the radial variation in the number of these sort of hot, post-horizontal-branch stars, you can fit the power-law slope; you know they fall off faster than the integrated light, and the population has the exact same slope as the low-mass X-ray-binary population. I throw that out there, but that doesn't necessarily mean anything.

The President. So it's still to be investigated.

Professor Dalcanton. I don't know that this is going to be the dataset with which we can do much with binaries. I don't know that we can necessarily resolve them, because the crowding uncertainties are always going to be larger in M31 than they are going to be in a globular cluster. So we are doing a lot of things, such as cross-comparing with the X-ray data, which is at least some tracker of binary populations.

The President. And presumably the binaries can be modelled and you can compare with expectations.

Professor I. W. Roxburgh. First of all, thank you for a fascinating talk! I would hope that the UK astronomical community here listens to your plea to support stellar astronomy, which is very poorly supported in the UK, as compared to France, for example. But a more positive comment is that there has been quite a substantial advance in our own Galaxy, using astroseismology on red giants, which overcomes at least the distance problem, and so there is quite a lot that could be added to what you said from Galactic sources.

Professor Dalcanton. Yes, and there is some work that has been done in the Magellanic Cloud; I've been very impressed with the work that Martha Boyer has been doing with the *Spitzer* survey, where they are also starting to get a handle on some of the very complex evolutionary pathways that are taken that affect the mid-infrared luminosity of these objects. So the astroseismology is fantastic, and I'm glad those people are finally getting the data they deserve. As a Hubble Fellow, I remember another Hubble Fellow who was an astroseismologist, and I always found his talks fascinating, but it was such a small community. But *Kepler* has changed it!

Professor Roxburgh. *CoRoT* actually, as well!

Dr. S. Eales. I was glad to hear that the centre of M31 is kind of weird! [Laughter.]

Professor Dalcanton. Yes, it's quite weird in the bulge, as you know, from the dust.

Dr. Eales. Yes, the *Herschel* observations do suggest that the dust is strange in the centre.

Professor Dalcanton. And you see it in the *Spitzer* data — if you look at the *Spitzer* colour images, the bulge looks just as weird in those as well. We've been working with some of the other sets of *Herschel* data, on M31, and there is a group at MPIA that has used six-filter photometry to fit for the effective temperatures of all the stars, independent of whether there is foreground dust or not; and so they have been able to generate stellar temperatures and bolometric luminosities and use those to predict what you actually expect for the dust heating. The first evidence seems to be that that is going to model successfully what we actually see for the emission in the bulge.

Dr. Eales. Can you get metallicity? I mean, can you estimate metallicity from your data or not?

Professor Dalcanton. I don't think so, because I don't believe the models are calibrated well enough. There are certain stellar phases where you can. For the red-giant branch, you can use the morphology: the shape and the colour of the red-giant branch changes systematically with metallicity. For stars of that age and that mass, you can really break down what the metallicity range is. And if you look at the bulge, the red-giant branch gets very curved — it gets very red, the tip gets fainter, and the distribution gets broad. You can see that there is a wide range of metallicities that extends to very metal-rich populations in the bulge. However, it's that one phase where you are capturing stars of a certain age and moment in time, but that doesn't necessarily tell you what's happening with younger stars, the metallicity of stars of intermediate age. We can get constraints from some of the phases where we do think the calibration is not badly wrong. But for some of the more subtle material, I don't believe it yet.

The President. Last question.

Mr. Hepburn. When an ordinary star in a globular cluster evolves through to the horizontal branch, it has already boiled off just over half of its mass. And a lot of that is hydrogen. I've heard people present the idea that in our own Galaxy there are new stars being formed even in the centre. Isn't that an alternative possibility for the blue stars that you see there, that they might simply be new stars forming from the hydrogen that's been boiled off from the evolving ones?

Professor Dalcanton. Well, if the hydrogen is in a neutral phase we can map it, and it doesn't seem like there is a huge reservoir of hydrogen that increases with the same slope towards the centre. We like to believe that while the initial mass function may not be constant, it is not pathological. The way that we first noticed these objects is that we looked at the colour–magnitude diagram in our two ultraviolet filters and the one in the bulge looked weird. So the majority of those stars are much bluer than any main-sequence star that you ever see. Also it's got a lot of curvature on the blue edge, whereas the main sequence that you see in the same filter set just a little bit further out is straighter, it's redder, and it really just doesn't look like the same population of stars in the ensemble. It doesn't necessarily mean that there aren't individual stars that may be there, but the bulk of the population is just not consistent with being a young, main-sequence population.

The President. Thank you very much, Julianne. You have demonstrated how strange even our nearest-neighbour galaxies are, which does rather remind me of a quote, I think from Jim Gunn, in the summary of a conference in the 1980s in Santa Cruz, the first Nearly-Normal Galaxies conference. And he said in the summary: "Galaxies are like people: the better you get to know them as individuals, the weirder they are." [Laughter.]

Professor Dalcanton. I've heard that quote ascribed to probably at least ten different people! [Laughter.]

The President. Well, let's thank Julianne again! [Applause.] We are now invited to a drinks reception in the library, and we meet again here on Friday the 11th of May for our AGM.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2012 March 28 at $14^{h}\ 15^{m}$
in Lecture Theatre 'B', University Centre, University of Manchester

R. L. Davies, *President*
in the Chair

The President. This is the RAS Community Session, and this is my opportunity to give you a bit of a 'heads-up' on what the RAS is doing, and what the RAS does for you. But before I start up on that path, I have a few thanks to convey. The RAS is delighted that we've had this joint meeting with the Astronomische Gesellschaft (AG), and I would certainly like to thank Andreas Burkert who has cooked up this idea with the RAS. That was more or less the end of our involvement however, and the work has been done by the University of Manchester people, and so I'd like first of all to thank the University of Manchester for hosting us in these tremendous facilities, and I'd like to thank as well the Scientific Organising Committee, and the Local Organising Committee chaired by Philippa Browning and Albert Zijlstra, who've done an excellent job — it is an enormous amount of work, so I think we should all give them a round of applause! [Applause.]

In addition to marshalling the talents of the session organizers, the chairmen, and the speakers, they have put together a very extensive public programme, and they've attracted, along with the German community, 935 registered participants, which is a record for a non-JENAM event; in fact the only NAM that has been larger was the Hatfield meeting with, I think, more than 1000 registrations. I'd like to thank all the session organizers, the chairmen, and speakers — we are having an exciting meeting, there is lots and lots going on, and the programme is crammed. I don't want to spend too much time on this kind of thing, but there are some other people who need to be thanked for their contributions: the Science and Technology Facilities Council, who co-sponsor this meeting with the Royal Astronomical Society; Winton Capital, who sponsor the prizes for the young researchers (I am delighted to see Chris Read here today); and Springer, who give the books which are the prizes for the poster competition. The student winners for the poster competition will be announced tomorrow at the dinner. I have one more thing to say before I go on to start telling you about what the RAS has been doing, and that is that our Executive Secretary, David Elliott, is retiring on May 11th. I certainly thought we should not let this event pass unmarked; David has been a wonderful Executive Secretary. He has guided the Society through some quite choppy waters, and some huge changes. At the beginning of David's appointment, we were accommodated in Burlington House, but actually there was some threat to that. There was a negotiation that had to take place, between all the societies around the Burlington House courtyard, and the Office of the Deputy Prime Minister, John Prescott. This was actually a turbulent time, a time of considerable uncertainty. The Society was guided very deftly and successfully through the negotiations by David, and he transformed that success into a triumph, following it by refurbishing the apartments! We are now accommodated in really wonderful, new facilities with which probably many of you are familiar. Furthermore, David had to deal with guiding the Society through the tribulations of the formation of the STFC and the budget cuts that came along after that. Those things were handled, I think, better than we perhaps would have been able to before we hired a policy officer, another thing in which David played a principal rôle. So David has been the quiet guiding hand, helping successive Presidents, one after another, to take the Society further on, and make us a much more effective unit than we were previously. I think it would be very appropriate for us all to thank David for his contributions now, and wish him well in his retirement! [Applause.]

I'm delighted to say that we have managed to appoint a successor to David, and she is with us this afternoon — Pamela Mortimer. Please stand up, Pamela! [Applause.] We're all looking forward to getting to know Pamela well, and I'm sure she will guide us in the same way that David has.

I want to give a taste, particularly for those who are not Fellows, of what the RAS is doing for you, the astronomical community — in the widest sense of its meaning — and perhaps persuade you to join!

Firstly, we argue the case for public funding of astronomy research and teaching with Government, MPs, MEPs, Parliamentary committees, and

Research Councils, and win public support by publicizing scientific breakthroughs. We are able to educate them and explain what astronomy does for the nation. Thus in the last year, for example, we made submissions to the inquiries of the Science and Technology Committees of both the House of Commons and the House of Lords on Higher Education in STEM subjects and Astronomy and Particle Physics, respectively. We have, for instance, recently looked into the position of the UK on leap seconds, and responded to a consultation on Postgraduate Education by the Higher Education Commission. We issued 52 press releases and gave 39 radio and 38 television interviews.

We support early-career researchers by, for example, giving grants to support attendance at international conferences, and awarding postdoctoral RAS Fellowships. Each year we have around 100 applications for these Fellowships and we award three. We have done this since 2009–10 to help offset the dramatic reduction in opportunities for young researchers. The Fellowships are funded from the RAS reserves and in the future we will only be able to afford to support one per year, so we are actively seeking sponsorship for these positions. Along with the Daphne Jackson Trust, we are also establishing a new fellowship to assist women to get back into science after career breaks. We provide cash prizes for outstanding PhD theses each year, and we can give a significant boost to careers through the Fowler and Winton Capital prizes. This year we have been monitoring employment prospects through a series of demographic surveys. We are also grateful to Patricia Tomkins who has given a gift which will help to support young postdocs working on instrumentation.

Thirdly, we encourage you to organize scientific meetings through, for example, specialist discussions every second Friday of the month during the academic year and at any other time when Fellows want them, and sponsoring meetings and lectures outside London, including the NAM, the Eddington Lecture at Cambridge, and the Grubb-Parsons Lecture at Durham.

We encourage people into our sciences by, for example, organizing free lunchtime public lectures, encouraging our Fellows to give school talks, supporting school teachers through course material, and by awarding the Patrick Moore Medal, this year for the first time, to a teacher who has made a big impact in our subject.

We connect with European and international astronomy through, for example, collaboration with other national astronomy societies (like the AG) and the European Astronomical Society. We have, for instance, Thierry Courvoisier, the EAS President with us today. The RAS is also the UK representative for the International Astronomical Union, and helps UK experts get involved in capacity development in poorer countries, in particular a new development in the Office for Astronomy Development in Cape Town which will enable scientists to travel to poorer countries to help with education in astronomy.

Perhaps the most important thing we do is to provide the research community with world-class organs for disseminating their findings — the *Monthly Notices*.

Finally, we award medals and prizes to scientists, young and not so young, whom their peers, the most demanding ajudicators, judge to be outstanding, and that brings up the next item on the agenda. I would now like to call on Jennifer Gupta and Paul Ruffle to come forward. They will read the citations and I will give each recipient the medal.

Miss Jennifer Gupta. The Gold Medal is the highest honour conferred by the Society. Professor John Brown, the 10th Astronomer Royal for Scotland and a former Regius Professor of Astronomy at the University of Glasgow, has had an outstanding career in research, leadership, and outreach.

Early in his career Professor Brown's 'collisional thick-target model' led to a new paradigm for the production of X-rays by electrons in solar flares. Identifying the mechanism of electron acceleration remains a central and unsolved problem in solar activity and his seminal work on deriving the accelerated-electron distributions from their observable X-ray emission is still the landmark paper in the field, cited over 600 times.

His leading rôle in NASA's award-winning *Reuven Ramaty High Energy Solar Spectroscopic Imager* mission is testament to his impact in high-energy solar physics, where his work encompasses the interpretation of the properties of X-ray signatures, the modelling of particle acceleration and transport in the solar atmosphere, and the analysis of the response of the flaring solar atmosphere.

Professor Brown has inspired the astronomical passions of thousands of people across the UK and overseas through presentations in person and on television and radio.

For his outstanding work Professor Brown is awarded the 2012 Gold Medal of the Royal Astronomical Society. [Applause.]

Dr. P. Ruffle. Dr. Mike Irwin, of the Institute of Astronomy, Cambridge, is known worldwide for his leading rôle in processing digital optical and infrared survey data. Since entering research in 1980 he transformed the Cambridge Astronomical Survey Unit (CASU) into a powerhouse, including handling the majority of new-generation surveys from the European Southern Observatory. In 1985 he published an automated method for analysing images where objects are crowded together, the genesis of much of today's image detection and analysis.

Alongside this major technical achievement, Dr. Irwin has made a series of important contributions to science, for example, the 1994 co-discovery of the Sagittarius dwarf galaxy, an object being disrupted by — and heading for a future collision with — the Milky Way. This led on to galaxies being discovered in the constellations of Sextans, Cetus, and Antlia, with a further 15 found in the last five years.

Over the last 25 years, his immense body of work has helped to shape modern astronomy and for this Dr. Irwin is awarded the 2012 Herschel Medal. [Applause.]

Miss Gupta. Professor Andrew Fazakerley, from the Mullard Space Science Laboratory, has played a leading rôle in the ESA *Cluster* science team since 1997. As Principal Investigator of the *Plasma Electron and Current Experiment* (*PEACE*), he and his team built, tested, and integrated eight *PEACE* sensors on the four *Cluster* spacecraft and then two others for the Chinese *Double Star* mission.

The multi-point electron measurements yielded by them have enabled very significant advances in our understanding of the terrestrial space-plasma environment. He is included in the author list of over 300 publications, including papers on magnetic reconnection and flux transfer in the magnetosphere, auroral particle-acceleration processes, the physics of the radiation belts, interactions between interplanetary current sheets and the Earth's bow shock, as well as serendipitous evidence of the crustal cracking of a distant neutron star.

For the quality of the data from the sensors he developed and his team leadership Professor Fazakerley is awarded the RAS 2012 Chapman Medal. [Applause.]

Dr. Ruffle. Professor Joss Bland-Hawthorn, before becoming the Federation Fellow Professor of Physics at Sydney University, led the world-renowned instrument-science group at the Anglo-Australian Observatory. He has made many important contributions to astronomical instrumentation, authoring more than 200 peer-reviewed papers as well as major reviews in astrophysics, optics, and physics journals.

During the 1990s he developed the 'nod and shuffle' technique for subtracting the influence of the background sky from optical-fibre spectrographs, invented the tuneable filter that allows very narrowband imaging over a wide range of wavelengths that has been adopted at most observatories, and, most recently, demonstrated a technique that suppresses the contamination of infrared spectra by emission lines from the Earth's atmosphere. This latter 'astrophotonic' technology promises to revolutionize infrared astronomy and forms the basis of prototype instruments that will see first light on the *Australian Astronomical Telescope* and *Gemini North Telescope* within the next two years.

For his many contributions to the development of novel astronomical instrumentation and his pioneering work on astrophotonic technology, Professor Bland-Hawthorn is awarded the Jackson-Gwilt Medal. [Applause.]

Miss Gupta. The consortium responsible for the UKIDSS project began their work in 2005 and since that time has published more than 200 refereed papers. Significant science results from it include the discovery of a quasar at a redshift of 7 (meaning that the light we detect from it left more than 13 billion years ago) and finding many examples of the new cool T-dwarf objects. Some of the latter are amongst the coolest astronomical objects known.

While in excess of 100 scientists have contributed to the success of UKIDSS, as Survey Heads Professor Steve Warren, Professor Andy Lawrence, Dr. Alastair Edge, Dr. Omar Almaini, Professor Paul Hewett, Dr. Phil Lucas, Dr. Mike Irwin, Dr. Nigel Hambly, Dr. Richard Jameson, Dr. Simon Dye, Dr. Andy Adamson, Dr. Luca Rizzi, Dr. Watson Varicatt, Dr. Mark Casali, and Dr. Tom Kerr played the leading rôles.

For the exemplary work in these and many other areas, the UKIDSS consortium receives the 2012 RAS 'A' Group Award. [Applause.]

Dr. Ruffle. While Professor Paul Murdin has a distinguished research record in high-energy astrophysics and the properties of objects identified by early X-ray satellites and has published more than 100 refereed papers, he is best known for his outstanding contribution to astronomy in public life in three areas: as a popular author and broadcaster, as a leader of a Research Council, and as Treasurer of the RAS.

Throughout his career he has communicated the excitement of astronomy to a wide audience through authoring popular books, by radio and television broadcasting, including many appearances on *In Our Time* and *The Sky at Night*, and by his public lectures. His popularity has its roots in his clear thinking and ability to translate complex physics into everyday language.

Professor Murdin, among his many rôles, has been a President of the European Astronomical Society, Trustee of the National Maritime Museum, Head of Operations at the Isaac Newton Group on La Palma, Director of the Royal Observatory Edinburgh, as well as occupying several leading positions in the Particle Physics and Astronomy Research Council and the British National Space Centre.

As Treasurer of the Royal Astronomical Society Professor Murdin oversaw a growth in the Fellowship from about 2800, a level it had been at for some time, to 3500 at the end of his ten-year tenure. Supported by greater financial strength, the Society took on a wider advocacy rôle, representing the astronomical community more effectively to government, the public, and the

Research Councils. Professor Murdin is visiting professor at Liverpool John Moores University and was awarded the OBE in 1988.

The RAS Service Award is a richly deserved acknowledgement of his many years of work on behalf of the entire astronomical community. [Applause.]

Miss Gupta. Dr. Becky Parker has been an enthusiast for astronomy and physics throughout her career in education, work that includes time as Head of Education at the Institute of Physics. This award, though, principally recognizes her achievements at Simon Langton Grammar School, Canterbury, where she established and directs the Langton Star Centre, a specialist facility with laboratories, classrooms, and an astronomical observatory.

The *Langton Ultimate Cosmic Ray Intensity Detector*, for which Dr. Parker raised £60 000 and which is scheduled to fly on the *TechDemoSat-1* satellite, and the Langton Universe Astronomical Research programme, which has allowed pupils to discover several near-Earth asteroids, have so inspired her former pupils that they constitute no less 1% of the national cohort of physics undergraduates.

She and her pupils work across regional and national boundaries, collaborating with NASA and ESA scientists and schools in the UK and elsewhere in the world. They have particularly close links with Dr. Obote College in northern Uganda.

For her work in physics education, Dr. Parker was awarded the MBE in 2008.

Her boundless optimism, willingness to innovate and collaborate, and her enormous success make her a very fitting winner of the first Patrick Moore Medal. [Applause.]

Dr. Ruffle. The Fowler Award is given to individuals who have made a particularly noteworthy contribution to the astronomical sciences at an early stage in their career.

Miss Gupta. Dr. Hiranya Peiris, of University College London, is one of the best of her generation working on the cosmology of the early Universe. She has made very significant contributions to the *WMAP* cosmic-microwave-background project, particularly concerning constraints on the inflationary models that describe the rapid expansion of the cosmos shortly after the Big Bang. In addition, her contributions to astrophysics more broadly include the analysis of large-scale-structure data, the development of statistical methods, and the field of Galactic structure.

She has been awarded many competitive post-doctoral fellowships (Fermi, Hubble, STFC Advanced Fellowship), became a Philip Leverhulme prize-winner in 2009, and has now been appointed to the Faculty of University College London.

For her wide-ranging interests and accomplishments across a broad range of cosmology and astrophysics, Dr. Peiris is awarded the RAS Fowler Award for Astronomy. [Applause.]

Dr. Ruffle. Dr. Matt Owens, of the University of Reading, is an outstanding and prolific young scientist in the field of solar-terrestrial physics whose work has already had a major impact in revealing the secrets of the Sun's magnetic cycles. These results point to key factors controlling the variations in the output of particles and fields from the solar atmosphere that impinges on the Earth.

He is notable for a young researcher in terms of the breadth and depth of his research activity, making use of analytical and numerical models as well as observations, and tackling a wide range of important problems. He has produced an extensive body of highly-cited publications in prestigious journals. The international standing of Dr. Owens' work is further evidenced by a number of significant review talks, as well as a strong network of collaborations with leading workers in the field.

Dr. Owens' early research was mainly concerned with the global structure and dynamics of coronal mass ejections in the interplanetary medium. These massive eruptions of material and magnetic field from the Sun are known to cause major disturbances in the near-Earth space environment, and understanding their properties is of societal value, as well as being a major unsolved scientific problem.

For his impressive record of past performance and present creativity, Dr. Owens is awarded the Fowler Prize for Geophysics. [Applause.]

Miss Gupta. Dr. Tom Kitching, from the University of Edinburgh, currently holding an RAS postdoctoral fellowship, has contributed at all levels to research into understanding weak gravitational lensing, from the details of shape measurement of galaxies, through development of sophisticated analysis tools, to leadership rôles in ESA's forthcoming *Euclid* space mission that will map Dark Matter and investigate Dark Energy.

As a student, he helped to develop the new field of 3D weak lensing and with its inventor, Professor Lance Miller, is the co-creator of an algorithm that measures the distortion of galaxy images. As a result of his particular expertise he was invited to join the leading ground-based lensing survey (CFHTLenS) and the leading space-based survey (COSMOS, using the *Hubble Space Telescope*).

For these and many other achievements Dr. Kitching is awarded the Winton Capital Award in Astronomy. [Applause.]

Dr. Ruffle. Election to Honorary Fellowship of the Society recognizes outstanding service made by non-UK-based scientists to astronomical and geophysical science, such as distinguished leadership of an institution or organization or exceptional work in education or public outreach.

Miss Gupta. Professor Hiromoto Shibahashi has had a long and distinguished career in stellar astrophysics and has made very significant contributions to the theory of helio- and astroseismology. Professor Shibahashi has played an outstanding leadership rôle in astronomy, both within Japan and internationally. He has led the Department of Astronomy at the University of Tokyo for more than a decade and served as the Vice-President of the Astronomical Society of Japan as well as an editor for its *Publications*. Professor Shibahashi is currently engaged in collaborative research with UK colleagues.

In recognition of his scientific achievements and contributions to the international community Professor Shibahashi is elected an Honorary Fellow of the Society. [Applause.]

