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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2010 March 12 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

A. C. FABIAN, *President*
in the Chair

The President. I'd like to get the meeting started. Our first speaker is Dr. Kevin Schawinski, formerly of the University of Oxford and now based at the Yale Center for Astronomy and Astrophysics. He is to be awarded the 2009 Michael Penston Prize, and then he will talk to us about his work. The presentation is to be made by Dr. Ray Boucher, Editorial Director at Wiley-Blackwell. [Applause.] We'd like to thank Wiley-Blackwell for sponsoring this award.

Kevin will now talk to us about 'Star formation and black-hole growth in early-type galaxies.'

Dr. K. Schawinski. The symbiotic relationship between galaxies and the supermassive black holes lurking at their centres remains a mystery at the heart of galaxy formation. Why do black holes, whose gravitational sphere of influence is tiny compared to the scale of galaxies, seem to know about the galaxies they live in? Why do these black holes consistently weigh about one thousandth of their host bulge? Since early-type galaxies by definition lack the discs of spiral galaxies, the question focusses on how the joint formation of galaxy bulges and black holes proceeds. The leading hypothesis for how this might happen is the coupling of the energy liberated by feeding black holes — active galactic nuclei (AGN) and quasars — to the state of the host galaxy.

As galaxies convert their gas into stars, some small fraction of that gas reaches the nucleus where it begins to accrete onto the black hole. Such an accretion event can liberate enormous amounts of energy that, if only a small fraction of this energy couples to the ambient gas, is sufficient to blow out and heat this gas. Thus, the fuel for star formation leads naturally not just to black-hole growth, but also to a termination of both processes, resulting in the observed correlation between galaxy and black-hole mass. Placing black holes in this critical rôle of 'thermostat' for the entire galaxy–black-hole system has been highly successful when implemented in simulations of galaxy formation.

But what is the empirical evidence for this feedback process actually occurring? In the nearby Universe, galaxies hosting AGN appear to cluster in a region between the red sequence of passively evolving galaxies and the blue cloud of actively star-forming galaxies. Their position in this 'green valley' between the two main galaxy populations has been interpreted as evidence that black-hole accretion phases are implicated in the transition of galaxies from blue to red. The massive but short-lived O and B stars that give star-forming galaxies their blue colour disappear, leaving the galaxy first green and, after about a billion years, all that remains are low-mass red stars that dominate red, passively evolving, early-type galaxies. Accretion phases occur when galaxies are green, therefore the energy liberated by them is affecting their host galaxies.

However, this interpretation is problematic: if all active black holes are in galaxies that are green and have already lost all their blue stars, then they cannot be responsible for the suppression of star formation that moves galaxies from blue to red. The massive, luminous OB stars have already ended their short lives before the central black hole starts to feed. The black-hole accretion is a consequence of the shutdown of star formation, not the cause. Detailed study of nearby early-type galaxies whose black holes are accreting significantly shows that star formation in them has already ceased, typically several hundred million years ago.

This delay between the termination of star formation and the start of significant black-hole growth poses a challenge to the picture where such accretion phases are directly responsible for the shutdown of star formation. But reality is perhaps more subtle. The activity of the black hole rises slowly over time and reaches its peak luminosity too late, leaving some room for early, lower-luminosity phases to have an impact.

The fuel for star formation is dense, molecular-hydrogen gas. Observations of this gas as a function of time, as early-type galaxies move from blue to red, show that the disappearance of this molecular gas is too rapid to be accounted for by the consumption due to star formation, and is coincident with the rise of a low-luminosity black-hole accretion phase. If black holes are responsible for the shutdown of star formation by destroying these molecular-gas reservoirs, then it must be during this early phase, and not in the highly efficient accretion phase peaking hundreds of millions of years later.

A possible interpretation for this sequence of events is that this early phase of accretion is radiatively inefficient and so the accreting black hole does not emit much radiation and instead is putting the bulk of its energy into thermal or kinetic energy that couples to the rapidly disappearing gas. Such radiatively inefficient accretion states were first proposed to explain the low levels of emission from the black hole at the centre of the Milky Way galaxy and have since been applied to other classes of active galactic nuclei. If such a phase is in fact present and affecting the gas reservoirs of star-forming early-type galaxies, then this would reconcile the weak emission from the black hole with the black hole's apparent transformative power over the host galaxy.

Many questions remain — is this interpretation correct? Observationally detecting this non-radiative energy output in the midst of a dying starburst may be difficult with present-day facilities. Are efficient black-hole-growth phases in post-starburst environments a generic feature in early-type formation, or are they a phenomenon only in the nearby, evolved Universe? It is plausible, even likely, that the massive spheroidal galaxies that formed in the early Universe underwent a different sequence of events, and that the relationship between galaxy and black hole was fundamentally different. Future facilities like the

James Webb Space Telescope and the *Atacama Large Millimeter Array* are needed to answer this question.

The President. Thank you for a very nice talk. Can I start by asking what fraction of the mass of the host galaxy is in the starburst and what is in the accretion?

Dr. Schawinski. The mass in the starburst ranges typically between one and ten per cent of the total mass. I'm not sure we can calculate the mass in the accretion because we might be undersampling the sequence: we might be missing things that still look like mergers that we have discarded, and also turning the [O III] luminosity into a reliable accretion rate is challenging. To work out how much mass is actually accreted onto the black hole, we would need X-ray data. My general feeling is that it is not that significant, because presumably the progenitors already have sufficiently large black holes that they may be growing by a factor of 10 at most.

The President. Is it possible that the Sanders picture may still apply at a redshift of 2?

Dr. Schawinski. Absolutely! The Sanders picture was designed for ultra-luminous infrared galaxies, which might be a scaled-up version of what is happening here; the difference I highlight here may not apply to those objects.

Professor R. C. Kennicutt. You've made an argument about the inability of the gas depletion from a Schmidt law to reproduce the results. From the curves you've shown, that must have assumed that the gas was distributed over the entire disc. Of course, if it were confined to the circum-nuclear regions, I presume that it would work fine — is that scenario consistent with what you'd expect in the merger-driven picture?

Dr. Schawinski. We do assume that the dynamical timescale is that of the whole galaxy. If you turn this into a nuclear starburst, then, yes, you can do this much faster. The reason why we think that's not the case is that when we look at these blue early-type galaxies, we see that they are blue all the way out to the effective radius and beyond.

Dr. C. Steidel. I think most of the evidence at high redshift points to the same kind of sequence. We only see the AGN activity in galaxies that are about to run out of gas anyway. It doesn't help solve the chicken-and-egg problem of whether it is star formation or the AGN that gets rid of the last bit. Many people have argued that it's hard to couple the energy produced by the AGN to move gas around, whereas it is easier to do that with supernovae.

Dr. Schawinski. I think that's true, and I think that theorists need to show how to blow the entire ISM out of a galaxy; jets seem not to be able to do it in objects like this, and you probably need either a wind or an outflow to do it.

Dr. S. Bamford. This may be an unfair question, as I'm not sure anybody knows the answer, but do you have any idea of how to stop the accretion onto the black hole when the galaxy is forming stars? It seems with this picture that when there is star formation, you can't have accretion on the black hole, and that as soon as star formation stops, it occurs.

Dr. Schawinski. I think one way to do it — and this is based on work which Rick Davies has been doing with IFU observations of nearby Seyferts — is to realize that it's very hard to get gas to go all the way down to the central engine; if you have something moving gas around at high velocities, say OB-star winds, or core-collapse supernovae (SNe), that creates conditions where it is very hard for the gas to reach the black hole. It's only once you no longer have core-collapse SNe and OB-star winds that the gas can make it down to the black hole. That's a very natural way to get this phasing.

The President. Thank you very much again. [Applause.]