Dr. Ruffle. Professor Hermann Opgenoorth obtained his doctorate for ground-breaking research into the dynamics of three-dimensional current systems in active aurorae. A pioneer in the combination of remotely-sensed and *in-situ* measurements of the space-plasma environment, he was a key figure in the exploitation of the *European Incoherent Scatter* (*EISCAT*) radar system and chaired the European Space Agency Working Group for *Cluster* Ground-Based Coordination. He was a co-investigator for instruments on the ESA *Cluster* and *Mars Express* missions and played a major rôle in establishing the *EISCAT* Svalbard Radar.

Professor Opgenoorth has chaired *EISCAT*'s Scientific Advisory Committee, the EISCAT Council, and the International 'Living with a Star' Programme, and has worked for ESA as Head of Division for both Solar and Solar-Terrestrial and Solar System Missions.

In recognition of his scientific achievements and contributions to the international community Professor Opgenoorth is elected an Honorary Fellow of the Society. [Applause.]

The President. Thank you, Jen and Paul [applause]. Actually, looking out at the audience I can see the two people I mentioned before — Philippa Browning and Albert Zijlstra. Philippa and Albert please stand up and be recognized. Thank you very much for organizing the meeting. [Applause.] Mike Edmunds is now going to give us a talk on 'Preserving the past for the future'. Mike is the Chairman of our Astronomical Heritage Committee and is going to tell us what they have been up to.

Professor M. G. Edmunds. Thanks, Roger. Actually, I'm not going to tell you what we've been up to — I'm going to tell you what we will be getting up to! The Astronomical Heritage Committee is one of those funny — but hopefully useful — little committees that you might come across in a Trollope novel. Today I want to talk about the work of a subcommittee which has been set up and the results of whose work I hope will be reported at next year's NAM at St. Andrews.

Many of you will have seen the nice article by Professor David Hughes in the 2012 February issue of *Astronomy & Geophysics* about the British National Astronomy Museum and the Chief Curator's collection policy. You may wonder where the Astronomy Museum is situated but in fact it doesn't actually exist. David was speculating about our astronomical heritage and the vexed question of what we should keep, and how we should preserve what we have now, for the future. I recommend that you read it. I imagine that many of you have been in the position of looking around your department at a piece of equipment which you do not know what to do with, but think that it might be important. It need not be only equipment — an old book, for instance, or handwritten notes from a former head of department and so on. You go to your Head of Department (HOD) and ask very politely "What should I do with this?" [Laughter.] The main problem that confronts HODs these days is space: where to store the item in question; how do you preserve it, what do you do with it? Inevitably there will be costs associated with this. Another consideration is that if the item is valuable, then it might have to be insured.

So what can we do with it and how do we decide what to keep? How do you record that is it there? How do you conserve it? — otherwise it ends up in the skip. The sub-committee is considering the years 1900–2013 because most material before the earlier date has probably already been thrown away. This represents an era of extraordinary progress in astronomy — greater than that of any previous time. It includes some observatories — radio astronomy and space-based — and is represented by much equipment and research documents, and, not to be forgotten, memories of previous researchers — the characters we knew in our youth. How is this best recorded and made known? Museums are very important but they can only show 5% or 10% of their material at any one time. They do not have the room to take all of your material although manuscripts can be dealt with. For instance, St John's College, Cambridge, has already embarked on a project to archive the papers of Fred Hoyle.

Next year at the NAM there will be a discussion session on heritage — what do we have and what do we do with it. It will include the Science Museum, the National Museum of Scotland, and as many other organizations as we can get involved. We'd like to define a policy for the RAS which will allow us to lay out a set of guidelines for those considering this problem. We also need to sign an agreement with museums which will not result in costs for those wishing to donate. What we need to decide are: (*a*) what is and isn't valuable; (*b*) how to preserve it; (*c*) how to build up participation with museums; and (*d*) what to do with recordings of data — how to store and index them, including oral and narrative data sets. Perhaps we should consider a web-based museum, but that has its own costs. We need to compile a national register of what there is and where it is. And finally we need to decide who will pay for it. The RAS can't do it but we'd like to provide the guidelines.

The sub-committee will work on the problem of how to assess priorities. David Hughes will be a prime mover in this project so contact either him (profdwhughes@btinternet.com) or me (Mike.Edmunds@astro.cf.ac.uk) if you have any ideas. Anyone with experience will be welcome and hopefully we can preserve more of the past for the future.

The President. Do you have questions for Mike ?

Dr. B. Sathyaprakash. Mike, you mentioned a number of things, such as lottery money?

Professor Edmunds. Lottery money? Ah! Are you offering to buy a ticket for us? [Laughter.]

Dr. Sathyaprakash. It could be that I don't need to!

Professor Edmunds. I'll touch you for a loan then instead! We haven't thought about sources of funding at all yet. It sounds silly, but the Astronomical Heritage Committee one day was thinking that we have to deal with certain things that the RAS owns — we get offered things occasionally for the RAS, and so on. And we realized we just haven't got a policy, or a set of guidelines, against which to judge this sort of thing or to know what to do with it. And so it's quite early days in trying to produce that. We know these things cost money, but we haven't sat down to work out what are the possible sources of funding. Obviously, if you were applying for something like lottery money, or any other source, if you've got a structure it would be much easier. But that's for the future. Any suggestions that people have about funding or funding mechanisms will be gratefully received. Donations even more so!

Professor J. Brown. Will the remit of this group extend to big things — as big as buildings, observatory remains, and so on?

Professor Edmunds. The answer is yes, it must do! The Heritage Committee does get involved in correspondence, certainly in recommendations about particular buildings around the UK that have astronomical significance. And we do often pass comment or write letters saying "Yes, this is wonderful, please pay for it". So, yes, it will.

Dr. P. Allen. Mike, in terms of preserving modern technological things, I know there's the National Museum of Computing, at Bletchley Park. Now, they obviously are focussed on computing stuff, but they might have useful advice on what to do about preserving high-tech stuff.

Professor Edmunds. That's a very good suggestion, we'll contact them.

Dr. C. Davies. Where is the boundary between objects and data? Would you consider preserving datasets, if they were on photographic plates or photo-positives that were not available anywhere else?

Professor Edmunds. I think the answer is that we have to find out from people what they think is worth preserving, and think how that might be done. So the answer to your question is yes! But I don't know what the relative priorities are between data and objects. An object is useful because it is there. Data may be even more valuable for something in the future, particularly as you say, saving old photographic plates, which you don't know what to do with now; storage may be a real problem, but if you could get them digitized, and put them away somewhere and then you want a reference set in 50 years to see what that funny object was that's moved, then that's going to be valuable. But the RAS can't do that, nor can the Astronomical Heritage Committee. But are there mechanisms in place that would allow that to be done somewhere, and find out who is prepared to take responsibility for that? So yes, data would be just as valuable.

Professor P. A. Charles. I was actually going to make a very similar point, and add to it, that the IAU is considering this, because there are big problems at observatories around the world which have huge plate collections, which are becoming too expensive even to curate them, and they need to be converted into a permanent form. So I think your committee will have some overlap and liaisons with them.

Professor Edmunds. That's very valuable again, presumably if you could do something globally where one observatory takes responsibility for one data set and another one for another, you might be able to do something at a reasonable cost. Is it a particular Commission which is doing that, do you know?

Professor Charles. I forget which Commission; I know Elizabeth Griffin is playing a significant rôle in this, and also people like Josh Grindlay at Harvard, because Harvard is desperate to get its hands on the space currently occupied by the Harvard plate collection.

Professor Edmunds. We must obviously try and coordinate with them.

Professor Charles. They have the same problem in South Africa as well, in fact.

Professor H. Opgenoorth. I have a comment on the space age. If we send something into space, an instrument, it is usually destroyed at re-entry, or sent so far that we won't get it back anyway. But there are spare flight instruments which have a purpose: if something goes wrong in space, we can carry them into the lab and measure what might have gone wrong. Alternatively one might, from the spare instrument, be able to find a workaround for the instrument still in space, or understand what went wrong in order to avoid the problem in future. But after that, these things are usually thrown away. And in a very distant future they may be of great interest.

Professor Edmunds. Exactly — I know examples that have gone out on the skip. And as you say, you don't know — it could be quite soon that they're of interest.

Miss Alison Boyle. This is more of a general announcement: my name is Alison, I am the astronomy curator at the Science Museum, which at the moment I think is the closest thing we have to a national astronomy museum. Although as Mike said, we simply haven't got enough room to collect everything, if you are aware of things in your department that are in danger of disappearing, please come and talk to me! Obviously it might take a very long time to set up a national astronomy museum, but in the meantime there are various national museums that do collect these types of material.

Professor Edmunds. I didn't know you were there Alison! I'm sure you will be working with us on this!

Miss Boyle. Yes, hopefully!

Dr. S. Mitton. This would be a good project. It should be one of the great things that we want to achieve by the bicentenary in eight years' time.

Professor Edmunds. Excellent idea! Hopefully we'll do it sooner.

The President. That's probably a good note to call a halt to Mike's discussion. So thank you very much. We have a little bit of time before tea, which provides me with an opportunity to ask you if there are things that you would like to see us doing that we're not doing, or alternatively, are there things that we are doing, that you think we're doing incorrectly or that are a waste of time? I am happy to have input from the floor! [Silence.] Gosh that's quite an endorsement! Is there nothing you think we should be doing that we're not doing? How about lobbying for higher postdoc salaries — who'd be in favour of that? [Laughter.] So there are some things we could perhaps think about!

Dr. C. Lintott. It occurs to me that the RAS puts a lot of efforts into meetings, for NAM and also in London and elsewhere, as you said. I think we do a pretty poor job at preserving those and getting them out to a wider community. Doing things live is hard, but recording and then webcasting is relatively easy these days. I'd like to see the RAS doing a bit more of that for those of us who can't get there every month.

The President. That's a very interesting point. I believe this was tried, and there were some technical difficulties, and I don't think that the resource was widely used. But maybe somebody who knows more about this than I do, David Elliott, might be able to say something.

Mr. D. Elliott. Well, it's true — a few years ago we employed a company, who recorded the specialist meetings and ordinary meetings. We put it on the website, and the take-up was pretty pathetic. Most of the people who were interested were at the meeting itself. And so, after paying for it for a couple of years, we discontinued it. However, repeatedly, particularly from our own speakers, we do get this message, "we can't get to these meetings, we'd like to be able to see them!" There must be a low-cost way of doing this. Various people have told me about a live-broadcast tool for doing this, but so far it's work in progress. Ralph [Spencer] is sitting there, talking about video conferencing, and talking about other forms of live and recorded media.

Professor R. Spencer. Katherine Blundell at Oxford and I are not particularly happy with the current situation, and obviously we're looking into various ways in which we could use improved video conferencing in Burlington House. Usage could range from large meetings to ones like this and down to very small groups of maybe only a few people on the screen. The latter would be much easier and cheaper to do rather than large meetings. But all these things are being looked at. One of the main issues at the moment is the lack of bandwidth between Burlington House and the rest of the world. I'm sure we could improve that. In fact, we have lots of potential suppliers available. Hopefully in a month's time we should know a lot more about the way forward. We are also looking into using podcasts. I will consult with the experts at Jodrell Bank Centre for Astrophysics.

The President. Yes, that is actually an absolutely topical question, and as you can see, we are where it's a live issue: we're trying to update the hardware. Our initial goal was to enable Councillors who are not in the country to participate in Council meetings, but equally the Society has roughly one third of its members that are international. And there are many ways in which such a facility would enable them to feel more involved in what we do.

Professor Philippa Browning. I know it's nothing like a video-conference unit or anything like that, but in terms of preserving something from this meeting for people who aren't here or for those of us who are here and would like to record it, we are offering to put up an archive of people's presentations, which I think hasn't been offered before. So if you send PDFs of your posters or talks, we'll build up an archive, which will be available after the meeting, and that may go some way towards meeting what people are looking for.

The President. Thank you, Philippa.

Dr. A. Jessner. We could also try to improve the awareness of radio-astronomical-spectrum protection in the UK, and elsewhere. We're willing to help with this, but there is the view held by Ofcom that radio astronomy, whilst it's a beautiful subject and what we are all doing is really impressive, it shouldn't be done in Europe or in the UK. Far better that it is carried out in the southern hemisphere, far away from us, so that the spectrum we cover can be used for commercial purposes. I argue the academic side of it — you know, teaching, university, and all those things, but they just shrug their shoulders. I think we need to have more awareness of that, through the general public and amongst the radio astronomers themselves, so that they push us a little bit.

The President. Thank you, Axel. Protection of the radio-frequency spectrum is a very important point, and one that will start to engage us more and more. But also recently we've dealt with leap seconds, and we deal continuously with night-sky-brightness issues, which have had a lot of coverage with *Stargazing Live* and so on this year. And so I can see that these interface issues between the academic demands of our discipline, with the commercial demands of spectrum analysis and lighting car lots and so on, will increase. We need to position ourselves so that we can be there when government is looking at regulation, and at changes, so that we can push back the other way. The other thing we need to do in this area, is that although we are passionate about what we do, and it's the most important thing in most of our lives, we are actually a rather small subject, and we don't have very much economic weight. We need friends in this area, and there are potential heavy-weight friends whom we could recruit. I can see a way in which we could sponsor, for example, a Specialist Discussion meeting, on these kinds of topics, because they will increasingly impinge on our ability to do our research in our home countries, and also to inspire people to get involved. The light-pollution issue does mean that people just don't see the things that we would like them to be able to see.

Professor Brown. I would just like to encourage the RAS to continue and grow in their rôle in politics. When I started as a Fellow, which wasn't exactly yesterday, with no disrespect to the Council, the ethos was that it was not at all gentlemanly or lady-like to lash out at governments and so on, but the RAS has actually made the ghastly things which we suffered in its initial years probably a good deal less bad than they might have been otherwise. We don't want the politics to take over the Society. As a scientific society, even five to ten years ago when it all started to happen, I was a bit sceptical, because the tradition of the RAS was that we don't do that, but I'm very impressed at the stronger voice it has acquired; it is something that has to be maintained.

The President. Thank you, John! Anybody else, who'd want to give us a steer on what they think we should be doing? [Silence.] I think it's almost tea time; tea is traditionally at half past three, but it's 25 minutes past now, so thank you all very much for coming, and listening.

COOL DWARFS IN WIDE MULTIPLE SYSTEMS

PAPER 4: A COMMON-PROPER-MOTION PAIR OF TWO IDENTICAL MID-M DWARFS SEPARATED BY ABOUT 10 000 AU

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LSPM J0651+1843 and LSPM J0651+1845 are two high-proper-motion stars recently claimed to form a binary system, FMR 83, by Rica[1]. Here we characterize the system in detail, using astrometric and photometric data, and find that the pair consists of two M4 ± 1 dwarfs separated by 9500^{+6200}_{-3800} AU. With these results, FMR 83 becomes one of the very few 'ultrafragile' systems (*i.e.*, systems with very low total masses and very wide physical separations), many of which have been identified in this series of papers.

Two identical mid-M dwarfs separated by about 10 000 AU

Rica[1] presented 173 new wide binaries found in the Lépine & Shara[2] catalogue of high-proper-motion northern stars with $\mu > 150$ mas yr^{-1}. Of them, four were pairs of M dwarfs with estimated physical separations of over 5000 AU and very low total masses ($M_A + M_B < 0{\cdot}4\ M_\odot$). Here, we study in detail the most promising binary from Rica[1] for the investigation of cool dwarfs in the least-bound systems[3].

The binary itself is FMR 83, which is formed by LSPM J0651+1843 (hereafter FMR 83 A) and LSPM J0651+1845 (FMR 83 B) (see Fig. 1). *VizieR* and *Simbad* only provide their coordinates, magnitudes in the photographic blue B_J, red R_F, infrared I_N, and 2MASS *JHKs* passbands, and proper motions (identical, of about 316 mas yr^{-1}) compiled by Lépine & Shara[2]. Additionally, Rica[1] provided rough estimations of spectral type, absolute magnitude in the *V* band, distance, tangential velocity, and mass for both components. He identified the pair using data from Lépine & Shara[2], verified its common proper motion with an RGB composition of Digitized Sky Survey images built with the *Aladin* interactive sky atlas[4], and, finally, confirmed the common proper motion using two astrometric epochs separated by 3·8 yr. He estimated a projected physical separation of 9800 AU and a total mass of 0·36 $M_\odot$. Although the derived data are correct in principle, here we revisit the system for several reasons: (*i*) There are not many known binaries with such wide separations and low total masses. Indeed, it may be one of the least-bound known binaries (see Paper 1 of this series[3] and references therein). (*ii*) *V* magnitudes from Lépine & Shara[2], in the absence of *Tycho-2* V_T data, were estimated from photographic B_J and R_F magnitudes, which have in general large uncertainties (of over $0^m{\cdot}4$ in some cases). (*iii*) Spectral-type estimations from *V–J* colours, as in Lépine & Gaidos[5], have turned out to provide types that are inaccurate by one subtype on average and up to four or five subtypes in extreme cases when compared with real low-resolution spectra (Alonso-Floriano *et al.*, in preparation — the authors carry out a detailed characterization of the M-dwarf input catalogue for *CARMENES*[6]). (*iv*) Rica[1] tabulated different distances for both FMR 83 A and B (78 and 61 pc, respectively). In spite of the wide separation, if physically bound, they should be located at the same distance. (*v*) Photometrically-estimated spectral types in Rica[1] were M4 V and M4·5 V. However, magnitudes of both FMR 83 A and B are different by less than $0^{m}\cdot1$ from 0·4 to 11 μm (see below), which indicates identical spectral types.

We carried out an analysis similar to that in previous issues of this series (*e.g.*, Paper 3[7]). First, we used the imaging instrument *CAMELOT* (2k × 2k, 0·305 arcsec/px) at the 0·8-m IAC-80 telescope at Teide Observatory, Tenerife, to obtain optical images of FMR 83 AB on 2012 February 28 in the Johnson *BVRI* bands and on 2012 February 29 in the SDSS $g'r'i'z'$ bands. We used the AAVSO Photometric All-Sky Survey (APASS, http://www.aavso.org/apass) to calibrate the *B*, *V*, g', r', and i' images (the eighth data release of the Sloan Digital Sky Survey[8] did not cover the area) and the *Third US Naval Observatory CCD Astrographic Catalogue*[9] (UCAC3) to calibrate the *R* image. The *I* image was calibrated with photometric standard stars observed at different air masses. We were not able to find a zero-magnitude for calibrating our z' image, but we measured $\Delta z' = 0^{m}\cdot05 \pm 0^{m}\cdot01$ on it (A brighter than B).

Our photometry, provided in Table I, is consistent with and dramatically enhances published photographic plate- (USNO-A2 $B_J R_F$, USNO-B1 I_N) and CCD-based (CMC14 r', UCAC3 *R*) magnitudes. (Only the Carlsberg Meridian Catalogue 14[10] tabulates accurate magnitudes for both FMR 83 A and B.) We complemented our data with infrared photometry from the Two-Micron All Sky Survey[11] and *WISE* Preliminary Data Release[12] (the *WISE W1*, *W2*, *W3*, and *W4* bands correspond to 3·4, 4·2, 11·6, and 22·1 μm, respectively; tabulated magnitudes are the average of two independent measurements).

TABLE I

Basic data for FMR 83 A and B

Datum	*A*	*B*	*Origin*
Name	LSPM J0651+1843	LSPM J0651+1845	1
α (J2000)	$06^{h}\,51^{m}\,04^{s}\cdot51$	$06^{h}\,51^{m}\,00^{s}\cdot65$	10
δ(J2000)	+18° 43′ 42″·2	+18° 45′ 19″·7	10
$\mu_\alpha\cos\delta$[mas yr^{-1}]	+203±2 (+205)	+201±3 (+205)	This work (1)
μ_δ[mas yr^{-1}]	−241±2 (−241)	−242±3 (−241)	This work (1)
B [mag]	18·96±0·03	19·06±0·03	This work
g' [mag]	18·06±0·02	18·05±0·02	This work
V [mag]	17·50±0·05	17·48±0·05	This work
R [mag]	16·86±0·08	16·76±0·08	This work
r' [mag]	16·79±0·05	16·84±0·05	This work
i' [mag]	15·16±0·02	15·16±0·02	This work
I [mag]	14·49±0·10	14·42±0·10	This work
J [mag]	12·983±0·023	12·981±0·021	11
H [mag]	12·527±0·023	12·484±0·025	11
K_s [mag]	12·216±0·018	12·210±0·020	11
W1 [mag]	12·05±0·03	12·01±0·02	12
W2 [mag]	11·82±0·03	11·81±0·03	12
W3 [mag]	11·45±0·20	11·31±0·19	12
W4 [mag]	> 9·0	> 8·4	12
Phot. Sp. Type	M4: V	M4: V	This work

Next, we quantified the constancy of the angular separation during eleven astrometric epochs spread over a time interval of more than 60 years. Most of the astrometric epochs corresponded to digitized images of old photometric plates (of the Digitized Sky Survey). We did not use the STScI QuickV digitization of the 1983 January 13 plate because of its apparent astrometric offset with respect to the rest of plates. Our proper-motion determination, shown in Table I, matches that of Lépine & Shara[2] within the uncertainties. In Table II, we provide observation date, angular separation, position angle, and origin of every astrometric measurement. FMR 83 B fell between two relatively blue background sources at the end of the 1990s and early 2000s, but this fact did not affect the relative astrometry. During the observed 60·3 yr, we measured an average constant angular separation of $111''\cdot85 \pm 0''\cdot10$ arcsec ($1'\cdot86$ arcmin) and position angle of $330^\circ\cdot69 \pm 0^\circ\cdot09$, thus confirming the membership in a common-proper-motion pair of both FMR 83 A and B.

By comparing the $r'-i'$ and $i'-J$ colours of the two stars with those of M dwarfs tabulated by West *et al.*[13], we estimated a spectral type M4 ± 1 V for both FMR 83 A and B. From the apparent *J* magnitude and the absolute *J* magnitude–spectral-type relation by Caballero *et al.*[14], we conservatively estimated an heliocentric distance of $d = 80^{+60}_{-30}$ pc. At this distance, the angular separation translates into a projected physical separation of $s = 9500^{+6200}_{-3800}$ AU (10^{+6}_{-4} kAU). These values are in agreement, within error bars, with those tabulated by Rica[1]. Dwarfs of spectral type M4 ± 1 have masses of $M = 0\cdot25 \pm 0\cdot07\ M_\odot$ (A. Reiners, priv. comm.), which makes the system have a total mass of $M_{\rm total} = 0\cdot50 \pm 0\cdot10\ M_\odot$.