Our next speaker is Dr. Jessica Irving of Cambridge, on 'East *versus* West: hemispherical structure in Earth's inner core.' I would just add that Jessica was a 2009 winner of the *Geophysical Journal International* (*GJI*) student-author award, designed to recognize and acknowledge the best papers submitted to *GJI* from young scientists in the field, for her paper, 'Normal-mode coupling due to hemispherical anisotropic structure in Earth's inner core.'

Dr. Jessica Irving. [No summary was received at the time of going to press. The speaker began by commenting that we now know the Earth's inner core has a radius of about 1220 km, just a little bigger than Pluto, but it was only discovered *after* Pluto, even though we are standing on it. From its density and inertial moments, one can infer that it must largely be a solid iron–nickel alloy. But studies of iron–nickel meteorites show admixtures of lighter elements; and it is very hard to predict the precise crystalline structure of the inner core owing to the sensitivity of *ab-initio* models to the inclusion of light elements.

Anisotropy in the inner core has been suggested to explain the variation of body-wave travel times with direction: such waves propagate more slowly parallel to the equatorial direction than when moving parallel to the Earth's rotational axis. The speaker described how time delays between earthquake-generated body waves passing through the mantle and outer core and those passing also through the inner core are used to measure this cylindrical anisotropy. Further, it is found that the polar paths of body waves show anisotropy only in the western hemisphere of the inner core: there is hemispherical structure in the inner core.

The speaker described further how she has been applying new theory and modelling to investigate the frequency spectra and splitting of normal modes — free oscillations of the Earth as it 'rings like a bell' — to demonstrate the differing anisotropy of the two hemispheres, and to attempt to probe more complicated forms of hemispherical structure. She concluded that there are indeed two distinct hemispheres in the Earth's inner core — a less-anisotropic eastern hemisphere, and a more-anisotropic western hemisphere. It has been suggested that the origin of this anisotropy may be related to non-uniform heat flux across the core–mantle boundary as the inner core grows, affecting the crystalline alignment of the inner core as it freezes out; or there may be an underlying magnetic cause.]

Professor P. G. Murdin. I am standing up to chair the rest of this session, as the President has been called away on other business at the Royal Society. Are there any questions?

Mr. M. Hepburn. Presumably you are not thinking of ferromagnetic interactions?

Dr. Irving. No, the geodynamo simulations that have been carried out for the Earth's magnetic field suggest that geomagnetic forces are caused by the geodynamo. As it is all happening in the outer core, it is more straightforward to understand how that linkage might take place through the outer core.

Professor D. Lynden-Bell. Is there a connection at all with the westward drift, and do we know how the inner core is rotating with respect to the outer core?

Dr. Irving. Yes — well, I will tell you I think I know, though other people would disagree quite strongly with this! There have been suggestions that the inner core is rotating by up to a couple of degrees per year with respect to the rest of the Earth. So those suggestions would mean that every 400 years or so the inner core would have done an entire extra lap, if you like. Given that we definitely see this hemispherical structure in the inner core, and that whether it is a deformation structure or a growth structure, it must have been either deforming or growing on the order of at least half a billion years, I think it is very difficult to envisage how we could have the inner core spinning round an extra degree per year. So in terms of thinking about inner-core rotation problems, one of the best constraints we have on possible inner-core rotation is the fact that we see these hemispheres; so the inner-core rotation is much more likely to be inner-core wobble, backwards and forwards. I think inner-core free rotation is ruled out by this type of data.

Rev. G. Barber. In that case, what is causing the wobble — is it a magnetic interaction, a transfer of angular momentum?

Dr. Irving. Yes, I think that's the most likely suggestion. There are a lot of people looking at the geodynamical possibilities at the moment; it's certainly not my field, but that's what they lead me to understand.

Mr. H. Regnart. Is it possible that the inner core has a slightly offset axis of rotation and might be precessing slightly?