Finding common-proper-motion stars separated by tens of thousands of astronomical units is not extraordinary: for example, Proxima Centauri, the closest star to our Sun, is located at a physical, non-projected, separation of 12 000 ± 600 AU to α Cen A. However, the low total mass of the FMR 83 system is remarkable, about four times lower than the triple α Cen system. This makes the FMR 83 gravitational potential energy, $U_g^\star$, computed as in Caballero[15], to be as low as $-(10–12) \times 10^{33}$ J. This value is comparable to those of the exclusive trio of very wide ($s > 1000$ AU), very low-mass ($M_{\rm total} \ll 1\ M_\odot$), equal-mass ($q = M_B/M_A \sim 1$), 'ultrafragile' binaries: Koenigstuhl 1[16], 2M0126–50[17], and 2M1258+40[18]. FMR 83 and Koenigstuhl 4, another wide low-mass binary that was discussed in Paper 1[3], have slightly larger binding energies and

TABLE II

Astrometric observations of the FMR 83 AB system

Epoch	*ρ (arcsec)*	*θ (deg.)*	*Origin*
1951 Nov. 08	111·94	330·65	POSS I Blue
1951 Nov. 08	111·91	330·54	POSS I Red
1989 Nov. 03	111·72	330·66	DSS 1989·843
1990 Dec. 17	111·79	330·85	POSS II Red
1993 Nov. 28	111·92	330·75	DSS 1993·857
1993 Dec. 05	111·89	330·69	POSS II Infrared
1993 Dec. 10	112·01	330·77	DSS 1993·942
1995 Oct. 27	111·92	330·80	POSS II Blue
1997 Nov. 28	111·71	330·63	2MASS[11]
2001 Aug. 31	111·83	330·65	CMC14[10]
2012 Feb. 29	111·72	330·65	This work [*CAMELOT*]
Average	111·85±0·10	330·69±0·09	This work

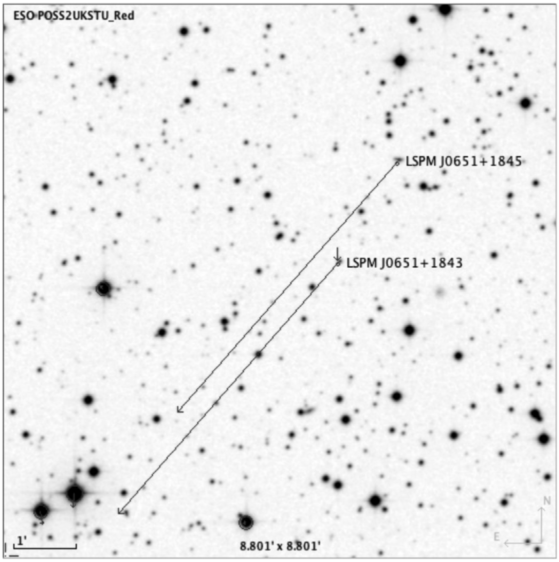

FIG. 1

Negative R_F-band image of *The Digitized Sky Survey* constructed with *Aladin* showing FMR 83 A (LSPM J0651+1843, southeast) and B (LSPM J0651+1845, northwest), which are labelled. The long arrows indicate the proper motions of stars as tabulated by *Simbad*. North is up, east is to the left. Approximate field of view is 8·8 × 8·8 arcmin^2.

higher total masses than the trio. Thus, they fill the gap in the binding-energy–total-mass diagram[15] between the fragile trio and the rest of resolved binaries of ultracool dwarfs with projected physical separations to which astronomers were used in the past.

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 226: HD 6840, HD 9996 (HR 465), HD 10332, AND HD 11571

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The four stars are all in the same part of the sky, but there their mutual resemblance ends. HD 6840 is double-lined, consisting of an unequal pair of metal-deficient late-F or early-G stars in an orbit of high eccentricity (0·744) and a period of 7·6 years that is determined to a precision of a single day. It has been resolved on the sky, and an astrometric orbit, too, is available. HR 465 is one of the most notorious 'peculiar A stars' (it is actually classified as B9p), and has extreme over-abundances of heavy elements, particularly the rare earths. Despite its early type, it gives a measurable cross-correlation with the K2-type masks in radial-velocity spectrometers, and a good orbit, with a period of 273 days and an eccentricity of 0·5, is established for it. HD 10332 and 11571 are relatively normal K-type stars with orbits of modest eccentricity and periods of about 10 and 27 years, respectively.

Introduction

The four stars are all in the same part of the sky, between 1 and 2 hours of right ascension and ranging only between 45° and 68° in declination — in Cassiopeia and immediately adjacent parts of Perseus and Andromeda. HD 6840 is the furthest north, a few degrees pole-ward of the familiar W of naked-eye stars in Cassiopeia and about 1½° preceding ψ Cas. HR 465 is specifically identified in *Norton*[1], by its variable-star identity GY And; it is some 5° north-preceding the beautiful visual triple system γ And. HD 10332 is about 5° north-preceding the Double Cluster (h & χ Per) and 2° following δ Cas; the $5^{m}\cdot8$ star 44 Cas is only about 5′ due east from it. Finally, HD 11571 is about 8° north of γ And.

HD 6840

Although this star is all-but bright enough to qualify for inclusion in the *Bright Star Catalogue*[2], and its inclusion in the *Supplement*[3] could certainly be hoped for, as far as *Simbad* is aware no *UBV* photometry has ever been obtained for it at all. Its V and $(B-V)$ have, however, been inferred from *Hipparcos*/*Tycho* measurements as $6^{m}\cdot55$ and $0^{m}\cdot55$, respectively. We are also indebted to *Hipparcos*[4] for discovering that the object is a close 'visual' binary, with components differing in brightness by about half a magnitude at a separation of $0''\cdot136$. No significant motion was noticed in the ~3-year duration of the satellite's observations. There is, in fact, photometry in a paper by Olsen[5], who found $V = 6^{m}\cdot55$, $(B-V) = 0^{m}\cdot367$ — the colour index is seriously discordant with the one derived from *Tycho* measurements. Olsen also obtained *ubvyβ* photometry.

The spectral type given for HD 6840 in the *Henry Draper Catalogue*[6] (p. 84) is G0. In 1921, not long after the relevant volume of the *HD* was published, Adams *et al.*[7], in one of the Mount Wilson catalogues of spectroscopic parallaxes, 'estimated' the type of HD 6840 to be F7 and 'measured' it as F8. The former method was the usual one of visual comparison of spectrograms of programme stars and standards, while the latter involved comparative measurements on tracings of certain pairs of lines. They considered the absolute magnitude of the star to be $4^{m}\cdot0$. Soon afterwards, Young & Harper[8], determining spectroscopic parallaxes at the Dominion Astrophysical Observatory (DAO), gave their independent assessments of the star's absolute magnitude (they identified it as Lalande[9] 1985) as $3^{m}\cdot6$ and $3^{m}\cdot5$, respectively; they classified the object as F9. A considerably later Mount Wilson listing[10] gave for HD 6840 a type of F6 and an absolute magnitude of $3^{m}\cdot5$. All those early luminosity estimates are remarkably near the truth as it is currently perceived, especially when it is recognized that they must refer to a mean of the components and cannot be expected to relate to their sum.

There was then for some 50 years an intermission of interest in such matters insofar as HD 6840 was concerned, until Abt[11], alerted privately by Olsen to the fact that the narrow-band photometry indicated that HD 6840 (among a lot of other stars) is weak-lined, obtained a 39-Å mm^{-1} spectrogram at the Kitt Peak 84-inch Cassegrain, confirming that it is a weak-lined star; he put the general type at F8 V, and noted that the metallic-line strength was equivalent to F5 but the G band to F9. Chen *et al.*[12,13] and Nissen *et al.*[14] (largely-overlapping syndicates) repeatedly published for HD 6840 a value of [Fe/H] = –0·45 that stemmed from a CCD spectrum (resolving power quoted as 40 000) obtained at the Xinglong 2·16-m coudé. Reddy *et al.*[15] obtained a very similar value of –0·43 from a spectrum of quoted resolving power 60 000 from the McDonald 2·7-m coudé. Lambert & Reddy[16], both of whom were members of the Reddy *et al.* syndicate, then published a mean (–0·44, obviously) of their value and the previous[12–14] one. None of the papers refers to the interesting fact that HD 6840 was already known from *Hipparcos* to be a binary system, so temperatures, abundances, *etc.*, determined as if it were a single star might well be misleading. Lambert & Reddy[16] actually noted specifically that the previous surveys upon which they relied "excluded spectroscopic binaries where previously known or detected in the course of the survey"; but that hardly squares with the fact that it was Tomkin, one of the members of the Reddy *et al.*[15] consortium, who kindly alerted the present writer to the fact that HD 6840 was double-lined, more than ten years before the publication of the paper[15] concerned. Nordström *et al.*[17], still treating HD 6840 as a single star, found an [Fe/H] value of –0·62. Unless duplicity is even more effective than the writer might fear in vitiating abundance studies, then, it could be admitted that HD 6840 is moderately metal-weak.

Horch *et al.*[18] were the first syndicate to report the resolution of HD 6840 by speckle interferometry. They made their first observation in 1997; it is probably not a coincidence that it was shortly after the *Hipparcos* catalogue was published. Since then, the object has been followed tolerably systematically by observers, particularly by Horch and his collaborators with the *WIYN* 3·5-m telescope and by the Balegas' group with the Russian 6-m. There is scarcely a need to give all the references here. By 2005 the speckle measurements spanned a complete revolution (they could hardly be said to *cover* it, since the whole periastron half of the orbit was represented by only one out of the total of ten observations that were then available), and the Balegas and their colleagues were able to present an orbit[19], which had a period of 7·30 ± 0·11 years.

Radial velocities and spectroscopic orbit of HD 6840

The radial velocity of HD 6840 was first measured by Adams & Joy[20] at Mount Wilson; they gave the results as a mean value from three plates, whose individual details were furnished after a lapse of nearly 50 years by Abt[21]. All three were obtained in the autumn of 1917 and agree well with one another, but are not of utility for present purposes because the double-lined nature of the spectrum was not recognized. A single measurement, obtained in 1922, was published from the Dominion Astrophysical Observatory (DAO) by Harper[22]. No other radial velocity is known to have been published for the system, although Nordström *et al.*[17] recorded that there were 36 measurements in the data base in Geneva of Haute-Provence (OHP) *Coravel* observations. They would include the 19 that were obtained by the present author with that instrument, but it would appear that he was not the only observer with an interest in the star.

When Tomkin 'sold' me HD 6840 it was immediately placed on the Cambridge spectroscopic-binary observing programme, which at that time (1993) was being carried out at OHP on a guest-observer basis in the absence of a functional instrument at home. Nineteen measurements, 12 of which were reduced as double-lined, were obtained at OHP, and a further 75 have been obtained with the Cambridge *Coravel*. For a long time after the observations on the home site began — for the first 15 observations — the object appeared to be single-lined. In fact it has such an eccentric orbit (and quite modest velocity amplitudes) that the radial-velocity traces *look* double-lined only for about one-tenth of the orbital period. Once the traces had been seen double-lined and the individual profiles of the two 'dips' were known, it became possible (by imposing the known profiles upon the solutions) to reduce all but one of the subsequent ones in such a way as to give two velocities. An example of a double-lined trace, obtained near the favourable node when the velocity separation of the components was near its maximum, appears as Fig. 1. It might well be possible, now that the two dip shapes are known, to salvage some of the first 15 traces that appeared to be (and were treated as) single, but because their phases have since come round again and the relevant traces (better integrated than the first set) have been 'split', there is no great incentive to try to do that. All the data from the two *Coravel*s are set out in Table I; the OHP velocities have been subject to the usual adjustment of +0·8 km s^{-1}, while the Cambridge ones have been adjusted by –0·4 km s^{-1} from the 'as reduced' values.

In the solution of the orbit it has been found appropriate to attribute half-weight to the OHP observations in comparison with the Cambridge ones, and (multiplicatively) to weight the secondary velocities one-fifth with respect

TABLE I

Radial-velocity observations of HD 6840

Except as noted, the sources of the observations are as follows:
1993–1998 — Haute-Provence Coravel (wt. ½); 1999–2004 — Cambridge Coravel (wt. 1)
Single-lined observations were not utilized in the orbit but are plotted in Fig. 2.

Date (UT)		MJD	Velocity Prim. km s⁻¹	Velocity Sec. km s⁻¹	Phase	(O–C) Prim. km s⁻¹	(O–C) Sec. km s⁻¹
1993	Feb. 10·81*	49028·81	−8·9	−10·9	0·680	+0·3	−1·0
	Mar. 18·78*	064·78	−9·1	−10·5	·693	+0·3	−0·8
	July 8·11*	176·11	−10·1	−8·6	·734	0·0	+0·4
	Dec. 25·89*	346·89	−11·3	−7·1	·797	+0·1	+0·4
1994	Feb. 19·77*	49402·77	−11·6	−5·9	0·817	+0·4	+1·0
	Aug. 2·11	566·11	−13·9	−5·5	·877	+0·4	−1·1
	Dec. 12·84	698·84	−17·2	−0·2	·926	+0·5	+0·4
1995	Jan. 3·79	49720·79	−17·4	+2·2	0·934	+1·1	+1·9
	June 7·12	875·12	−27·8	+9·5	·991	−0·3	−0·8
	Dec. 31·83	50082·83	−6·4	−13·0	1·067	+0·3	−0·3
1996	Mar. 29·79	50171·79	−6·0	−13·9	1·100	−0·4	0·0
	Apr. 24·83	197·83	−6·0	−15·6	·109	−0·5	−1·5
	Nov. 18·89†	405·89	−7·7		·186	—	—
	Dec. 4·79†	421·79	−7·7		·192	—	—
	16·82	433·82	−7·7		·196	—	—
1997	Jan. 24·81	50472·81	−7·8		1·210	—	—
	Mar. 6·80	513·80	−7·3		·225	—	—
	Apr. 25·82	563·82	−7·9		·244	—	—
	July 21·12	650·12	−8·3		·276	—	—
	Sept. 10·02	701·02	−8·4		·294	—	—
	Dec. 20·88	802·88	−7·8		·332	—	—
1998	July 10·12	51004·12	−8·4		1·406	—	—
1999	Dec. 19·84	51531·84	−8·5		1·599	—	—
2000	Feb. 28·77	51602·77	−8·7		1·625	—	—
	July 21·12	746·12	−9·7		·678	—	—
	Aug. 29·04	785·04	−9·7		·692	—	—
	Oct. 9·05	826·05	−9·5		·708	—	—
	Dec. 1·94	879·94	−9·5		·727	—	—
2001	Feb. 6·86	51946·86	−10·0		1·752	—	—
	July 16·12	52106·12	−10·7		·810	—	—
	Sept. 30·03	182·03	−11·0		·838	—	—
	Oct. 19·02	201·02	−11·4		·845	—	—
	Nov. 9·95	222·95	−11·0		·853	—	—
	Dec. 14·90	257·90	−11·4		·866	—	—
2002	Jan. 24·85	52298·85	−14·9	−5·3	1·881	−0·4	−1·2
	Feb. 16·82	321·82	−14·8	−3·1	·890	+0·2	+0·5
	Mar. 7·82	340·82	−15·5	−3·0	·897	−0·1	+0·2
	June 23·08	448·08	−18·5	−0·1	·936	+0·3	−0·7
	July 27·09	482·09	−20·5	+1·7	·949	−0·1	−0·7
	Aug. 29·12	515·12	−22·4	+3·8	·961	0·0	−0·8
	Sept. 27·07	544·07	−24·7	+7·4	·971	−0·1	+0·4
	Oct. 18·05	565·05	−26·6	+9·0	·979	−0·4	+0·2
	Nov. 10·98	588·98	−27·6	+10·2	·988	−0·1	0·0
	Dec. 4·94	612·94	−26·6	+8·3	·997	+0·1	−1·0
	11·07	619·07	−25·8	+9·1	·999	+0·2	+0·6

TABLE I (*concluded*)

Date (UT)			MJD	Velocity Prim. km s⁻¹	Velocity Sec. km s⁻¹	Phase	(O–C) Prim. km s⁻¹	(O–C) Sec. km s⁻¹
2002	Dec.	17·76	52625·76	−25·1	+8·0	2·001	−0·2	+0·6
		19·82	627·82	−24·2	+6·9	·002	+0·4	−0·1
2003	Jan.	4·76	52643·76	−21·6	+3·0	2·008	−0·2	−0·5
		11·87	650·87	−19·9	+1·2	·011	0·0	−0·6
		23·87	662·87	−17·4	−0·9	·015	+0·1	0·0
	Feb.	1·80	671·80	−15·7	−2·5	·018	+0·2	+0·1
		13·85	683·85	−14·4	−4·2	·023	−0·4	+0·5
		18·86	688·86	−12·9	−4·6	·024	+0·4	+0·8
	Mar.	14·79*	712·79	−11·6:	−6·3:	·033	−0·8	+1·9
	June	11·08*	801·08	−6·6	−13·3	·066	+0·2	−0·7
	July	14·09	834·09	−6·4	−14·2	·078	−0·2	−0·9
	Aug.	20·11	871·11	−5·7	−14·4	·091	+0·1	−0·7
	Sept.	18·12	900·12	−5·6	−14·1	·102	0·0	−0·1
	Oct.	18·03	930·03	−5·6	−14·8	·113	−0·2	−0·7
	Nov.	27·94	970·94	−5·2	−14·5	·128	+0·1	−0·2
2004	Jan.	9·79	53013·79	−4·9	−14·5	2·144	+0·3	−0·1
	Feb.	25·83	060·83	−5·0	−15·1	·161	+0·2	−0·7
	July	3·09	189·09	−5·7	−14·9	·208	−0·4	−0·6
	Aug.	31·07	248·07	−5·5	−14·6	·230	−0·1	−0·4
	Sept.	26·07	274·07	−5·2	−14·6	·239	+0·2	−0·4
	Oct.	26·01	304·01	−5·3	−14·6	·250	+0·2	−0·5
	Dec.	17·88	356·88	−5·4	−14·2	·270	+0·2	−0·2
2005	Aug.	11·13	53593·13	−5·7	−13·5	2·357	+0·4	−0·1
	Oct.	26·99	669·99	−6·0	−13·8	·385	+0·3	−0·6
2006	Jan.	28·78	53763·78	−6·6	−13·4	2·419	0·0	−0·5
	Mar.	6·79*	800·79	−7·1	−12·1	·433	−0·4	+0·7
	July	29·13*	945·13	−6·2	−12·6	·486	+0·9	−0·3
	Sept.	30·11*	54008·11	−6·9	−12·9	·509	+0·4	−0·8
	Nov.	28·00*	067·00	−7·4	−12·8	·531	+0·1	−1·0
2007	Aug.	1·12*	54313·12	−8·3	−10·7	2·621	+0·2	+0·1
2008	Aug.	13·14*	54691·14	−11·2	−6·7	2·760	−0·6	+1·7
	Oct.	17·00*	756·00	−11·4	−6·1	·784	−0·3	+1·8
	Dec.	6·99*	806·99	−12·3	−5·5	·803	−0·7	+1·8
2009	Feb.	3·80*	54865·80	−12·8	−5·2	2·824	−0·6	+1·5
	Aug.	12·11	55055·11	−15·0	−3·7	·894	+0·2	−0·3
	Sept.	10·10	084·10	−15·6	−3·0	·904	+0·3	−0·4
	Oct.	13·01	117·01	−17·1	−2·1	·917	−0·3	−0·5
	Nov.	20·96	155·96	−17·8	+0·2	·931	+0·4	+0·3
	Dec.	20·87	185·87	−19·3	+0·9	·942	+0·2	−0·5
2010	Jan.	26·78	55222·78	−21·8	+3·4	2·955	−0·3	−0·2
	Mar.	4·81	259·81	−23·7	+7·0	·969	+0·4	+0·6
	June	24·09	371·09	−20·4	+1·5	3·010	−0·1	−0·7
	July	30·12	407·12	−13·7	−4·8	·023	+0·1	+0·1
	Aug.	24·14*	432·14	−11·4	−5·9	·032	−0·4	+2·1
	Sept.	17·13	456·13	−9·6		·041	—	—
	Dec.	8·96	538·96	−6·4	−13·7	·072	+0·1	−0·7
2011	Sept.	13·07	55817·07	−5·1	−13·9	3·174	+0·1	+0·5
	Nov.	27·95	892·95	−5·1	−14·1	·202	+0·2	+0·2

* Close blend — weight halved.
† Observed with Cambridge *Coravel*.

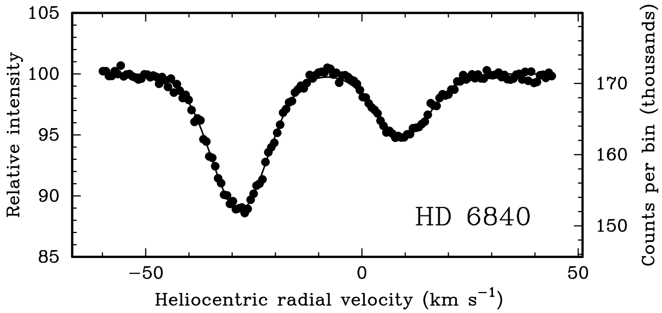

FIG. 1

Radial-velocity trace of HD 6840, obtained with the Cambridge *Coravel* on 2002 November 10, within just a few days of the nodal passage when the velocity separation between the components is as large as it can ever become.

to the primary ones. It is hardly surprising that velocities derived from close blends have statistically larger residuals than the rest; those obtained when the (computed actual) velocity difference between the components was less than 6 km s^{-1} have had their weights halved. Also, a pair of Cambridge measurements noted as sub-standard at the time of observation and identified with colons in Table I have been given half the weight that they would otherwise have had. On that basis the orbit that is illustrated in Fig. 2 is obtained; its elements are presented in Table II, with the corresponding elements (where they exist) from the astrometric orbit by Balega *et al.*[19].