Dr. Irving. This is something that has been discussed fairly continuously for some time, and to be quite honest the jury is still out. Certainly the precession of other parts of the Earth is studied in much more detail. The problem with the Earth's inner core is that whatever sort of data you use, the signal is damped by the rest of the Earth. As with the body-wave data I showed at the beginning, we have to use reference phases because the mantle, outer core, and crust are in the way, and that's certainly the case when we're looking at other sorts of inertial questions. So the answer to your question is 'possibly'.

The Vice-President. Thank you again, Jessica, for a very clear presentation. [Applause.]

Our third speaker this afternoon is Rob Kennicutt of Cambridge, talking about 'Hubble's constant in the era of precise technology.'

Professor Kennicutt. Recently I was invited by the RAS to give a reprise of the Gruber Cosmology Prize Lecture that Wendy Freedman, Jeremy Mould, and I delivered last year at the IAU General Assembly, in recognition of our work on measuring the extragalactic distance scale and Hubble constant. Today I thought it might be more interesting briefly to summarize that work (which by now is nearly a decade old), and then describe how the subject has progressed over the past decade.

The Hubble constant measures the slope of the velocity-*versus*-distance relation for galaxies, and scales inversely with the expansion age of the Universe. Today it is common to see measurements of H_0 quoted with precisions of a few percent or less, which is remarkable considering that H_0 was not known to better than a factor of two as recently as 20 years ago. How did we make such remarkable progress, and are the new precise measurements to be believed?

The difficulty in measuring H_0 arises from the vast distances over which the distance ladder must be extended to track accurately the cosmic expansion rate, out to at least 100 Mpc. By comparison, ground-based measurements of Cepheid variable stars, the most reliable extragalactic standard candle at the time, could only be applied to distances of $\sim$5 Mpc. To bridge this large 'twilight zone' in between, other 'secondary' distance indicators needed to be calibrated to extend the Cepheid scale. These included type-Ia supernovae, the Tully–Fisher and fundamental-plane relations for spiral and elliptical galaxies, respectively, surface-brightness fluctuations, planetary-nebula luminosity functions, and other methods. These methods could extend the reach of the Cepheid distance scale but their zero points needed to be calibrated by using the handful of galaxies with Cepheid distances from the ground. As a result, many of the secondary candles rested on as few as one or two zero-point measurements; thus it is hardly surprising that different methods gave values of H_0 which differed by up to factors of two.

The *Hubble Space Telescope* (*HST*) was key to breaking this impasse, because its superb imagers could resolve Cepheid variable stars out to distances of 20 Mpc and beyond. This was not far enough to measure H_0 directly, but it was sufficient to provide ample robust calibrations for several secondary distance methods. A Key Project was defined with the goal of measuring H_0 to an accuracy of 10%, and our team was fortunate enough to be awarded the project. Skipping to the conclusion (and glossing over a decade of hard work by a team of more than 25 people!), we used Cepheid distances to 24 galaxies to calibrate five different secondary distance indicators, and used the consistency of the results along with tests of the Cepheid distances themselves to determine robustly the uncertainties in our measurements. Our final result, published in 2001, gave $H_0 = 72 \pm 7$ km/sec/Mpc, just under the 10% benchmark.

Although these results received considerable attention in the professional community as well as in the popular media, not everyone was prepared to believe that we had achieved a 10% measurement after decades of previous claims which later proved unfounded. Consequently it came as a welcome surprise to us when the first-year results on the cosmic microwave background (CMB) from the *Wilkinson Microwave Anisotropy Probe* (*WMAP*) produced a completely independent measurement of H_0 which fell within 2% of our own! In succeeding years the *WMAP* results have been further improved, and the agreement between the CMB-based results and the Cepheid-based distance ladder has persisted. This consistency is a primary pillar in what is now coined the 'concordance cosmology', and most astronomers take the quoted precision of the CMB measurement for granted.