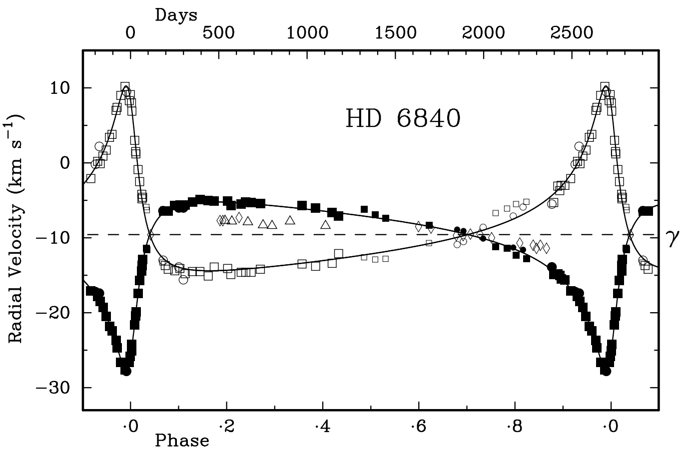

FIG. 2

The observed radial velocities of HD 6840 plotted as a function of phase, with the velocity curves corresponding to the adopted orbital elements drawn through them. Filled squares and circles denote measurements of the primary star with the Cambridge and Haute-Provence (OHP) *Coravels*, respectively; corresponding open symbols plot the secondary. The OHP measures were half-weighted in the orbital solution, and (multiplicatively) the secondary observations were given one-fifth the weight of the primary. Similar but smaller symbols plot similar observations that were made when the components' signatures in the observed radial-velocity traces were closely blended together; their weightings were halved in the solution of the orbit. Open diamonds and open triangles plot observations made at Cambridge and OHP respectively, but reduced as single-lined and not useable in the solution.

TABLE II

Orbital elements for HD 6840

Element	*This paper*	*Balega et al.*[19]
P (days)	2722·0 ± 1·0	2666 ± 40
T (MJD)	52622·2 ± 0·9	49976 ± 40
γ (km s^{-1})	−9·57 ± 0·04	
K_1 (km s^{-1})	11·18 ± 0·06	
K_2 (km s^{-1})	12·34 ± 0·12	
q	1·104 ± 0·012	
e	0·7442 ± 0·0020	0·720 ± 0·008
ω (degrees)	215·2 ± 0·5	219·1 ± 1·4
$a_1 \sin i$ (Gm)	279·4 ± 1·9	
$a_2 \sin i$ (Gm)	308 ± 3	
$f(m_1)$ ($M_\odot$)	0·1176 ± 0·0023	
$f(m_2)$ ($M_\odot$)	0·158 ± 0·005	
$m_1 \sin^3 i$ ($M_\odot$)	0·574 ± 0·014	
$m_2 \sin^3 i$ ($M_\odot$)	0·520 ± 0·010	
R.m.s. residual (wt. 1) (km s^{-1})	0·27	

The two values of T in the table above do, of course, refer to different epochs of periastron; if the astrometric epoch is brought forward one cycle by the addition of the astrometric period, it becomes MJD 52642 ± 57, only about a third of its standard deviation from the spectroscopic value (which is obviously very much more precise). The other quantities that can be compared could be considered to be in tolerable agreement, though not within the standard errors of their respective differences. The two values of ω *ought* to differ by 180°, owing to differences in the way in which the spectroscopic and astrometric quantities are defined: in the former case, ω is the longitude of periastron in the orbit of the primary, but astrometrically it refers to the position of the secondary star when it is at periastron in its orbit, relative to the position of the primary which is taken as the fixed origin of the measurements. The speckle measurements upon which the orbit is based probably have a quadrant ambiguity and should all be reversed.

A value for the mass ratio (though no orbit) has been given in Nordström *et al.*'s[17] Table 2, which is not accessible even in the electronic version of their paper but resides in a computer at the CDS; it is 0·990 ± 0·020, in serious disagreement with the 1·104 ± 0·012 found above, even when the discrepancy is slightly reduced by taking the reciprocal. The ratio is believed to have been obtained by what is known* as Wilson's method and may not be as reliable as the one found here from the orbital elements.

The factor $\sin^3 i$ that appears in the masses derived from the spectroscopic orbit (Table II above) can be eliminated in the light of the orbital inclination of 54°·7 ± 1°·5 found astrometrically[19]. From that inclination, $\sin i$ is found to be 0·816 ± 0·015, and its cube is 0·543 ± 0·030. Substituting that value in the expressions $m_{1,2} \sin^3 i$ in Table II, we obtain the masses of the two stars as 1·06 and 0·96 $M_\odot$, with uncertainties that are about 6% in each case and are dominated by the uncertainty in the inclination.

The Washington Double-Star (WDS) data base lists 14 measurements of the magnitude difference between the components; they range from the 0^{m}·47 found by *Hipparcos* up to 0^{m}·96, without any obvious systematic dependence

*Wilson did indeed publish a paper[23] describing the method, but omitted to refer to Joy[24], who had used just the same method previously.

on the wavelength of the assessment; they are concentrated in the middle of the range, close to $0^{m}\cdot75$, where also those with the smallest claimed uncertainties are to be found. A somewhat independent assessment can be made here from the relative areas of the two dips seen in resolved radial-velocity traces such as that of Fig. 1; the mean ratio is 0·48 to 1, which is arithmetically equivalent to a Δm of $0^{m}\cdot80$. According to a 'rule of thumb' adopted previously[25], the difference in V magnitude should be 1·15 times the Δm corresponding to the ratio of dip areas, giving $\Delta V \sim 0^{m}\cdot92$ — provided that the stars can be assumed to be a normal pair of main-sequence stars. That may be a somewhat risky assumption in view of the reports of significant metal-deficiency, but those reports themselves were based on the implied (but false) assumption that they were dealing with a single star. The $0^{m}\cdot92$ value is distinctly discrepant with the majority verdict of the direct estimates, whose lack of clear dependence upon wavelength may indicate that the component stars in HD 6840 are of similar colour, in which case the plain ratio of dip areas, $0^{m}\cdot80$, would be appropriate, and would also be in satisfactory agreement with the direct estimates. In the absence of actual spectroscopy it is not possible to adjudicate on that issue (and even if spectra were available it would be difficult).

The revised[26] *Hipparcos* parallax puts the distance modulus of HD 6840 at $3^{m}\cdot69$ and the absolute magnitude of the whole system at $2^{m}\cdot86$. With a magnitude difference near $0^{m}\cdot8$, the individual stars must be close to $3^{m}\cdot3$ and $4^{m}\cdot1$. If they were a normal main-sequence pair their types would have to be near to F4/5 and F8/9. It seems possible, if they are old, metal-weak stars — and it would be consonant with the lack of clear colour-dependence of their Δm and with the F8 classification of the system as a whole — that they have quite similar colours, and that the primary star has made a significant start on its evolution and is now something like three-quarters of a magnitude above the main sequence; its mass, however, which has been computed above at $1\cdot06 \pm 0\cdot06\ M_{\odot}$, is by no means excessive for a star of its supposed type. It must be easy to classify metal-weak stars as being earlier in type than they really are, and their colours must tend to be misleading in the same direction. There is probably nothing that is known about HD 6840 that would conflict seriously with the idea that it is a pair of early-G stars with luminosities (particularly in the case of the primary) somewhat raised by the early stages of evolution away from the main sequence.

**HR 465* (*HD 9996, GY Andromedae*)

HR 465 is a notoriously extreme Ap-type star, hot enough in fact to have been classed[27] as B9p, with the annotation (Cr,Eu); that is the type listed in the *Bright Star Catalogue*[2]. No classification could really do it justice, however, since HR 465 is one of those early-type stars whose spectra are crammed with lines that are not ordinarily seen, of elements whose abundances are orders of magnitude higher than in normal stars. In those respects HR 465 is right up there with Przybylski's star[28] (HD 101065) and α^2 CVn. Its oddity appears first to have been recognized, in part at least, by Zirin[29], and was soon seized upon by Bidelman, who had an insatiable interest in peculiar stars.

There has been much discussion about elemental abundances in HR 465 and the reasons for them, so much that only a brutally abbreviated summary can be

*The section on this star is dedicated to the memory of Prof. William P. Bidelman, stellar spectroscopist *par excellence*.

given here. The consensus, to the extent that there *is* one, seems to be that the iron-group elements are enhanced by a factor of order ten over normal stellar abundances, Sr and Zr are up by a factor of a thousand, and the rare-earth enhancements range from there up to perhaps 10^5 — although only on one side of the star! Such numbers were first promulgated by (Margo F.) Aller[30], who made a model-atmosphere analysis of the star in 1972, on the basis of 2-Å mm^{-1} plates taken at the Lick coudé in 1960–69 by her father-in-law Lawrence Aller and by Bidelman, an interval in which the rare-earth lines started particularly strong and then declined. It seems to be accepted that the basic reason for the anomalous abundance enhancements in the Ap stars and their ilk arises[31] from diffusion in a highly stable atmosphere, without convectional and rotational-circulation currents that are enough to negate a slow process that is driven by radiation pressure, acting most effectively on relatively rare species and counter-intuitively pushing even heavy ones out to the top of the atmosphere. The process operates at a characteristic speed only of the order of a millimetre a minute, but even so it can stratify an otherwise quiet Ap atmosphere in a time of something like 10^4 years. A strong magnetic field is helpful in stabilizing the atmosphere, and is also capable of directing the flow of radiation-driven atoms and ions towards particular areas of the stellar surface.

Bidelman, characteristically, took a great interest in HR 465 at an early date; he identified Pd and Hg in its spectrum[32] in addition to many other unusual elements which had only rarely been seen in other stars, and in a conference address in 1967 he remarked[33] that its spectrum (of which an illustration accompanies the report) is "simply loaded with rare earth elements" and is "about as complicated as stellar spectra ever get". Ultimately, in collaboration with others, he published[34] a massive (80-page) list of absorption lines in the region λλ3180–4731 Å, with identifications for the great majority of the lines. Dworetsky[35] identified Pt in HR 465, and Cowley & Hartoog[36] U, with an over-abundance of a factor of a million! Aller & Cowley[37] suggested that promethium could be identified in the spectrum; if so, it would really 'put the cat among the pigeons', because the longest-lived isotope has a half-life of only 18 years, so the element would have to be being made *in situ* and in 'real time', as one watches, on the surface of the star. They met opposition from Wolff & Morrison[38] and from Havnes & van den Heuvel[39], to which they responded[40,41] in slightly half-hearted fashion. Comparatively recently the question has been re-opened by Cowley *et al.*[42], who offered evidence from wavelength-coincidence statistics that would seem rather compelling if the conclusion that it supported were a more likely one. (Inevitably, the unbeliever will ask why it is necessary to appeal to statistics and *why can he not be shown the exact lines that are being attributed to the element in question?*. But then Fivet *et al.*[43], who had the advantage of far-UV spectra where some of the strongest lines of Pm lie, set out to supply just that lack; their published tracings of the relevant sections of the spectrum, however, have the reverse effect to what was probably intended and leave (at least) the present writer altogether convinced that there is no case in favour at all!)

Another extraordinary characteristic of HR 465 is that its spectrum changes on a long time-scale. In a short but incisive paper in 1970, Preston & Wolff[44] demonstrated major changes in the spectrum, accompanied by variations in the strong magnetic field that Babcock[45,46] had previously demonstrated to exist in the star, and also in its brightness. The changes appeared to have a period of about 23 years, which has subsequently been fully vindicated. The strength of the rare-earth lines varied conspicuously during the cycle; curiously, lines of chromium, particularly, among the iron-peak group of elements, varied almost in anti-phase with them. Babcock[45] also definitely showed the star to be a spectroscopic binary, though that had already been proposed, but without complete certainty, by Harper[47] in 1938 and by (R. E.) Wilson & Joy[48] in 1950. Preston & Wolff[44] rounded out their paper by presenting a preliminary spectroscopic orbit for the object. They gave the data (described in more detail below), and a graph of the orbit, but owing to the phase distribution being less than ideal they did not provide actual elements although they determined the period as 273·2 days.

The photometric changes during the 23-year cycle range over a little more than $0^{m}·1$ and prevent exact photometry being quoted here, but representative values are $V \sim 6^{m}·35$, $(B-V) \sim 0^{m}$, $(U-B) \sim -0^{m}·1$. It was probably Abt & Golson[49] who in 1962 first demonstrated slight photometric variability in HR 465. On their evidence Kukarkin *et al.* gazetted the star in the *60th Name-List of Variable Stars*[50] as GY And (but only after an 'induction period' of 13 years, during which time several previous name-lists had been promulgated, so probably the naming authorities bided their time until confirmatory evidence of variation had accrued). Slight variability is apparent in the *Hipparcos* 'epoch photometry', in which there was suggested (ref. 4, **11**, p. P2) to be a period of 39·76 days, of character 'ACV' (α^2 CVn: arising from rotation of a star with azimuthal inhomogeneities). The proposed light-curve, showing the 90 data points folded on that period, is plotted in **12**, p. A29, but does not appear at all convincing. It is only fair to record, however, that Rakosch & Fiedler[51] had already proposed a period in the range 35–40 days, most probably 36·5 days, as long ago as 1978.

The rotational velocity of HR 465 has been referred to a number of times in the literature. Although the amazing elemental abundances have been ascribed to diffusion in an atmosphere that is rotating only slowly, the four values of $v \sin i$ noted in the *Simbad* 'measurements' section range from 20 to 50 km s^{-1}. The two largest values are not original but are to be found merely in secondary sources. The two original ones are fairly recent (1995 and 2002) and both come from spectra obtained on CCDs with the 'coudé feed' telescope and the spectrogaph of the Kitt Peak 84-inch reflector. Abt & Morrell[52] found $v \sin i = 23$ km s^{-1} from spectra at 10 Å mm^{-1}, and subsequently Abt, Levato & Grosso[53], from material at 7 Å mm^{-1}, gave the rate as 20 km s^{-1}. Such values may not sit comfortably with the idea of diffusional stratification of the elements in the atmosphere, and are certainly incompatible with the explanation of the apparent cyclical abundance changes in terms of a 23-year rotation period, although the 273-day orbit also may represent a difficulty for that hypothesis. Preston[54] found $v \sin i \leq 5$ km s^{-1} from coudé spectra; Carrier *et al.*[55] derived a value of $2·0 \pm 1·7$ km s^{-1} from observations with the OHP *Coravel*.

Radial velocities and spectroscopic orbit of HR 465

There are several papers in the literature giving radial-velocity measurements for HR 465, of which three even offer orbits — but the aim in this present paper is to improve on them. First, Harper[47] gave seven measurements from spectra taken at 30 Å mm^{-1} at Hγ on the 72-inch DAO reflector. He noted, "An α Cygni type of spectrum and strongly suspect it is a binary." The reference to α Cyg may have been intended to convey an impression of the sharpness of the lines, probably the Balmer lines, whose narrowness would normally be an indication of high luminosity. The parallax[26], however, demonstrates that HR 465's absolute magnitude is about $+0^{m}·3$, with an uncertainty of about a quarter of a magnitude — exactly what would be expected for a star of type B9 V. Next, Young[56], on the basis of six spectra, probably of 33 Å mm^{-1} at Hγ, taken at the David Dunlap Observatory 74-inch Cassegrain, gave just a mean velocity of +5·0 km s^{-1} with a 'probable error' of 3·3 km s^{-1}. A note tells us that the range of the six measurements was 31 km s^{-1}; evidently that was still not enough to warrant an assertion that the velocity was variable, although an asterisk flags it up as "showing a somewhat larger range than the agreement of the lines would lead one to expect". (It is difficult to avoid thinking that the cross-correlation method has been beneficial!) Analogously, Wilson & Joy[48], in a tabulation from Mt. Wilson, gave a mean and 'probable error' of $-1{\cdot}6 \pm 2{\cdot}2$ km s^{-1}, from four plates, and because they did not agree as well as might be hoped they gave the four individual velocities (but still no dates) in a footnote. The note adds, "Fine spectrum; velocity is probably variable." The dates, and the dispersions (which ranged from 10 to 70 Å mm^{-1}), of the four plates were eventually divulged by Abt[21]. The Mt. Wilson authors, too, were misled by the character of the lines into thinking that HR 465 is a high-luminosity star: they classified it as 'cA0'.

Next, in 1958, Babcock, who acknowledged that he had been alerted to HR 465 by Sanford, reported[45] that "the principal metallic lines are very sharp and deep, but there are large numbers of weak, shallow lines". He went on to say that he had taken six [Mt. Wilson/Palomar coudé] spectrograms but had measured only two; he gave the velocities from them, differing by no less than 18 km s^{-1}, and remarked with studied under-statement that "The range in velocity suggests that the star must be a spectroscopic binary." In another paper[46] published in the same year he claimed explicitly to have *discovered* the binary nature of the object.

Fehrenbach[57] included HR 465 among a lot of stars for which he (with collaborators) published radial velocities obtained by his objective-prism technique, which has not proved to be particularly reliable. The mean velocity from eight plates was listed as -21 km s^{-1}, with quality 'A', which was supposed to mean 'probable error' $< 2{\cdot}5$ km s^{-1} — but that velocity is some 15 km s^{-1} lower than is ever actually reached by HR 465. The star was classified from the objective-prism plates as A2 II — again, a huge over-estimate of its luminosity. At much the same time Palmer *et al.*[58] published five velocities, given individually with dates, but not much more reliable than Fehrenbach's, from prismatic spectra of 120 Å mm^{-1} taken with the *Yapp* 36-inch reflector at Herstmonceux.

In their 1970 paper, Preston & Wolff[44] provided a list of 34 radial velocities, mostly from the Mt. Wilson, Palomar, and Lick coudé spectrographs. They identified the orbital period as 273·2 days and plotted the velocity data folded on that period; the result looks exactly like an orbit, but owing to poor coverage of the sharp maximum of velocity they refrained from computing actual elements, preferring instead to draw a 'freehand curve' through the points and declaring that its shape corresponds to that of an orbit with $e \sim 0{\cdot}4$ and $\omega \sim 0$. In 1978 Scholz[59] utilized Preston & Wolff's velocities and listed a further 26 of his own, obtained with the 2-m Tautenburg reflector, mostly at 8 Å mm^{-1}; he gave orbital elements, but (considering the phase coverage near maximum velocity still to be deficient) did not specify their uncertainties. The same author[60] later gave 17 additional radial velocities, 12 of which were made in one five-day observing run (probably, it seems, on the 2-m telescope of the Rozhen Observatory in Bulgaria, but the paper is not at all explicit on that question). The intention was to look for short-term radial-velocity variations, which did not in fact manifest themselves.

Stickland & Weatherby[61] published for HR 465 two radial velocities obtained at 8·6 Å mm^{-1} with the *Isaac Newton* telescope while it was yet at Herstmonceux, as part of a more general programme on stars that showed the Hg II line at λ3984 Å.

To watch for the suspected long-term (23-year) rise and fall of the rare-earth spectra in HR 465, Rice[62] made annual observations in 1977–85 with the DAO 1·2-m telescope and coudé spectrograph at 2·5 Å mm^{-1}; he published 11 radial velocities, the observations in just two of the years being duplicated.

The most recent publication of radial velocities of HR 465 appears to be that of Carrier *et al.*[55], who credit Preston & Wolff[44] with discovering its binary nature. They give 43 measurements made with the OHP *Coravel*, and derive from them an orbit, without making any effort to avail themselves of any of the other data (some of which are of much higher quality) already in the literature. They seem a trifle scathing of the performance and forbearance of their predecessors, in comparison with their own excellence: "The duplicity of this B9 CrEuSi (Osawa 1965) star has first been detected by Preston & Wolff (1970) who found an orbital period of 273 days. They did not attempt to determine the orbital elements because of the poverty of the data. Scholz (1978) tried to determine the orbital elements, but the shape of the velocity curve in the vicinity of the maximum remained ill-defined. The 43 CORAVEL measurements (Table 1) confirm the 273-day period. Thanks to the precision and homogeneity of the data, our velocity curve is more precise than the one based on the data gathered by Preston & Wolff (1970) and Scholz (1978), so that a satisfactory determination of the orbital elements is possible." They are obliged, however, later to refer to "The rather large rms scatter of the residuals (1·24 km s^{-1}) ..." (it is actually given as 1·33 km s^{-1} in their Table A.1).

HR 465 was placed on the Cambridge radial-velocity programme at the explicit request of Dr. W. P. Bidelman, made in a letter dated 1994 February 24. Dr. Bidelman had a totally amazing encyclopaedic knowledge and recall of the nature and properties of innumerable stars, many of them (such as HR 465) being bizarre objects, and many of *them* were his own discoveries. It is of course a matter of regret that this publication of its orbit has been so long in gestation that he is no longer in a position to read it, at least in the normal way, although he did receive one or two progress reports.

With a spectral type of B9p, HR 465 was far earlier than any other star that had been observed with photoelectric radial-velocity spectrometers, which mostly utilized masks that were designed by reference to the spectrum of Arcturus (K2 III). Nevertheless HR 465 proved to give a significant cross-correlation signature, exemplified here in Fig. 3; it may be supposed that there remain enough vestiges of lines of neutral atoms in the B9p spectrum, and/or there are enough counterparts of ionic lines in the K2 mask, to produce a usefully measurable 'dip' in the cross-correlation function. Naturally the dip is quite shallow (about 3% of the 'continuum', whereas a late-type giant gives a depth of 30% or more), but the star is bright and there is no difficulty in obtaining a trace with enough *S*/*N* to be measured with somewhere near the same sort of precision as stars of types more appropriate to the photoelectric instruments. Initially the writer's measurements were made with the *Coravel* at OHP, but later the programme was transferred back to the Cambridge home site when a somewhat analogous instrument became available on the 36-inch telescope there. Altogether 14 measurements were made of HR 465 at OHP and 67 at Cambridge; they form the final tranche of data in Table III.

For the determination of the orbit, we have an almost embarrassing wealth of material, but the fact that it comes from about a dozen different sources, of very different characters and reliabilities, warrants some careful weeding and weighting. First, it is noted that the observations of Young[56] and Fehrenbach[57] cannot in any case be utilized because they were never specified individually;

TABLE III

Radial-velocity observations of HR 465

Except as noted, the sources of the observations are as follows:
1948–1969 — Preston & Wolff[44] *(wt.1); 1972–1976 — Scholz*[59] *(wt.1);*
(the timings of those series are actually given only to 0·1 day);
1980–1993 — Carrier et al.[55] *(wt. 1/10); 1994–1998 — OHP Coravel (RFG) (wt. 1/4);*
1999–2012 — Cambridge Coravel (weight 1)

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
1948 Nov. 10·20*	32865·20	−4·1	0·384	+0·5
23·20*	878·20	−5·9	·431	−1·5
Dec. 19·20*	904·20	−3·6	·527	+0·1
1949 July 19·40*	33116·40	−4·0	1·304	+0·4
Dec. 6·10*	256·10	+6·4	·816	+2·3
1956 Sept. 26·40	35742·40	+14·4	10·929	+0·2
1965 Aug. 17·40	38989·40	+4·8	22·830	−0·2
19·40*	991·40	+5·9	·838	+0·4
1966 July 27·50*	39333·50	+2·6	24·092	−1·3
31·50*	337·50	+2·4	·106	+0·1
Aug. 2·40	339·40	+1·7	·113	0·0
5·50	342·50	+0·6	·125	−0·2
6·50	343·50	+0·9	·128	+0·4
Oct. 2·30	400·30	−3·9	·336	+0·7
4·50	402·50	−4·0	·344	+0·6
Nov. 24·20*	453·20	−4·2	·530	−0·6
26·30*	455·30	−3·5	·538	0·0
27·10	456·10	−3·5	·541	0·0
30·10	459·10	−3·5	·552	−0·1
1967 Jan. 2·10	39492·10	−1·2	24·673	0·0
Aug. 18·50	720·50	−3·6	25·510	+0·3
26·50	728·50	−3·2	·539	+0·3
Oct. 13·40	776·40	−0·2	·715	−0·1
1968 Aug. 16·40	40084·40	+5·8	26·844	−0·1
1969 Aug. 26·40	40459·40	−3·3	28·218	0·0
Oct. 30·10	524·10	−4·7	·455	−0·4
Nov. 21·30	546·30	−4·1	·537	−0·5
24·40	549·40	−4·8	·548	−1·4
Dec. 21·10	576·10	−1·4	·646	+0·4
1972 Dec. 21·80	41672·80	−1·1	32·666	+0·3
1973 Jan. 22·80	41704·80	+1·8	32·783	−0·6
23·80	705·80	+2·0	·787	−0·6
24·80	706·80	+2·5	·790	−0·3
25·80	707·80	+3·7	·794	+0·7
Nov. 13·80	999·80	+6·9	33·864	−0·5
15·80	42001·80	+8·2	·872	+0·2
Dec. 7·70	023·70	+17·6	·952	+0·8
10·70	026·70	+18·0	·963	0·0
29·70	045·70	+13·1	34·032	−0·3
30·90	046·90	+13·4	·037	+0·8
1974 Jan. 4·70	42051·70	+8·7	34·054	−0·6
5·70	052·70	+8·6	·058	−0·1
8·80	055·80	+7·1	·069	+0·2

TABLE III (*continued*)

Date (UT)			MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
1974	Jan.	9·80	42056·80	+6·7	34·073	+0·4
		30·70	077·70	−1·1	·150	−0·3
	Feb.	2·70	080·70	−1·4	·161	0·0
		10·80	088·80	−2·7	·190	−0·2
1975	Nov.	23·90	42739·90	−2·5	36·577	+0·5
1976	Mar.	10·80	42847·80	+18·7	36·972	0·0
		11·80	848·80	+18·1	·976	−0·8
		12·80	849·80	+18·6	·980	−0·4
1977	Aug.	31·45 †	43386·45	+16·4	38·947	+0·1
1978	Aug.	8·45 †	43728·45	−3·1	40·200	−0·3
1979	July	29·48 †	44083·48	−4·4	41·501	−0·5
1980	Aug.	13·42 †	44464·42	+10·4	42·898	−0·1
	Nov.	19·86	562·86	−4·5	43·258	−0·5
		20·87	563·87	−2·8	·262	+1·3
1981	Jan.	13·78	44617·78	−2·4	43·460	+1·9
	Aug.	18·44 †	834·44	−4·2	44·254	−0·3
	Oct.	6·03	883·03	−4·3	·432	+0·1
	Dec.	19·81	957·81	+0·1	·706	+0·4
1982	Sept.	2·42 †	45214·42	−1·9	45·647	−0·1
		9·16	221·16	−0·5	·671	+0·7
	Oct.	29·90	271·90	+6·6	·857	−0·3
	Nov.	13·91	286·91	+13·4	·912	+1·3
	Dec.	12·81	315·81	+16·6	46·018	+0·6
1983	July	16·44 †	45531·44	+3·6	46·809	−0·1
		17·43 †	532·43	+3·6	·812	−0·3
	Sept.	8·04	585·04	+18·0	47·005	+0·1
	Nov.	10·90	648·90	−1·8	·239	+1·9
	Dec.	5·79	673·79	−2·6	·330	+2·0
1984	Jan.	24·76	45723·76	−2·1	47·513	+1·7
	Aug.	1·13	913·13	−1·9	48·208	+1·1
		11·43 †	923·43	−3·1	·245	+0·7
		12·45 †	924·45	−3·3	·249	+0·6
		15·13	927·13	−3·9	·259	+0·1
		26·11	938·11	−3·9	·299	+0·5
	Sept.	7·10	950·10	−4·2	·343	+0·4
	Nov.	26·95	46030·95	+2·5	·639	+4·4
	Dec.	4·92	038·92	+1·4	·669	+2·7
1985	Mar.	2·76	46126·76	+20·1	48·991	+1·2
	Aug.	5·13	282·13	−3·0	49·560	+0·3
	Sept.	3·02	311·02	−1·4	·666	0·0
		3·40 †	311·40	−1·3	·667	0·0
	Dec·	3·84	402·84	+16·0	50·002	−2·1
		18·81	417·81	+7·8	·057	−1·0
1986	Jan.	13·80	46443·80	−1·6	50·153	−0·6
	Aug.	4·13	646·13	+9·1	·894	−1·1
	Oct.	5·99	708·99	+0·4	51·125	−0·4
		29·96	732·96	−2·4	·212	+0·8
	Dec.	11·82	775·82	−4·2	·369	+0·4

TABLE III (*continued*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
1987 Mar. 15·80	46869·80	+0·9	51·714	+1·0
18·79	872·79	+1·5	·725	+1·3
1989 July 21·10	47728·10	+6·7	54·860	−0·4
29·13	736·13	+8·4	·889	−1·3
Aug. 12·14	750·14	+13·6	·941	−1·9
21·11	759·11	+17·4	·973	−1·3
22·10	760·10	+17·4	·977	−1·5
24·12	762·12	+19·4	·985	+0·4
27·13	765·13	+18·3	·996	−0·4
30·13	768·13	+17·0	55·007	−0·7
Sept. 4·11	773·11	+11·5	·025	−3·4
Dec. 21·82	881·82	−5·6	·423	−1·1
1990 Dec. 14·90	48239·90	+0·6	56·736	0·0
1994 Aug. 2·11	49566·11	−3·4	61·597	−0·7
3·09	567·09	−2·8	·600	−0·1
7·02	571·02	−3·5	·615	−1·1
Dec. 10·87	696·87	+8·2	62·076	+2·3
27·92	713·92	+0·6	·138	+0·8
1995 Jan. 2·82	49719·82	−0·6	62·160	+0·7
8·83	725·83	−1·3	·182	+1·0
1996 Feb. 8·80	50121·80	−3·6	63·633	−1·5
Nov. 20·92‡	407·92	−0·9	64·682	+0·1
Dec. 1·92‡	418·92	+0·8	·722	+0·6
1997 Jan. 26·82	50474·82	+14·1	64·927	+0·2
July 23·11	652·11	−3·8	65·577	−0·8
Sept. 10·02	701·02	+0·1	·756	−1·2
Dec. 20·89	802·89	+0·1	66·130	−0·3
1998 July 12·10	51006·10	+7·9	66·874	−0·4
24·14	018·14	+13·3	·919	+0·4
31·12	025·12	+14·9	·944	−1·1
1999 Dec. 19·87	51531·87	+3·8	68·802	+0·5
28·88	540·88	+4·7	·835	−0·6
2000 Jan. 8·82	51551·82	+8·1	68·875	−0·2
17·77	560·77	+11·3	·907	−0·3
Aug. 29·12	785·12	+0·5	69·730	+0·1
Sept. 21·08	808·08	+4·8	·814	+0·8
Oct. 9·07	826·07	+8·5	·880	−0·3
Nov. 4·08	852·08	+18·8	·975	0·0
13·05	861·05	+17·7	70·008	+0·2
Dec. 29·84	907·84	−1·4	·180	+0·8
2001 Jan. 16·83	51925·83	−4·5	70·246	−0·7
27·86	936·86	−4·2	·286	+0·1
Oct. 4·07	52186·07	−2·8	71·199	0·0
19·00	201·00	−3·7	·254	+0·2
Nov. 14·03	227·03	−5·4	·349	−0·8
Dec. 29·79	272·79	−3·3	·517	+0·5
2002 Aug. 29·13	52515·13	−4·9	72·405	−0·4
Sept. 5·12	522·12	−4·8	·431	−0·4
27·08	544·08	−3·8	·512	0·0
Oct. 18·04	565·04	−3·2	·588	−0·3

TABLE III (*concluded*)

Date (UT)			*MJD*	*Velocity* km s^{-1}	*Phase*	*(O – C)* km s^{-1}
2002	Nov.	4·05	52582·05	−1·1	72·651	+0·6
		11·00	589·00	−1·7	·676	−0·6
	Dec.	17·90	625·90	+4·2	·811	+0·3
2003	Jan.	7·00	52646·00	+8·6	72·885	−0·7
	Feb.	14·85	684·85	+13·8	73·028	−0·6
	Aug.	15·12	866·12	−0·9	·692	−0·2
	Sept.	11·04	893·04	+2·7	·791	−0·1
		29·05	911·05	+6·3	·857	−0·5
	Oct.	12·09	924·09	+11·3	·904	+0·1
		25·09	937·09	+17·2	·952	+0·3
	Nov.	4·06	947·06	+19·1	·989	+0·1
		13·98	956·98	+15·4	74·025	+0·6
		26·91	969·91	+6·6	·072	+0·2
		27·92	970·92	+6·1	·076	+0·2
	Dec.	5·92	978·92	+2·6	·105	+0·2
2004	Aug.	17·16	53234·16	+11·9	75·041	+0·1
	Sept.	2·09	250·09	+2·6	·099	−0·4
	Oct.	7·08	285·08	−4·2	·227	−0·7
	Nov.	5·03	314·03	−4·1	·334	+0·5
		14·99	323·99	−4·4	·370	+0·2
	Dec.	17·86	356·86	−4·0	·491	0·0
2005	Sept.	8·13	53621·13	−4·3	76·459	0·0
	Oct.	26·04	669·04	−2·0	·635	0·0
	Nov.	29·90	703·90	+2·6	·763	+1·0
2006	Jan.	4·86	53739·86	+10·0	76·894	−0·2
	Feb.	9·83	775·83	+14·7	77·026	+0·1
		28·78	794·78	+3·1	·096	−0·3
	Aug.	30·14	977·14	+2·1	·764	+0·5
	Oct.	5·07	54013·07	+11·2	·896	+0·9
	Nov.	2·05	041·05	+18·3	·998	−0·2
2007	Jan.	25·89	54125·89	−5·2	78·309	−0·7
	Aug.	7·14	319·14	+16·5	79·018	+0·4
	Dec.	12·97	446·97	−3·5	·486	+0·6
2008	Aug.	13·15	54691·15	−5·5	80·381	−0·9
	Oct.	19·00	758·00	−2·1	·626	+0·1
2009	Feb.	3·85	54865·85	+15·5	81·021	0·0
		7·83	869·83	+12·4	·036	−0·4
	Oct.	13·03	55117·03	+16·0	·942	+0·3
		25·08	129·08	+19·1	·986	+0·1
	Nov.	23·91	158·91	+2·6	82·096	−0·8
2010	Oct.	20·13	55489·13	−4·0	83·306	+0·4
2011	Sept.	28·09	55832·09	−4·0	84·563	−0·8
2012	Jan.	26·84	55952·84	+18·4	85·005	+0·6
	Feb.	7·77	964·77	+10·1	·049	−0·2
		18·77	975·77	+4·2	·090	+0·1

* Lower dispersion; weight ¼.
† Rice[62]; weight 1.
‡ Observed with Cambridge *Coravel*.

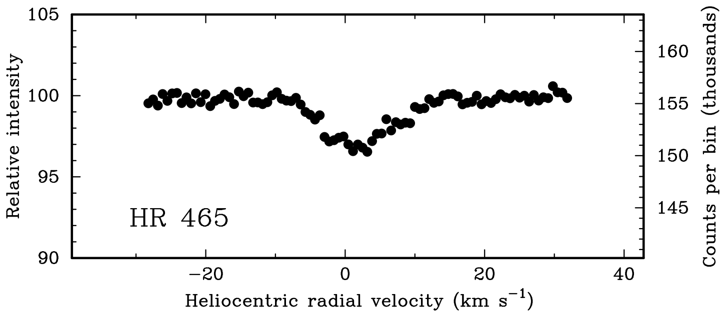

FIG. 3

Radial-velocity trace of HR 465, obtained with the Cambridge *Coravel* on 2004 September 2. It illustrates the fact that, even though the star is of type B9, its spectrum evidently carries enough of the absorption-line pattern that is present in Arcturus (K2, whose spectrum informed the design of the cross-correlating mask in the *Coravel*) to give a significant cross-correlation function ('dip').

however, that is really no loss, because they were not of great accuracy and at best would scarcely have contributed anything useful to the orbit. Next, we may omit measurements[58] made at very low dispersions, and those[61] that are so few in number that we would use up half the number of degrees of freedom in simply trying to establish the zero-point offset. Then, we notice that the four measurements referred to by Wilson & Joy[48] and later specified by Abt[21] are also included in the data set given by Preston & Wolff[44]; three of them are from low-dispersion plates, and the set also includes two other velocities from rather low dispersion; those five measures are omitted here. Among the 29 remaining measures in Preston & Wolff's list, 19 are at high dispersion (~4 Å mm^{-1}) while the remaining ten are at more moderate dispersions of 8 or 10 Å mm^{-1}; we treat them here as two distinguishable data sets. Scholz's Tautenburg set[59] of 26 velocities includes three (two of them at half the dispersion of the third) made on a single night; the two low-dispersion ones are omitted here. In two other cases there were two measurements on a single night: they have been averaged and treated as single measurements. Scholz's later observations[60] were mostly made in a single run, and all but one are close to one particular orbital phase; they are omitted here.

The data that survived that preliminary screening are listed in Table III. They fall into seven series, as follows. There are the high- and not-so-high-dispersion series from the listing by Preston & Wolff[44] (19 and ten measures, respectively). Then there are 22 accepted velocities from Scholz[59], 11 from Rice[62], and 43 OHP ones from Carrier *et al.*[55]. Finally there are the author's own measurements, 14 from OHP and 67 from Cambridge.

In the solution of the orbit, it has been found that four of the data sets are of sufficiently similar quality that they can all be granted unit weight. They are the high-dispersion set from Preston & Wolff, the series from Scholz and from Rice, and the Cambridge set. The 'low'-dispersion set from Preston & Wolff, and the author's OHP measures, deserve a weighting of ¼, while the OHP velocities vaunted by Carrier *et al.* merit only ⅒. The difference between the author's and Carrier's velocities, made with the same instrument, may be related to the integration times spent on them, but without access to the details on the data base in Geneva it is impossible to be sure.

In addition to the weighting of the different data sets, it has been needful to homogenize the zero-points. That has been attempted by treating the OHP velocities as setting the standard but adding 0·8 km s^{-1} to them, as is normal in this series of papers, in an effort to keep to the zero-point initially set up[63] at Cambridge in 1969. Surprisingly (since blue stars normally require a considerable negative correction) the Cambridge data on HR 465 need no adjustment at all. That does call into question the correctness of the OHP zero, which has possibly suffered by being extrapolated from more normal colour indices, on this occasion; however, the principal concern here is with the orbital parameters rather than the γ-velocity *per se*. The other four data sets have all needed positive offsets to bring them, too, into homogeneity with the OHP and Cambridge zero: the offsets needed are +2·4 km s^{-1} for the Preston & Wolff high-dispersion observations and +2·0 km s^{-1} for the lower-dispersion ones, +1·7 km s^{-1} for Scholz, and +1·9 km s^{-1} for Rice. The mutual offsets for the four full-weight observational series are established to a precision of 0·1 km s^{-1}, judged by the standard errors of the means of their respective residuals from the orbit.

The writer is a bit sensitive to the possibility of objection to this whole process, and distrust of the reliability of the final elements, on the grounds that the above-described picking and choosing and preliminary grooming of the data have compromised their independence to such an extent that one cannot believe anything that they may now indicate! He is, however, quite as keen himself as potential critics may be to avoid any falsification of the results by inappropriate tampering with the input data set. It is an unfortunate fact that radial-velocity zero-points do not agree between different data sets, and

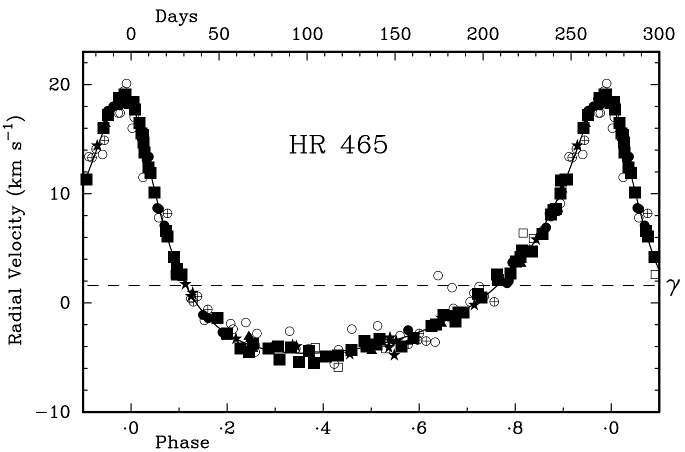

FIG. 4

The observed radial velocities of HR 465 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Full-weight measurements are plotted with filled symbols — squares for the Cambridge *Coravel*, stars for Preston & Wolff's high-dispersion Mt. Wilson observations[44], circles for Scholz's Tautenburg velocities[59], and triangles for Rice's quasi-annual DAO ones[62]. Open squares refer to the lower-dispersion measures by Preston & Wolff (weighted ¼ in the solution of the orbit), while open circles plot measurements made with the OHP *Coravel*. Those circles that have plusses in them represent observations made personally by the author of this paper and merited weight ¼, while the plain ones identify the measurements published by Carrier *et al.*[55] and warranted a weighting of only 1⁄10.

we have actually seen that in this case there are discrepancies that reach over 2 km s^{-1} and can be determined to 0·1 km s^{-1}. It would clearly worsen the computed orbit enormously if obvious systematic discrepancies amounting to 20 standard errors were left in the input data, when they can be corrected at the cost of one degree of freedom for each data set whose zero-point is adjusted. Equally, it would make nonsense of the results if all observations, however good or bad, were given equal weight in the solution, and it is no more than sensible — as well as being in accord with correct statistical practice — to determine and apply proper weightings to the different contributory data sets with a view to bringing their weighted variances into near-coincidence.

After that attempt to justify the procedures and to assure the reader of their propriety, it now remains only to give the orbit to which they finally lead. It is shown here in Fig. 4, and its elements appear in Table IV, which also includes for comparison the elements given previously by Scholz[59] and Carrier *et al.*[55].

TABLE IV

Orbital elements for HR 465

Element	*Scholz*[59]	*Carrier*[55]	*This paper*
P (days)	272·99	272·88 ± 0·20	272·833 ± 0·006
T (MJD)	42047·53	44491·84 ± 2·24	48039·18 ± 0·30
γ (km s^{-1})	−0·55	+0·97 ± 0·22	+1·59 ± 0·04
K (km s^{-1})	11·3	11·12 ± 0·29	11·83 ± 0·07
e	0·47	0·532 ± 0·023	0·504 ± 0·004
ω (degrees)	17·7	20·17 ± 0·35	19·3 ± 0·6
$a_1 \sin i$ (Gm)	37·4	35·34 ± 1·11	38·33 ± 0·25
$f(m_1)$ ($M_\odot$)	—	0·0237 ± 0·0022	0·0302 ± 0·0006
R.m.s. residual (wt. 1) (km s^{-1})	—	1·33	0·45

Despite its extraordinary surface abundances, HR 465 can probably be relied upon to have the mass of about 3 $M_\odot$ that would be usual for a B9V star; in that case the mass function requires the companion object to have a mass of no less than about 0·75 $M_\odot$. It is most unlikely to be white dwarf, which would have had to go through its evolution while still remaining in quite a small and eccentric orbit, so it must be expected to be a main-sequence star no later than early K. It could be quite a lot brighter than a star of such a type before its addition to the already overloaded spectrum of the primary could be recognized. The radial-velocity spectrometer, however, would be sensitive to the pattern of late-type lines, no matter how complex the spectrum might otherwise be, and would easily have recognized a 'dip' having a depth of as much as 1% of the 'continuum' of the cross-correlation function. An assessment of the dip depths to be expected from main-sequence companions of different types suggests, however, that the Δm with respect to the primary is always just too great in relation to the dip that they might be expected to contribute to the radial-velocity trace to allow their recognition.

Although the star was under observation with the Cambridge *Coravel* for 12 years — a good half of the ~23-year period of the rise and decline of the rare-earth spectrum — no significant changes in the depth or character of the 'dip' were noticed with any certainty; it is a bit unfortunate that right at the end, in 2012, the last two traces appeared to show a small increase in the depth and width of the dip, but whether it was significant or should be put down to random error in the traces cannot be decided. Certainly up to that time there was no evidence of any broadening of the 'dip', such as would arise from any significant rotational velocity. The constancy of the dip parameters may suggest that the stellar lines that give rise to the observed cross-correlation are mostly those of iron-peak elements (iron itself being by far the best-represented element in the design of the cross-correlating mask in the *Coravel*) and not ionic lines of heavier elements, which do have a few counterparts in the mask.

HD 10332

The literature on the last two stars treated here is relatively sparse, despite their brightness. In fact there does not seem to be any ground-based photometry of HD 10332, and we rely on *Hipparcos/Tycho* for the quantities $V = 6^{m}\cdot98$, $(B - V) = 1^{m}\cdot31$. Adams *et al.*[10] gave the star's absolute magnitude as $-0^{m}\cdot2$ and its spectroscopic parallax as 0″·003 — the same as *Hipparcos*[26] has found. Even before the publication of the *MKK Atlas*[64] of spectral classification, Keenan[65] gave the MK type of HD 10332 as K1+II–III, the M_V as $-1^{m}\cdot0$, and the distance as 410 pc. There have been two subsequent classifications, but they both relied on objective-prism spectra — by Farnsworth[66], who noted the star as K1 III in the course of a survey with Case Western's *Burrell Schmidt* of the northern Milky Way, and gave it the identification LF5 +60° 196, and Boulon *et al.*[67], who observed it in their 'Champ I' and found its type to be K2 II. The (revised[26]) *Hipparcos* parallax is 2·82 ± 0·68 arc-milliseconds; it corresponds to a distance modulus of $7^{m}\cdot75$ and so to an absolute magnitude of about $-0^{m}\cdot8$, with an uncertainty of about half a magnitude. That is rather brighter than normal giants used to be supposed to be, but is within the spread of luminosity class III in Keenan & Barnbaum's[68] diagram of post-*Hipparcos* luminosities.

HD 10332 has been listed as a 'double or multiple star', and is ADS 1337 in Aitken's great *New General Catalogue of Double Stars*[69]. There it is shown as having been 'discovered' by Burnham, though without having been dignified(?) with any 'discovery designation'. Burnham actually measured two 13^{m} stars, no doubt physically unconnected with HD 10332, *en passant* while he was really more concerned with the adjacent star (*cf.* the *Introduction* section above) 44 Cas, which is β 872. 44 Cas is listed in Burnham's Yerkes enterprise[70], wherein he measured the positions of random faint stars in the vicinities of many bright ones, with a view to providing reference positions for the future measurement of the proper motions of the latter. The two faint stars near HD 10332 are 12″ and 26″ distant from it.

Radial velocities of HD 10332 were first published by Redman[71,72] — the star was among the 425 7^{m} K giants near the Galactic equator that he measured at the DAO in 1928–30 in order to chart Galactic rotation. Unusually, it was observed twice and so features in both of the papers by Redman, who classified it as type K3 in the first one[71] but as K2 (in agreement with the *Henry Draper Catalogue*[6] (p. 119)) in the second[72]. A subset of 87 of the stars was re-observed by the writer on his 'Redman K-Star programme'[73,74] (which admittedly had a less-well-defined objective); orbits of 17 of those stars have been given in this series of papers and eight others (plus two more doubtful cases) elsewhere*. HD 10332 was not among the writer's sample of the Redman stars, but entered his observing programme only in 2002 after de Medeiros & Mayor, having identified it in their 1999 paper[75] as a spectroscopic binary, lodged

*A listing of all 27 orbits, with bibliographical references, is to be found in ref. 74.

with the CDS a listing of the individual radial velocities and made it easier for an interested party to select objects for further observation. Redman was not actually the first person to measure the velocity of HD 10332 — the star had been observed three times at Mt. Wilson in 1926–28, but the results, plus one later one, were published only in 1950 by Wilson & Joy[48] in a paper that just put into the public domain a lot of radial velocities stemming from miscellaneous or aborted programmes. In that paper there is an annotation to HD 10332 that "denotes a revision of an earlier published value on the basis of additional plates or measures", but efforts to retrieve such an earlier Mt. Wilson publication have been unsuccessful.

Five measurements were made of HD 10332 by the objective-prism method favoured by Fehrenbach and his collaborators: a mean radial velocity of zero, with quality 'A', supposed to indicate a 'probable error' less than 2·5 km s^{-1}, was published by Boulon *et al.*[67]. That paper, originally in *Journal des Observateurs*, was reprinted[76] in the *Publications de l'OHP*. Long afterwards, Fehrenbach[77] proposed a blanket correction of –8 km s^{-1} to all the objective-prism velocities published in 'Champ I', the field that included HD 10332.

The Mt. Wilson and DAO (Redman) radial velocities are listed at the head of Table V. The Mt. Wilson ones were published[48] initially only as a mean, but the four individual results were given later by Abt[21]. It has been possible to include Redman's velocities only because the writer is in possession of Redman's original reduction sheets, which give the dates (as well as a decimal place to the velocities, which were rounded to the nearest integer in Redman's publications). The objective-prism velocities were given as a mean and so cannot be included in the table. The six de Medeiros & Mayor velocities come next. All the published velocities have been adjusted by +0·8 km s^{-1} in an effort to align them with the Cambridge scale. Finally, Table V lists the 42 measurements made since 2002 with the Cambridge *Coravel*. In the solution of the orbit the old photographic measures have been given zero weight, for reasons that are painfully apparent from Fig. 5, which illustrates it; the OHP and Cambridge velocities have been weighted equally. The orbital elements are as follows:

P	=	3588 ± 4 days	$(T)_1$	=	MJD 54085 ± 11
γ	=	+2·91 ± 0·04 km s^{-1}	$a_1 \sin i$	=	281·0 ± 2·4 Gm
K	=	6·10 ± 0·05	$f(m)$	=	0·0689 ± 0·0018 $M_\odot$
e	=	0·356 ± 0·007			
ω	=	309·3 ± 1·4 degrees	R.m.s. residual (wt. 1)	=	0·22 km s^{-1}

When they evolve, stars from quite a range of the main sequence — and consequently of quite a range of masses — congregate in the region occupied by late-type giants in the H–R diagram, so the interpretation of the mass function (itself a blunt instrument) is quite uncertain. If, however, we were to hazard a guess that the mass of the HD 10332 primary is about 2 $M_\odot$, then the mass function requires the secondary to be 0·8 $M_\odot$ as a minimum. Minima corresponding to primary masses of 1 and 4 $M_\odot$ are about 0·55 and 1·2 $M_\odot$, respectively. Since the HD 10332 system has not featured in ultraviolet surveys, as it might be expected to do if it contained a white dwarf, its secondary object is probably a main-sequence star, no fainter than K0 for a 2-$M_\odot$ primary, and about one spectral class later or earlier if the primary mass were half or double that estimate, respectively.

The discussion in the previous paragraph may be read as suggesting that the linear separation of the components is of the order of three times $a_1 \sin i$, or

TABLE V

Radial-velocity observations of HD 10332

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

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O–C)* *km s*$^{-1}$
1926 Oct. 29·33*	24817·33	+3·3	$\bar{8}$·842	+4·2
1927 Jan. 24·11*	24904·11	−2·2	$\bar{8}$·866	−1·9
1928 Nov. 2·36*	25552·36	+11·6	$\bar{7}$·047	+1·4
6·29†	556·29	+2·6	·048	−7·6
1930 Sept. 16·43†	26235·43	+0·5	$\bar{7}$·238	−5·5
1947 Aug. 29·51*	32426·51	+9·2	$\bar{6}$·963	+3·8
1986 Aug. 19·99‡	46661·99	+2·7	$\bar{2}$·931	−0·2
20·96‡	662·96	+3·0	·931	0·0
Dec. 12·84‡	776·84	+5·7	·963	+0·4
1987 Aug. 13·97‡	47020·97	+9·5	$\bar{1}$·031	−0·3
1997 Aug. 31·00‡	50691·00	+10·1	0·054	−0·2
Sept. 18·98‡	709·98	+10·3	·059	−0·1
2002 Sept. 2·08	52519·08	−0·5	0·564	0·0
Oct. 22·02	569·02	−0·3	·577	+0·3
2003 Jan. 7·01	52646·01	−0·8	0·599	+0·1
Mar. 15·82	713·82	−0·7	·618	+0·4
Aug. 9·13	860·13	−1·5	·659	−0·1
Oct. 12·09	924·09	−1·4	·676	+0·2
Dec. 5·94	978·94	−1·4	·692	+0·3
2004 Mar. 1·78	53065·78	−2·1	0·716	−0·3
Sept. 2·09	250·09	−1·9	·767	−0·1
Nov. 14·01	323·01	−1·7	·788	0·0
2005 Jan. 3·93	53373·93	−1·7	0·802	−0·1
Feb. 8·80	409·80	−1·4	·812	0·0
July 20·10	571·10	−0·4	·857	+0·2
Sept. 17·07	630·07	−0·1	·873	−0·1
Nov. 5·06	679·06	+0·5	·887	0·0
2006 Jan. 4·85	53739·85	+1·5	0·904	+0·2
Mar. 6·80	800·80	+2·1	·921	−0·2
June 22·06	908·06	+4·1	·951	−0·3
July 24·11	940·11	+5·0	·960	−0·1
Sept. 30·13	54008·13	+6·8	·979	+0·2
Nov. 24·04	063·04	+7·9	·994	+0·2
2007 Jan. 1·96	54101·96	+8·5	1·005	0·0
Feb. 7·79	138·79	+8·9	·015	−0·2
Aug. 31·10	343·10	+10·7	·072	+0·3
Sept. 26·09	369·09	+10·8	·079	+0·5
Nov. 1·02	405·02	+10·0	·089	−0·2
Dec. 12·95	446·95	+9·9	·101	−0·1
2008 Jan. 16·85	54481·85	+9·5	1·111	−0·3
Mar. 31·81	556·81	+9·0	·131	−0·2
Aug. 13·15	691·15	+8·3	·169	+0·2
Oct. 17·03	756·03	+7·8	·187	+0·3
Dec. 6·99	806·99	+6·9	·201	−0·2

TABLE V (*concluded*)

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2009 Feb. 10·81	54872·81	+6·7	1·220	+0·2
Aug. 30·07	55073·07	+5·0	·275	+0·1
Nov. 23·91	158·91	+4·6	·299	+0·3
2010 Mar. 4·82	55259·82	+3·6	1·327	−0·1
July 30·12	407·12	+2·6	·369	−0·2
Sept. 17·15	456·15	+2·0	·382	−0·5
Nov. 28·06	528·06	+2·1	·402	0·0
2011 Sept. 13·15	55817·15	+0·2	1·483	−0·5
Nov. 27·99	892·99	+0·4	·504	0·0
2012 Mar. 1·81	55987·81	0·0	1·530	0·0

* Mt. Wilson measurement[48,21]; weight 0.
† Observed at DAO by Redman[71,72]; weight 0.
‡ Observed with Haute-Provence *Coravel*[75]; wt. 1.

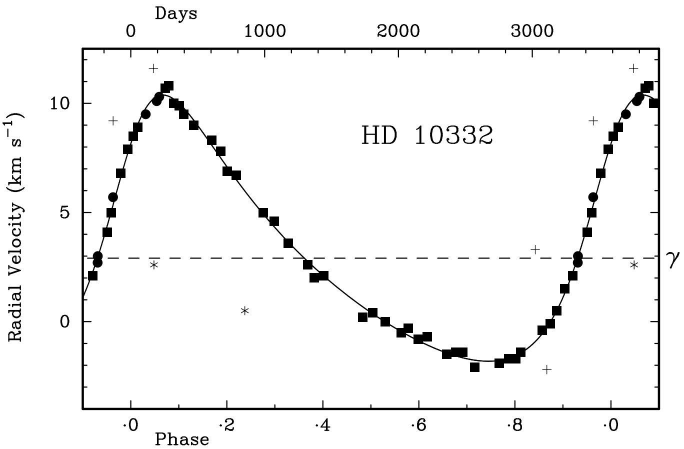

FIG. 5

The observed radial velocities of HD 10332 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The squares and circles represent velocities obtained with the *Coravel*s at Cambridge by the writer and at OHP by de Medeiros & Mayor[75], respectively. Not included in the solution of the orbit are the earlier photographic measures, by Redman[71,72] (asterisks) and by Wilson & Joy[48,21] (plusses).

about 6 AU, since sin *i* cannot be much less than unity without the system being noticeably double-lined. At the (not very accurately determined) distance of HD 10332, such a separation would subtend an angle of somewhat less than 20 milliseconds of arc.

HD 11571

In the early years of the Cambridge radial-velocity work, when the writer's photoelectric spectrometer, operating by cross-correlation, was the only such instrument in existence, there was what was dubbed the 'thick-night' observing programme, upon which an enthusiast who was trying to observe on a night of very poor transparency or other adverse conditions could fall back. It consisted of stars that were particularly easy to observe, selected from the *Henry Draper Catalogue* for their helpful nature as regards position, brightness, and spectral type. Thus they were all at declinations of 40°–50°, so they would pass close to the Cambridge zenith (52°), but just to the south of it so that the dome could remain in that orientation; they had to be brighter than 8^m, and they had to be of type K2. In actual fact, out of the 160 stars that qualified for the programme only about 40 were ever observed*, and they were all between 22^h and 5^h RA. Ten of the 40 have proved to be spectroscopic binaries; orbits of seven of them[78,79] have graced Papers 27, 39, 40, 57, 101, 174, and 205 of this series (HD 11579, 27144, 11613 (HR 551), 222018, 6645, 221422, and 9519, respectively), and now HD 11571 makes an eighth. Remaining unpublished are orbits for HD 20577 and HD 26446; the former, which was overlooked when Paper 174 asserted that HD 9519, 11571, and 26446 were the only ones then outstanding, appears to be a triple system, as its γ-velocity is variable.

It may be remarked that the binary frequency of 25% among the 40 stars is quite similar to the 30% found among the 'Redman K stars'[74], and might yet increase if the 'thick-night' stars were to be observed as attentively as the Redman ones have been. It might also be recalled, by way of illustrating the businesslike terseness of the early papers in this series, that the whole of the texts of the first two mentioned above (Papers 27 and 39) occupied only seven and nine lines of print, respectively; each of those whole papers occupied at most two pages of this *Magazine* and the corresponding reprints were therefore just single sheets of paper!

Despite the brightness of HD 11571, hardly anything has been published about it. There are no *UBV* magnitudes or MK spectral classifications. The *Simbad* bibliography consists of just four papers. There is the writer's Paper 174 which mentioned that HD 11571 was one of the 'thick-night' stars whose orbits remained to be written up; there is a paper by Famaey *et al.*[80], whose tabulation gives a mean radial velocity that is derived from the Geneva data base where those authors no doubt found some of the present writer's measurements; there is a catalogue that simply records that mean velocity; and there is a paper[81] that actually refers to *AG* 11571† and not to HD 11571 at all, and should never have been listed under the latter identity.

Once again, therefore, we have to turn to *Hipparcos*/*Tycho* for basic information about HD 11571, in particular for $V = 6^m{\cdot}83$ and $(B - V) = 1^m{\cdot}58$, and for the (revised[26]) parallax of 6·13 ± 0·54 arc-milliseconds. Those data would correspond to a type of about K5 IIIb or III–IV — a bit unpleasant, since it falls in an area of the colour–magnitude diagram that is altogether un-populated in Keenan's[68] diagram, which shows the luminosity to be that of 'clump' giants which, however, all have substantially smaller colour indices.

The writer made the initial radial-velocity observations of HD 11571 in 1967 and 1968. Some years later, in 1973, after he had become aware that stellar velocities were liable to change on leisurely time-scales, he observed it again, and subsequently, for the same reason, in 1979, when a distinct change was

*A few others that qualified were observed on other programmes — notably nine of them on the 'Redman K-star' programme[71,72].

†That *AG* number, which is not unique, was copied from Heard[82], who took it (indirectly, through the relevant *Yale Zone Catalogue*[83]) from the Cambridge zone of the original *Astronomische Gesellschaft Katalog* (*AGK1*); it refers to the star also known as BD +26° 3943. Spot checks suggest that analogous mistakes have been made on a wholesale scale in *Simbad*.

TABLE VI

Radial-velocity observations of HD 11571

Except as noted, the sources of the observations are as follows:
1967–1990 — original Cambridge spectrometer (weighted 1/10 in orbital solution);
1991–1998 — OHP Coravel (weight 1); 1999–2012 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity* km s⁻¹	*Phase*	*(O–C)* km s⁻¹
1967 Nov. 21·92	39815·92	−22·7	0·128	−0·7
1968 Dec. 21·84	40211·84	−22·3	0·167	0·0
1973 July 31·11	41894·11	−23·2	0·334	+0·9
Nov. 11·94	997·94	−23·1	·344	+1·1
1979 Jan. 13·84	43886·84	−25·9	0·531	−0·4
Sept. 23·05	44139·05	−25·3	·556	+0·3
1980 Jan. 2·78	44240·78	−23·8	0·566	+1·8
1981 Feb. 1·80	44636·80	−25·6	0·606	+0·1
Sept. 19·02	866·02	−24·3	·628	+1·3
Oct. 13·02	890·02	−25·4	·631	+0·2
1982 Jan. 10·77	44979·77	−26·2	0·640	−0·6
Mar. 5·80	45033·80	−26·3	·645	−0·7
Sept. 1·03	213·03	−26·3	·663	−0·7
Oct. 4·04	246·04	−25·4	·666	+0·1
Nov. 26·14*	299·14	−25·3	·671	+0·2
Dec. 10·96	313·96	−25·9	·673	−0·4
1983 Sept. 20·07	45597·07	−26·5	0·701	−1·1
Oct. 24·39†	631·39	−24·9	·704	+0·5
28·35†	635·35	−24·9	·705	+0·5
Nov. 21·91	659·91	−26·1	·707	−0·8
1984 Jan. 4·88	45703·88	−25·9	0·711	−0·6
18·81	717·81	−27·1	·713	−1·8
Sept. 2·13	945·13	−25·4	·735	−0·3
Oct. 20·99	993·99	−25·6	·740	−0·5
Dec. 11·86	46045·86	−26·0	·745	−0·9
1985 Sept. 26·99	46334·99	−24·4	0·774	+0·4
Oct. 20·01	358·01	−24·4	·776	+0·4
Nov. 11·96	380·96	−24·2	·779	+0·5
1986 Jan. 25·79	46455·79	−24·6	0·786	+0·1
Aug. 29·13‡	671·13	−24·9	·807	−0·5
Sept. 19·09	692·09	−23·5	·809	+0·9
Oct. 12·01	715·01	−25·5	·812	−1·1
Nov. 11·92	745·92	−25·9	·815	−1·6
1987 Jan. 3·81	46798·81	−25·1	0·820	−0·8
Feb. 28·78‡	854·78	−23·9	·826	+0·3
Oct. 17·98‡	47085·98	−23·4	·849	+0·5
1988 Jan. 26·19†	47186·19	−23·7	0·858	+0·1
Mar. 15·78‡	235·78	−23·6	·863	+0·1
Oct. 11·03	445·03	−24·6	·884	−1·2
Nov. 4·03‡	469·03	−23·1	·887	+0·3
Dec. 12·87	507·87	−23·4	·890	−0·1

TABLE VI (*continued*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
1989 Jan. 17·76	47543·76	−22·3	0·894	+1·0
Mar. 26·78‡	611·78	−22·9	·901	+0·3
Sept. 7·11	776·11	−23·6	·917	−0·6
Oct. 29·95‡	828·95	−22·8	·922	+0·1
Nov. 25·98	855·98	−23·2	·925	−0·4
1990 Jan. 30·88‡	47921·88	−22·9	0·931	−0·1
Oct. 8·04	48172·04	−23·6	·956	−1·1
1991 Jan. 28·87	48284·87	−22·6	0·967	−0·3
Oct. 29·98	558·98	−22·4	·995	−0·3
1992 Jan. 17·81	48638·81	−22·1	1·003	−0·1
Aug. 14·07	848·07	−21·9	·023	0·0
1993 Feb. 16·78	49034·78	−21·8	1·042	0·0
1994 Jan. 7·82	49359·82	−21·7	1·074	+0·1
Aug. 4·13	568·13	−21·7	·095	+0·2
1995 Jan. 6·79	49723·79	−21·8	1·110	+0·1
Dec. 26·89	50077·89	−21·9	·145	+0·2
1996 Apr. 2·81	50175·81	−22·3	1·155	−0·1
1997 Jan. 23·88	50471·88	−22·5	1·184	0·0
July 23·12	652·12	−22·8	·202	−0·2
Dec. 24·75	806·75	−22·6	·218	+0·2
1998 July 13·09	51007·09	−23·0	1·237	0·0
1999 Dec. 29·81	51541·81	−23·6	1·290	0·0
2000 Sept. 4·11	51791·11	−24·2	1·315	−0·3
Dec. 15·91	893·91	−24·5	·325	−0·5
2001 Mar. 14·79	51982·79	−23·6	1·334	+0·5
Aug. 25·12	52146·12	−24·8	·350	−0·5
2002 Feb. 5·81	52310·81	−24·3	1·367	+0·1
2003 Jan. 11·91	52650·91	−24·7	1·400	0·0
Sept. 13·09	895·09	−25·0	·425	−0·1
2004 Feb. 23·86	53058·86	−25·2	1·441	−0·1
Oct. 19·08	297·08	−25·1	·464	+0·1
2005 Feb. 15·81	53416·81	−25·2	1·476	+0·1
Sept. 8·11	621·11	−25·2	·497	+0·2
2006 Feb. 9·85	53775·85	−25·6	1·512	−0·1
Sept. 9·12	987·12	−25·1	·533	+0·5
2007 Jan. 31·81	54131·81	−25·6	1·547	0·0
Sept. 12·12	355·12	−25·7	·569	−0·1
2008 Feb. 15·84	54511·84	−25·6	1·585	+0·1
Oct. 12·03	751·03	−25·7	·609	0·0
2009 Mar. 5·80	54895·80	−26·0	1·623	−0·4
Sept. 4·14	55078·14	−25·6	·641	0·0

TABLE VI (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2010 Sept. 15·09	55454·09	–25·9	1·678	–0·4
2011 Sept. 14·10	55818·10	–25·1	1·714	+0·2
2012 Jan. 28·82	55954·82	–25·3	1·728	–0·1

* Observed with Palomar 200-inch telescope; wt. 1.
† Observed with DAO 48-inch telescope; wt. ½.
‡ Observed with Haute-Provence *Coravel*; wt. 1.

indeed recognized. The star has been observed in every one of the ensuing 33 seasons. Table VI gives a total of 85 radial velocities of it; 36 were made with the original spectrometer at Cambridge, 23 and 22 with the *Coravel*s at OHP and Cambridge, respectively, three at the DAO, and one at Palomar. It has not been possible to enter Redman's original observation in this case, because the relevant reduction sheet is missing from the set that Redman entrusted to the writer. In the solution of the orbit the variances of the 'original Cambridge' and DAO measurements have been brought into approximate equality with the others by the adoption of weights of ⅒ and ½, respectively. The star is found to have an orbit of modest eccentricity and a period of 10 000 days (27 years). It is portrayed in Fig. 6 and has the following elements:

P	=	10084 ± 249 days	$(T)_1$	=	MJD 48613 ± 464
γ	=	–23·92 ± 0·05 km s⁻¹	$a_1 \sin i$	=	266 ± 10 Gm
K	=	1·93 ± 0·05	$f(m)$	=	0·0074 ± 0·0006 $M_\odot$
e	=	0·108 ± 0·029			
ω	=	331 ± 17 degrees	R.m.s. residual (wt. 1)	=	0·25 km s⁻¹

The amplitude is small — smaller indeed than had ever been plausibly established for any star at the time that the writer's observations of this one began, even though it would now be considered huge in relation to some orbits of planet-bearing stars. The eccentricity is also small, and has a proportional uncertainty of rather more than a quarter, so the uncertainty in ω cannot avoid being just over a quarter of a radian, and that in turn leads to the rather large uncertainty of some $\frac{1}{4} \times P/2\pi$ in T, which in this case is appreciably more than a year. The laxity of those elements arises merely from the smallness of the eccentricity, and does not imply that the position of the whole velocity curve along the time axis is uncertain by anything like a year. It is useful in such a case to give, in addition to T, the quantity T_0, the time of nodal passage or of maximum radial velocity, which is here MJD 49446; it has the relatively moderate standard error of 49 days or only 0·5% of the orbital period.

The mass function of HD 11571 is small and does not require the secondary star to have a mass greater than about 0·35 $M_\odot$, corresponding to that of an M2 or M3 main-sequence star that would be getting on for ten magnitudes fainter than the primary. A sufficiently low orbital inclination would allow the companion star to be well above that minimum, but the system does not represent an attractive candidate for direct optical resolution.

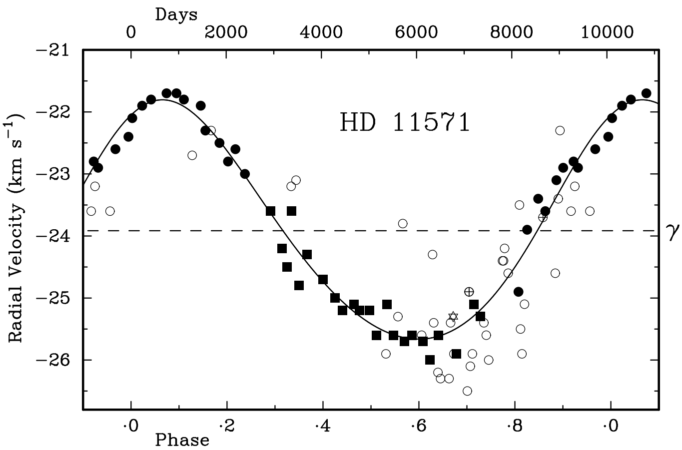

FIG. 6

The observed radial velocities of HD 11571 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The squares, filled circles, open circles, open circles with crosses in them, and the single star, represent velocities obtained by the writer with the Cambridge *Coravel*, at OHP, with the original Cambridge spectrometer, at the DAO, and at Palomar, respectively; the DAO ones were given half-weight in the solution of the orbit and the 'original Cambridge' ones one-tenth.

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CORRESPONDENCE

To the Editors of 'The Observatory'

The Supernova of 1054 AD, the Armenian chronicle of Hetum, and Cronaca Rampona

Historical records of astronomical phenomena are often useful for dating historical events[1], and occasionally also for understanding those phenomena themselves. This letter concerns the famous supernova of 1054 AD, the progenitor of the Crab Nebula (Messier 1) in Taurus, described in Chinese, Japanese, and Arabic records. Although those sources mention that the event was seen even during the daytime, along with some other details, there is no accurate information on the date of its first appearance, and hence any new record is of particular value. Whether there are reliable records in Europe is still a matter of debate; the presence of such sources was argued by Collins *et al.*[2], while the contrary is concluded by Stephenson & Green[3]. Both groups of authors discuss the *Cronaca Rampona* (first published by Sorbelli[4]) and other chronicles, along with the Armenian chronicle of Hetum, a 13th-Century author, known as Hetum Patmich (historian). Hetum's chronicle was first published by Hakobian[5] and has been discussed since the 1960s by Tumanian & Astapovich[6], initially in the context of a meteor event, and by Collins *et al.*[2] in relation to the 1054 supernova and other chronicles. Note that Armenian medieval sources do contain records of numerous astronomical phenomena (see, *e.g.*, ref. 7). Stephenson & Green[3] note that "the renewed examination of the entry in the Armenian chronicles is desirable."

I have translated that entry from the manuscript No.1898 (see the image in Fig. 1) in Matenadaran, the Institute of Ancient Manuscripts, in Yerevan: "1048 AD. It was the 5th year, 2nd month, 6th day of Pope Leo in Rome. Robert Kijart arrived in Rome and sieged the Tiburtina town. There was starvation over the whole world. That year a bright star appeared within the circle of the Moon, the Moon was new, on May 14th, in the first part of the night." Here, Pope St. Leo IX (1049–1054 April 19), and Tiburtina, then a suburb of Rome, are mentioned. The 'circle of the Moon' refers to the Moon's disc, hence, describing a conjunction with an impression of appearance of the 'bright star' within the disc (for discussion see refs. 2 and 3).

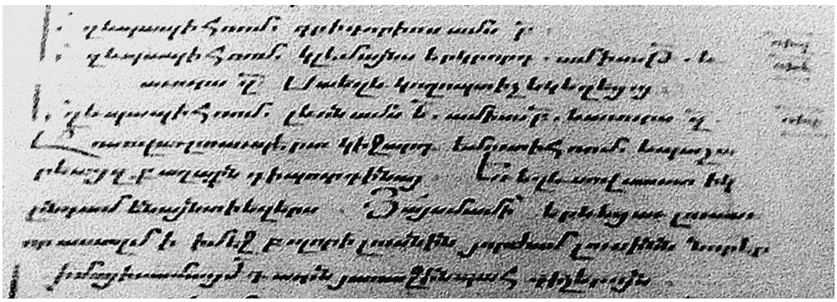

FIG. 1

The entry of Hetum's chronicle with the astronomical record; from the Armenian manuscript No.1898 in Matenadaran, Yerevan (photo by V. G. Gurzadyan).

An unexpected conclusion can be drawn from the translated passage: the similarity of its wording, including the mentioning of Tiburtina, with that of *Cronaca Rampona*[3], leaves no doubt that we are dealing with an identical source for both of these chronicles. Hetum's chronicle spanning the history from 1 AD to 1294 AD, as the author himself mentions, includes compilations from the French[5]; its source cannot be a single one, among those, *e.g.*, the 13th-Century chronicle of Martinus Polonus[8].

Thus, we conclude that: (*a*) Hetum's chronicle and *Cronaca Rampona* must have a common source and a search for it is of particular importance; (*b*) the conjunctions of the Moon have to be analyzed not for an observer in Armenia (as attempted in refs. 2 and 3) but in Western Europe.

The clarification of these issues and of a number of related ones (*e.g.*, the rôle of near-horizon refraction in the appearance of the conjunction, *i.e.*, linked to the geographic location) and the joint analysis of various copies/translations will reveal whether the original source we seek really indicates a European observation of the supernova of 1054 AD.

Yours faithfully,
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REVIEWS

Space Chronicles: Facing the Ultimate Frontier, by N. deGrasse Tyson (W. W. Norton, London), 2012. Pp. 364, 24 × 16·5 cm. Price £16·99/$26·95 (hardbound; ISBN 978 0 393 08210 4).

Neil deGrasse Tyson is the Director of the Hayden Planetarium in New York, and a well-known popularizer of astronomy and space science. The present book is essentially a compilation of short essays, contributions to TV talk shows, and keynote speeches written or delivered over the last decade or so. As such it gives glimpses into Tyson's thinking on the subject of space exploration over this period, albeit at a fairly superficial level and with a certain amount of repetition. It is not immediately obvious at whom the book is aimed, as the content is probably too shallow (and lacking in supporting references to other work) to appeal to space-policy makers and academics, yet lacks the coherence (and appealing visual imagery) of a popular work on space exploration such as Carl Sagan's *Cosmos*. That said, the individual chapters are written in an engaging style, and do contain some useful nuggets of information and arguments for increased public funding for space exploration.

Insofar as there is a common thread running through the book it is that exploration is necessary to keep alive a vision of the future that will attract people, and especially young people, into science and engineering, and that will help maintain a scientifically literate culture on which ultimately our well-being depends. As he says (p. 230) "If you're going to attract the next generation [into science] you need and want to be working on something *big* [my italics], something worth dreaming about", and an ambitious space programme is one of the few activities open to western civilization likely to have sufficient impact in this respect. I certainly agree with this, and with Tyson's argument that the societal benefits of space exploration are more than enough to justify at least doubling NASA's budget (currently less than half of one percent of US government spending), but with the caveat that in addition to increased funding we also need renewed political leadership and *vision* which at present are conspicuous by their absence.

Tyson's discussion occasionally touches on the question of whether space exploration should be pursued by people or by robots, and concludes, rightly in my view, that we need both. We demonstrably need both humans and robots for science (as I have argued elsewhere; see *A&G*, **53**, 2.22, 2012), and we especially need the human element in order to maximize the inspirational and educational potential of exploration; as Tyson says (p. 135) "My reading of history and culture tells me that people need their heroes." This leads him to advocate an ambitious human and robotic exploration programme (p. 202) such that "No part of the solar system should be beyond our reach. We should deploy both robots *and* [his italics] people to get there, because, among other reasons, robots make poor field geologists." He goes on to argue, again I am sure correctly, that the development of such an ambitious space-exploration programme would result in "an academic pipeline bursting with the best and the brightest astrophysicists, biologists, chemists, engineers, geologists and physicists" and that many economic and societal benefits would follow in areas far removed from space exploration.

Tyson's arguments are throughout couched in purely US terms, but they are just as valid elsewhere in the world, especially in Europe, which also needs to reinvigorate its scientific and engineering base for the 21st Century (and where a doubling of ESA's budget might be expected to yield comparable scientific and societal benefits this side of the pond). Indeed, my main disappointment with the book was the lack of an internationalist approach to space exploration. Wherever Europe, Russia, Japan, or China are mentioned in the book it is as competitors with the US, whereas what we really need is the development of a genuinely global space-exploration programme (such as envisaged by the Global Exploration Roadmap of 2011; see http://www.globalspaceexploration.org/). Nevertheless, this criticism aside, we all have an interest in seeing the enhanced space-exploration programme that Tyson advocates in this book, and so we must hope that his arguments are able to make a difference. — IAN CRAWFORD.

The Elusive Wow: Searching for Extraterrestrial Intelligence, by Robert H. Gray (Palmer Square Press), 2011. Pp. 260, 23·9 × 16·5 cm. Price £19·95/$29·95 (hardbound; ISBN 978 0 98395844 4).

In 1977, on the night of August 15, the Ohio State University Radio Observatory — "Big Ear" – was pointing 20 degrees above the southern horizon. Just after 23:15 one of the telescope's two feed horns began to register a signal. Over the next minute or so the signal reached a strong peak before fading as the Earth rotated.

No one saw the telescope register the signal. The setup was such that a printer clattered out a line of alphanumeric characters, one every 12 seconds, with the characters reflecting intensity. It was only later that the astronomer Jerry Ehman, checking through wads of computer printout, saw a pattern: 6, E, Q, U, J, 5. He circled the characters and scribbled "Wow!" beside them. Ehman knew precisely what an interstellar radio transmission was supposed to look like — and it looked like this. It had the same signature as a celestial source passing through the telescope's antenna beam, but the only natural radio sources in the beam were a thousand times fainter than this. It had a narrow bandwidth. The frequency was close to the hydrogen line, which is a plausible channel for extraterrestrial communication. Most intriguingly of all there were hints (if you really looked for them and then cast a favourable eye) that there was some sort of pattern involved with weaker signals. The Wow remains perhaps our best candidate for a signal from an extraterrestrial civilization. The trouble was, Big Ear looked for the signal again but in about a hundred days of additional observations (admittedly adding up to only four hours) it saw nothing. The telescope was there to do astronomy, not to search for extraterrestrial intelligence, and so scientists involved wrote up their observations and moved on to other things.

Enter urban planner and data analyst Robert H. Gray. In *The Elusive Wow*, Bob Gray describes his remarkable attempt to track down the source of the Wow signal. The word 'remarkable' is appropriate here because Gray was an outsider. He had no astronomy PhD, no funding, no institution. Nevertheless he managed to build his own automated microwave observatory (I'd love to know what his neighbours thought when they saw him rolling a 12-foot ex-military dish antenna through the narrow Chicago alleyways near his home) and got time on a Tasmanian radio telescope, a Harvard receiver, and even the *Very Large Array* in order to look for the Wow signal. He achieved this because at all times he presented strong, well-reasoned, science-based arguments for continuing the search. His analysis of the data generated by the various instruments was clearly of professional standard.

The Elusive Wow is really two different books. Part One describes Gray's personal relationship with the Wow signal. The story is told with clarity and humour, and along the way the reader learns a lot about how astronomy is actually done. Part Two is more traditional. It presents an overview of the search for extraterrestrial intelligence and gives the rationale behind, and the history of, SETI. For the newcomer to SETI, it might be advisable to read Part Two first; a SETI veteran, I suspect, would enjoy Part One but skim Part Two. There's also an extensive bibliography, some useful links, and a photogallery of several SETI luminaries.

Did Gray succeed in tracking down the Wow signal? No! Despite his remarkable tenacity and detective work, he didn't catch sight of it again. The Wow signal *might* have come from a distant extraterrestrial source. But my bet? I think it was man-made interference of some sort, but that we'll never know for sure. Frustrating, or what? — STEPHEN WEBB.

Oxford Dictionary of Astronomy, by Ian Ridpath (Oxford University Press), 2012. Pp. 535, 19·5 × 12·5 cm. Price £12·99/$18·95 (paperback; ISBN 978 0 19 960905 5).

No-one sits down to write a dictionary — and no reviewer will actually read one from cover to cover. A dictionary is the product of numerous contributors, and how well the entries match in detail and style is a measure of the success of the dictionary's editor. Ian Ridpath has done a magnificent job in producing a comprehensive, modernized compilation, and there is surely little doubt that, in the words of the publisher's blurb, the book is "an invaluable reference for students, professionals, and anyone with a keen interest in astronomy". The principal changes to the first (1997) edition are the addition of over 50 new space missions, catalogues, projects, *etc.*, and web-links, and updates of nearly 500 other entries — itself a major undertaking.

Not being routinely familiar with the original version, I have to admit some initial surprise to find thumbnail biographical sketches included in what I believed to be a book dedicated to explaining or translating words (to paraphrase the *OED*). That initial surprise was further compounded by a mixing of nomenclature [names] and terms [definitions]; however, the *OED* goes on to define an "extended use" of the term "dictionary" as "a book of information or reference ...; an alphabetical encyclopedia." And that does better describe the *Oxford Dictionary of Astronomy*.

Given that mix of names and terms, it might have been more helpful to separate them: all the *names* (descriptions, not definitions) of Solar System bodies, for instance, could have made a separate section, and would have been more informative that way. The same is true of the "eminent astronomers" who have been included, though it is still difficult to class people as 'information or references' as in the *OED* quote above. However, invidious as it undoubtedly is to include some big names to the exclusion of others, I do believe the line should be drawn above those who are still in the land of the living.

While I did not read all the entries, and do not have the expertise to comment on a large number of them, in my own field of stellar spectroscopy I found ones which I wanted to query. The four contacts of an eclipse, we are told, relate to solar eclipses (what does the AAVSO make of that?); forbidden lines are emission lines that are so-called because they do not occur under normal conditions on Earth (with no mention of the fact that they are normally not 'allowed' as transitions — hence the term — and also that they are seen in absorption); that Arcturus is a K1·5 giant (but not according to most past classifiers); and that in an eclipsing binary the primary has the "higher surface luminosity" and that the secondary is "fainter" (so the late-K supergiant in ζ Aur is the secondary, as the dictionary actually confirms, notwithstanding having an M_V more than 2 magnitudes brighter than its hot-dwarf companion). Those instances alone slightly undermined my confidence. There are also rather a lot of explanations of mathematical terms which, while possibly used in astronomy, tended to dilute the main contents of the book.

Against that, there is a great deal of information which is useful, helpful, and adequate in condensed form; the occasional figures, such as an H–R diagram, a luminosity function, or telescope mountings, speak more eloquently than words, while tables — such as the physical data of planets, lists of satellite launches, lunar probes, or the nine Appendices of planetary data, Messier objects, bright stars, *etc.* — make for easier reading. I believe the book serves its purpose as an excellent first point of reference, even if the searcher thinks that the web might ultimately do better. — ELIZABETH GRIFFIN.

Observing and Cataloguing Nebulae and Star Clusters: From Herschel to Dreyer's New General Catalogue, by W. Steinicke (Cambridge University Press), 2010. Pp. 648, 25·5 × 19·5 cm. Price £90/$145 (hardbound; ISBN 978 0 521 19267 5).

The New General Catalogue (NGC) is the best-known catalogue of bright nebulae, clusters, and galaxies. It is so familiar to amateurs and professionals alike that its compilation and publication by John Dreyer in 1888 is perhaps taken for granted. It contains 7840 entries and, other than the Messier catalogue, is far more used and useful than the superfluous new additions such as the Caldwell catalogue.

It was based on the great surveys of the Herschels (William and John) but evolved over the 19th Century and involved the efforts of a very large number of observers from Charles Messier to Lewis Swift.

Dr. Wolfgang Steinicke is a very experienced observer and astronomical historian and this volume has grown from his doctoral thesis, and what a piece of work it is. He describes in great detail the development of the NGC, the catalogues that preceded it and led to its present form, and the many characters involved. The book gives a marvellous feel for the way that the exciting story of the discovery of the deep sky developed.

Within this story, each character is given a short biography, and it is a wonderful addition for those readers who enjoy the history of astronomy to have so many within one volume. It brings many to life, and could act as a launch pad for more detailed research, although that presented should be more than adequate for most. The book is lavishly illustrated with portraits of the observers, many of the telescopes used, drawings of astronomical objects (some famous, many unfamiliar), and photographs of many objects, mainly taken from the Digitized Sky Survey (DSS).

This reviewer particularly enjoyed Chapter 11, 'Special Topics', in which Steinicke goes into even greater detail on a variety of subjects such as making drawings, spiral structure (of Messier 51 in particular), Hind's Variable Nebula, other "variable nebulae" (including eta Carinae), and the Pleiades Nebula. All provide fascinating stories and the depth of research is extraordinary.

The index is excellent, with separate indices for names (with the short biographies highlighted), sites of interest, astronomical objects, and general subjects that make enquiry very straightforward.

There is a very valuable reference section with 1628 entries, predominantly taken from astronomical journals, many of which should be available through the great libraries such as that of the Royal Astronomical Society.

There is little to criticize in this book. The prose can be rather heavy going and the style slightly turgid as English is not the author's first language. It may not be a book to read from cover to cover, but probably is best as a reference book where large chunks can be enjoyed while researching a subject. It would be difficult to challenge the facts unless one were a very serious historian of the subject, but occasionally one stumbles on something that raises an eyebrow; for example, was Stephan really still at the École normale supérieure until 1862 (aged 25)? Perhaps that was why he was top of his class! However, this is trivial in the context of such a detailed book. There are an enormous number of tables, some of which could be regarded as unnecessary.

Steinicke's book contains such a wealth of information in an easily accessible form that it must become the standard reference on the history of 19th-Century deep-sky astronomy for the foreseeable future. I am sure all with an interest in this aspect of the story of the discovery of the Universe will want to own or have access to it. — NICK HEWITT.

Guidebook to the Constellations, by P. Simpson (Springer, Heidelberg), 2012. Pp. 875, 25·5 × 17·5 cm. Price £31·99/$34·95/€34·95 (paperback; ISBN 978 1 4419 6940 8).

For years, members of the Alamogordo Astronomy Club in New Mexico listened attentively to Phil Simpson's constellation-of-the-month talks, asked questions, and made suggestions. Unwittingly, they were participating in the genesis of this book, which combines Simpson's experience of presenting the night sky to beginners with photographs and drawings by 13 other amateurs around the world. The result is a meaty tome of well over 850 pages, packed with information and illustrations that should keep any enthusiastic observer of the night sky busy for years.

Simpson's approach is original. He groups the constellations according to the myths behind them or, in the case of modern constellations, by their inventors. His chapters have imaginative titles such as 'The Assassin and his Associates' (Corona Australis, Ophiuchus, Sagittarius, Scorpius, Serpens); 'Hospitality and Homicide' (Boötes, Canis Minor, Virgo, Canes Venatici, Corona Borealis, Libra); and 'Unbelievable Music, Unbearable Sorrow' (Lyra and Eridanus).

Each chapter opens with an extensive narrative of the constellation myths or the story of their inventors. Well-drawn finder charts accompany tables of the main stars and features of interest, offering a plentiful supply of targets for observers to chase. Wide-angle photographs of the constellations are included, but the faintest constellations have come out largely black and featureless on the printed page, as is the usual fate of photographs of star fields.

Telescopic views of deep-sky objects fare better in reproduction. In several cases, photographs are paired with drawings to give a better idea of how the object actually looks through a telescope.

I welcome the author's approach of introducing the night sky through the ancient stories of the stars. His constellation mythology and history is generally well-informed, although I noticed two statements that need correcting. Firstly, Malus, the mast, was not one of the sections into which Lacaille broke the Greek ship Argo; Malus was actually a later suggestion by John Herschel, but was never widely adopted. And, secondly, Flamsteed Numbers were not allocated by Flamsteed.

This book would not be a proper member of Springer's *Practical Astronomy* series without the usual liberal sprinkling of typos to keep the reader alert. Additionally, there seems to be a systematic error in the page numbers in the Index, and the running headers on the Index pages come from a completely different book.

These irritations aside I can heartily recommend this book to all those learning their way around the sky, and who appreciate knowing the ancient stories of the stars as well as the modern science. — IAN RIDPATH.

Our Explosive Sun, by P. Brekke (Springer, Heidelberg), 2012. Pp. 168, 20·5 × 20·5 cm. Price £26·99/$29·95/€29·95 (hardbound; ISBN 978 1 4614 0570 2).

Warm encouragement is given to professional and amateur astronomers these days for engagement with the public in their understanding of the sometimes bewildering developments in our subject. The Sun is a good place to start, for everyone understands how important its rôle is in sustaining life and supplying energy.

Pål Brekke's lavishly illustrated book is a model of how this can be done effectively. In less than 200 pages and ten short chapters, a huge number of topics are touched upon and by and large very clearly and concisely explained, with some of the best illustrations I have ever seen in a popular science text. The Sun's place among stars and the Solar System, the solar interior, and its impact on the Earth including space weather are all dealt with in a breezy but very precise way that will engage all but those with the most severe cases of attention-deficit disorder. The illustrations include many from the *SOHO* spacecraft, which Brekke has worked on, as well as space pictures from NASA and ESA. Full marks to Trond Abrahamsen who did the fine artwork that helps to explain concepts that might initially be challenging for young people — for instance, the way blue light is scattered much more than red light. Journalists who grill scientists whenever there is a threat of a geomagnetic disturbance would do well to look at the illustration on how solar storms affect our high-technology society.

The author's Scandinavian background comes through with several shots of Norwegian landscapes and the Swedish telescope on La Palma, but particularly entertaining is a snapshot of the work of the great auroral scientist Birkeland, with a photograph of his laboratory experiment that simulated the northern and southern lights. There are a couple of other nods in the direction of the history of solar science.

All in all, a great introduction to solar astronomy and the effects of the Sun on the Earth, very much aimed at a young readership, especially those who are not heavily into science, for example, those who are studying art subjects at high-school level. The price is modest considering the many colour illustrations. — KENNETH J. H. PHILLIPS.

The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution (IAU Symposium No. 276), edited by A. Sozzetti, M. G. Lattanzi & A. P. Boss (Cambridge University Press), 2011. Pp. 563, 25 × 18 cm. Price £73/$125 (hardbound; ISBN 978 0 521 19652 9).

I first picked up this volume with much eagerness as well as many dynes, hoping for the 'best current answer' to whether our own Solar System will be stable for a million, a billion, or some other number of years. But this turns out not to be what the symposium organizers and editors had in mind by "dynamical evolution", with one exception: a suggestion from M. B. Davies that a system like ours, if forced to live long in a star cluster, might end up looking more like known exo-systems. And S. Elser *et al.* find that one terrestrial planet in 10^4, or rather one terrestrial-planet simulation in 10^4, should have a massive moon like ours.

The contributions range from 8–12-page invited presentations down to two-page poster presentations. Both sections are divided in four — planet formation; structure and atmospheres; interactions; and the next decade. These last include no stock-market data but, rather, focus on some potential future missions and searches and what they might find. The poster sessions are arranged alphabetically by first author, so it is not a value-judgement by the editors that puts the Las Cumbres Observatory Global Telescope Network second to last in the volume.

Of the 200-plus participants, 27% were women, and comparable fractions of speakers and other presenters. The standard photographs manage to be both black-and-white and fuzzy, though not quite fuzzy enough to conceal the detail that rather few of the participants thought the event worth dressing up for. My favourite line drawing is the "tidal downsizing hypothesis" of S. Nayakshin, which looks at first glance like a Ptolemaic exo-system.

All in all, this is probably a volume for specialists, or perhaps for grad students looking for an interesting thesis project. — VIRGINIA TRIMBLE.

The Chemical Cosmos: A Guided Tour, by S. Miller (Springer, Heidelberg), 2012. Pp. 248, 23·5 × 15·5 cm. Price £26·99/$29·95/€29·95 (paperback; ISBN 978 1 4419 8443 2).

To concentrate on the chemistry of the Universe, and the *real* chemistry — *i.e.*, molecules and molecular ions rather than simply the atomic elements — is a rather novel approach for a popular book. Our guide on this tour through astronomy is the physics of the H_3^+ ion, at least until conditions become unfavourable for its existence. An unusual view then, leading from the interstellar medium to star and planet formation, and the possibilities for life. The writing is lively and at times quite exciting — for example, in the descriptions of Jupiter and of Titan. The narrative is also seasoned with glimpses of the author Steve Miller's personal interest in Hawaii.

The communication of relative distances and timescales is always difficult in non-technical writing, but the reader's head soon begins to spin with numbers — on one page I counted the use of the words "million" five times and "billion" six times. Use of ratios or more comparisons would have helped. The choice of illustrations is rather strange. There are a few diagrams, but not necessarily where they are most needed — for example, there is no picture of a spectral line, and yet for no obvious reason a few photographs of some relatively less-well-known astronomers have been included.

What is one to make of a sentence like "[the] laboratory and calculated line wavelengths would match to an accuracy greater than the actual line measurements themselves"? Or writing about the pulsar with the first detected planets "the wobble in PSR B1257+12's position in the heavens was tiny, just about half a centimetre"? — the distance of the pulsar from the barycentre (if that is what is meant) is surely much greater. There are far too many muddled examples like this — the book could have been much improved with good sub-editing.

You will probably either enjoy the jokey style or groan in despair. I could not help a smile at the image of a photon struggling through scattering as though "Jack the Ripper slid undetected past groping policemen, hidden by the gloom", but I began to wince at the thought of what properties of methane might be emphasized. The two shortest sentences in the book are "OK?" and "Phew". I seem to remember another quite short one in the New Testament … .

Despite my caveats, the book might well inspire A-level students or their teachers to see the Universe as a place with many very interesting chemistry problems. — MIKE EDMUNDS.

The Molecular Universe (IAU Symposium 280), edited by J. Cernicharo & R. Bachiller (Cambridge University Press), 2012. Pp. 500, 25 × 18 cm. Price £76/$125 (hardbound; ISBN 978 1 107 01980 5).

While some may quibble and ask if there really is such a thing as 'the molecular universe', others will recognize that molecular astronomy has indeed come of age (as the editors claim) and now contributes enormously to astronomy. Rather few astronomical investigations can still be completely untouched by molecular astrophysics. The scientific areas covered in this symposium read like a list of many of the current 'hot topics' of modern astronomy. A casual glance at any journal shows that star formation remains one of the most active areas of astronomy today, and excellent progress continues to be made as the papers in this section show. But most impressive and exciting for this reviewer were the sections on extragalactic chemistry and on the Solar System and extrasolar planets. On reading papers in these sections, one has the feeling that we are truly on the cusp of striking advances in both areas, and that *ALMA* and other new facilities will surely bring them to fruition.

The symposium on which this book is based is one of a series that recurs every five years or so. Each volume shows accelerating progress, not only in astronomical discoveries and numbers of papers presented but also in the underpinning laboratory and theoretical work that ensure future advances. The next few years will surely continue this progress, and this volume provides an essential overview of the present status of the subjects covered. Readers should note that this large volume contains only the reviews and invited talks; the four hundred contributed talks and posters can be found on the website of the conference. Your reviewer has already found that site to be an excellent additional resource. — DAVID WILLIAMS.

The Fifth Meeting on Hot Subdwarf Stars and Related Objects (ASP Conference Series, Vol. 452), edited by D. Kilkenny, S. Jeffery & C. Koen (Astronomical Society of the Pacific, San Francisco), 2012. Pp. 266, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 786 5).

In the autumn of 1964, I began my life in astronomy as an undergraduate at the University of St. Andrews, where one of my classmates was Dave Kilkenny. In the course of our studies we were introduced to the faint blue stars known as subdwarfs, by the late Phil Hill. Whereas I went on to wander aimlessly across the H–R diagram, Dave concentrated his efforts in the subdwarf arena and duly became a pundit. Thus it happened that he was honoured by his colleagues at a workshop in 2011 July, the fifth in a series on the topic, in celebration of his 65th birthday. The location was Stellenbosch, the heart of the wine-producing region of South Africa — not a total surprise, knowing Dave! And neither was it a surprise to find several other alumni from St. Andrews in attendance.

The meeting covered four principal topics: 'Formation and evolution'; 'Atmospheres'; 'Binaries'; and 'Pulsations'. In each, the most modern observational technology has expanded our capabilities to probe these stars in their advanced state of evolution, from full-spectrum studies of abundances through to results from *Kepler* on the pulsational activity in sdB stars. Simultaneously, ever-more-sophisticated atmospheric and interior modelling has been applied to reveal the structural and evolutionary status of this fascinating group of objects and their relatives (including the pre- and post-subdwarf stages).

I'm sure that in the fullness of time there will be a sixth meeting, and I'd also be prepared to have a small wager that Dave will still be contributing. — DAVID STICKLAND.

Tracing the Ancestry of Galaxies: On the Land of our Ancestors (IAU Symposium No. 277), edited by C. Carignan, F. Combes & K.C. Freeman (Cambridge University Press), 2012. Pp. 348, 25 × 18 cm. Price £75/$125 (hardbound; ISBN 978 0 521 76602 9).

This is the proceedings of a meeting held in Burkina Faso in 2010 December, with the dual aims of reviewing work on the evolutionary links between high-redshift and nearby galaxies, and supporting the development of astronomical research in African countries outside of South Africa. Judged from the list of attenders, there was a large French and Canadian presence, though many other countries were represented. The main scientific emphasis was on large surveys at all wavelengths, covering the stellar, gaseous, and kinematic properties of galaxies. Although there are some slightly longer (six-page) reviews from invited speakers, the rest is a fairly uniform set of four-page papers noting recent work in many areas covered by the umbrella of evolution. This is a useful and wide-ranging (if incomplete) summary of the state of play in these areas at the time of the symposium; nevertheless I would imagine that the meeting itself was more valuable to the participants than the proceedings will be to future readers. — STEVE PHILLIPPS.

The 16th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (ASP Conference Series, Vol. 448), edited by C. M. Johns-Krull, M. K. Browning & A. A. West (Astronomical Society of the Pacific, San Francisco), 2011. Pp. 549, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 776 6).

It is somewhat challenging (or "difficult", as we used to say before it became non-U to admit to anything that could embrace failure) to review the proceedings of a conference. In its accepted apparition, the book is a collation of papers that reflect the oral and (possibly) poster presentations of the conference, and the editors usually see their job as trying to ensure that each submission is expressed in adequate language, is consistent in its numbering and placement of figures, tables, bibliographic details and footnotes, fits within the allocated number of pages, and runs correctly through the publisher's word-processor. Those books are primarily reports of meetings — expected by the community, required by the organizers, and anticipated by the contributors. The contents are not refereed, and while they may constitute valuable sources of reference for some subjects the majority usually describes work that is already, or will be, in print in a journal that is refereed. Conference proceedings have no competitors, so if a presentation was delivered then the written version is bound to be included. This one has write-ups of what were judged to be the top 15 posters as well.

So why buy conference proceedings? Is *Cool Stars XVI* just another 'same old'? Its Foreword is a touch self-deprecating, describing both the contents and the organizational efforts as "usual", but those contents magnificently defy any inkling of sameness. The many outpourings of (as it were) 'accidental' science from *Kepler* are mind-boggling enough, but there is also a rich offering of hot topics ranging from Li abundances in planet-hosting stars, CMEs in young stars, and stellar magnetism everywhere, to the exciting aspect of measuring interferometrically how some giants change in size and shape in just weeks. Every star whose $T_{\rm eff}$ can be written in less than five figures is here, and some T Tau and Be stars have crept in under the canvas too.

The splinter sessions which have become a tradition of 'Cool Star' meetings were run as mini-conferences. Surprisingly, not all were about astroseismology, time-domain science and new surveys, or cool stars as planet hosts; fundamental parameters and stellar modelling are strongly featured too. The sessions are written up as reviews or condensed reports of contributions, and while some were able to schedule an 'open discussion', we do not find the kind of stop-press news that is seeded by face-to-face discussion. But the book is already nearly two years old anyway.

I had just a few grumbles. The editing has not been perfect, and while not all that many typos or other mistakes slipped in there are still more than there should be. There is no indication against each article of whether it was invited, contributed, or originally a poster (that information is reserved for the index only). I also do not think the snapshots (one cannot describe them more flatteringly) of people in half-empty rooms at coffee-breaks add anything to the presentation of the book. But those are relative trivia, and may be too deeply embedded in the tradition to undo. Anyone new to astrophysics need not feel the urge to move to more exotic fields in order to find really hot science — it is all here, among the mundane cool stars and stellar systems, a treasure-house of new information and a valuable starting-point for every seeker of current information about stellar research. — ELIZABETH GRIFFIN.

OBITUARY

Peter Dennis Hingley (*1951–2012*)

On June 22 the RAS made the shocking announcement that its Librarian Peter Hingley had died. He had been unwell for a week, but his number came up on Wednesday 20th. Peter would certainly have thought the Reaper had lost all sense of reality, not to mention gentlemanly consideration, since he was only 60, his friend Françoise was due to arrive at the weekend to commence a trip on the Norfolk Broads with him, his favourite 'Dotty Aunt Peg' was shortly to celebrate her 91st birthday, he had articles in draft, models half built, steam trains waiting, and committee meetings scheduled which needed his sage input.

His paternal grandfather had lived to 96, his great-aunt to 98, and Peter was a man in the full flow of life.

However, his health had been noticeably poor for about eighteen months, and he was hospitalized after a fall, and with a nasty virus, in February. He returned to work in good spirits, and pitched into his various commitments while at last taking his full weekends off, enjoying model-making or music if it was wet, rust removal and painting old steam engines if it was fine, telling his awful jokes to anyone nearby. He relished retiring on August 31 and moving to Crewe — at the heart of a web of steam railways, canals, and other essentials. Alas! It was not to be. He fell ill again in mid-June, and this time his usual head of steam failed him.

Peter was a polymath scholar and dedicated librarian and archivist with a fine mind, great memory, quick wit, mischievous sense of fun, passion for all things historical, and he had a great big heart. He was tirelessly interested in and encouraging and helpful to all researchers and enquirers to the RAS's beautiful library. In 2011 Dr. Barbara Becker published *Unravelling Starlight*, her biography after 20 years of research on William and Margaret Huggins; "Without [Peter's] enthusiastic intercession on behalf of my manuscript, it would still be filed away out of public view." When a team of amateurs in Australia started restoring the *Great Melbourne Telescope*, a friend here asked Peter if he had any photos; he found some they did not have, and provided prints that have been immensely helpful. He was a willing horse on any committee he was asked to serve, the first to step into any gap regardless of personal over-load. He was in demand to give talks to astronomical societies, learned and other societies, at home and abroad, too numerous to tally.

Peter was born on 1951 October 6 in Pedmore, near Stourbridge, Worcestershire, and was inordinately proud of being "descended from long lines of Black Country ironworkers and Staffordshire and Shropshire yokels". His male Huguenot line to his delight produced Noah Hingley & Sons, who made chain cable and anchors for many great ships, including the *Titanic*.

After attending King Edward VI Grammar School, he "staggered out of Lancaster University in 1973 with an indifferent degree in Environmental Sciences". He took a labouring job in a cotton mill for a short time, but having "been treated kindly by agreeable and civilized librarians" he identified that profession as a route to remote locations, escape from sciences, and possibilities to engage in subjects that actually interested him. He was a countryman at heart, having spent much of his youth in his beloved Shropshire. With his usual unerring aim his first post was in Piccadilly, London, as Librarian to the Society of Antiquaries — hardly remote, but specializing in history and archaeology. In 1980 October he was "rustled" to work as Assistant, then Librarian, at the RAS. He found that job most rewarding and pleasant, and it led him to describe himself as "an aesthete on the edge of science", although in reality many scholars have benefitted from his profound knowledge of astronomy and other sciences. When Halley's Comet returned in 1986, Peter cycled across London to Edmund Halley's grave near Greenwich, and observed it from there. Of course.

Meanwhile Peter thoroughly enjoyed serving eighteen years in the Royal Naval Reserve, achieved the rank of Lt-Commander, and received the Reserve Decoration. His ex-wife Sheila visited him on his ship in Portsmouth, and never saw him happier. He could park a minesweeper before he belatedly passed his driving test.

Peter enjoyed concerts, such as those at Wigmore Hall, Thames barges, cycling, and passionately loved the Lake District. He rescued the last Severn Trow from Diglis Basin — *The Spry* is now in a display shed at Blist's Hill open-air museum, part of the Ironbridge Gorge Museum. Sundays in London would often be spent walking to 'Ally Pally' and throughout his life runs a skein of a passionate interest in gardening, possibly inherited from his maternal grandfather.

Recent published work included *Droitwich Sailing Barges*, and *A Far Off Vision — a Cornishman at Greenwich Observatory* about astronomer Edwin Dunkin, a lengthy series of short notes in *Astronomy & Geophysics* on various items from the library and archives, Warren De La Rue and the *H.M.S. Himalaya* expedition, Father Stephen Perry and the Transit of Venus, and other worthy topics. His desk and computer hide drafts on Shuckburgh and the English [telescope] mounting, Shropshire shipbuilders, the history of Durham University Observatory, and a diverging flow of other topics.

As RAS Librarian Peter was custodian of T. W. Webb's original observing notebooks and wanted to see something done with them. Webb spent much of his later life as Vicar of Hardwicke near Hay-on-Wye. About 25 years ago the rectory at Hardwicke passed into the hands of Janet and Mark Robinson who were happy to be cajoled by Peter into delving deeper into Webb's life and times. Peter rounded up a distinguished set of international contributors to provide individual chapters. The resulting book, *The Stargazer of Hardwicke*, edited by the Robinsons and dedicated to Peter, came out in 2006.

For some years he has been a Consultant to Commission 41 of the IAU, and was elected a full IAU member at the 2006 General Assembly in Prague. Peter was founder member Number 13 of the Society for the History of Astronomy in 2002, and was hugely supportive, including hosting Council meetings in the library, and in his own time "stuffing and posting" publications and mailings. He was elected a Council Member in 2005, and in 2008 upon the death of a colleague volunteered to take on being Membership Secretary. When there was another crisis in 2010 he was about to take on the Treasury too. That's how he was, regardless of his own well-being, giving himself to whatever he really believed was worthwhile.

Peter leaves his daughter Eleanor finishing her Master's degree in Norfolk, his ex-wife Sheila with whom he kept in touch, at Durham University, his musical sisters Jane Rigby (singer) and Clare Walker (a fine bassoonist), Clare's son Joseph (his godson), and his 'Aunt Peg' (a retired teacher and B.A.) with her four cats in Cannock. His endlessly loving and supportive mother, with her sharp intellect and wonderful sense of humour, had died in 1999. He also leaves Françoise Launay, his loyal, learned, and wise companion.

Peter's extraordinary mind, informal ways, and outgoing personality gained him many friends in many countries. A gentle man who really did make a difference, he will be remembered by anecdotes, with gratitude and smiles. — ROGER HUTCHINS.

EDITORIAL

Subscription Prices

In the October issue last year (on p. 336), subscribers were cautioned that a price increase for 2013 was almost certain, and the Editors regret that it has become necessary to make that prediction come true. This is largely owing to a very substantial increase in prices by Royal Mail in 2012 April, where, in probably the most serious case, the cost of airmailing (at the printed-paper rate) a typical 120-g magazine to the USA has risen from £2·32 to £3·86, an alarming 66%. It is not at all clear that above-inflation price rises by Royal Mail will not continue into the future, but they do seem to provide the most reliable means of distribution.

It has been our policy in the past simply to break even, financially, and that we intend to continue to do. We would, however, point out that the price of a basic subscription for institutional subscribers has remained constant for three years (and longer for personal subscribers) while inflation has continued (in spite of the recession). We have therefore carried out a full review and hope that with the prices given below, we may enjoy a further period of stability.

Thus for 2013, the price (including postage) to institutions in the UK will be £80 and that to individuals (who undertake not to re-sell or donate their copies to libraries) will be £20. The postage supplement for overseas subscribers will be £15; thus prices for overseas institutions will be £95 or US$150, and for individual subscribers will be £35 or US$60.

Here and There

FISHING EXPEDITION

… we await the observations of NASA's *Juno* mission with baited breath. — *The Observatory*, **132**, 62, 2012.

STRANGE TWIN

Arcturus … used to be identical to the Sun … — *Daily Telegraph*, The Night Sky for April.

BAD NEWS?

… they knew they were close to their destination when Arcturus had moved to be above their heads. — *Daily Telegraph*, The Night Sky for April.

WE WOULDN'T WANT ANYTHING INDECENT SENT TO MARS

NASA providing … key instruments, communications ... as well as a decent system to get the rover to the martian surface. — *Astronomy & Geophysics*, **53**, 2.4, 2012.

SHORT OF A FEW ZEROS

Nomad planets in Milky Way may outnumber stars… . Researchers … estimate there may be up to 100 000 such planets in the Milky Way alone … . — *Astronomy & Geophysics*, **53**, 2.5, 2012.

AN UPRIGHT ASTRONOMER INDEED

I was able to go from my home … to evening classes in astronomy at the Normal Lockyer Observatory. — *Astronomy & Geophysics*, **53**, 2.11, 2012.

IN-DEPTH STUDY

Robert Ballard, a professor of oceanography at the University of Rhode Island, said last week that he will apply for a permit from US authorities to conduct an ambitious operation nearly 212 miles beneath the surface. — *Victoria Times-Colonist*, 2012 April 14.