Given this story, should we regard the H_0 problem as solved, and move on to other astrophysical pursuits, or should we retain a measure of cautious scepticism? Although I would be delighted to see this concordance confirmed, there are good reasons for improving the earlier measurements, and testing this apparent agreement. For one thing, the CMB mapping does not uniquely measure the Hubble constant; its power spectrum is also influenced by the acceleration history, the densities of dark matter, dark energy, and baryons, and other parameters, and as a result the H_0 measurement is dependent on prior assumptions about the cosmological model. Most of these are likely to be robust, but a strong independent measurement of H_0 provides a useful test.

Recent work in this area has focussed on reducing the largest sources of systematic error in the Cepheid distance ladder and on developing new single-step methods which bypass the many other rungs of the distance ladder. The former include new infrared measurements of the Cepheid period–luminosity (Leavitt) relation to reduce errors from dust extinction, calibrations of the dependence of the Leavitt relation on metal abundance, and independent local-distance calibrations based on other standard candles, for example, the red-giant-branch-tip luminosity. Other projects have redefined the zero point of the Leavitt relation using other galaxies (*e.g.*, M33, NGC4258), reducing the singular dependence on the Large Magellanic Cloud distance in the *HST* project. At the same time work continues on calibration of single-step techniques, including time-delay measurements of gravitationally lensed quasars, Sunyaev–Zel'dovich-effect measurements in clusters, and most promising of all the measurements of luminous circumnuclear masers around nearby galaxies, which offer the potential of a direct trigonometrically calibrated distance scale. To date this work has reduced the uncertainty in the H_0 ladder to less than 5%, in agreement with the CMB measurements and our *HST* Key Project results. The era of truly reliable measurements of Hubble's constant at the 1% level may not be far away.

The Vice-President. Thanks, Rob, for that insight into at least a decade of your life! Are there questions? Donald?

Professor Lynden-Bell. Much of the readily accessible, non-obscured sky is away from the Galactic plane, and it may be a reasonable thing to ask what is your limit on the anisotropy of the Hubble constant?

Professor Kennicutt. These measurements are not the way to measure that. We made tests based on our secondary indicators: in fact, we were not so interested in anisotropy, but to test whether we could be in a bubble, essentially to look at the Hubble constant as a function of distance. Along the way, I recall that somebody did a cursory analysis for anisotropy, but there are so many better ways to do that. I would say based on what I know of the latest of that work, the interesting result, as you know, is that we are not at rest with respect to the cosmic microwave background, but that there is a 600 km s^{-1} motion towards an apex. No survey of redshifts of galaxies up to any distance to date has detected all of that motion — there is of course the Great Attractor and other components to it, but that is one of the thorns in the side of the concordance picture.

Mr. Hepburn. What is the attitude of the 'Holy Office' to Allan Sandage, who is still smuggling out papers at least to argue for a Hubble constant of about 60–65, quite substantially lower than your 70–75?

Professor Kennicutt. Of course, there is always a history to this — actually having answers within 10–15 percent is progress, compared to a factor of two. If you hold up their analysis to ours, I will defend our analysis; of course, I think ours are the right answers. But I have to say, and I am not the only one, I have been uncomfortable with the rapidity with which people like Allan were ignored afterwards. Part of the reason that a value of 72 was accepted is that it now fits, just as 20 years ago a value of 50 fitted an inflationary cosmology; I think whether you agree with Allan or not, I for one believe that it is essential there are critics who peck away at this at least for another decade or so.

The Vice-President. I think we need to move on.

The Eddington Lectures were initiated two or three years ago by the Institute of Astronomy, Trinity College Cambridge, and the RAS, and the fact that there are so many sponsors implies that it has to be given more than once; it was given in Cambridge yesterday, and a version will be given here today. Dr. Peter Smith, from the Lunar and Planetary Laboratory in Arizona, will give the Eddington Lecture, on 'Searching for life on Mars'.

Dr. P. H. Smith. [It is expected that a summary of this lecture will appear in a forthcoming edition of *Astronomy & Geophysics*. Since at least the 17th Century, scientists have wondered about the chances of finding life on Mars. They were taunted by blurry images seen through primitive telescopes that allowed a wide variety of interpretations concerning the surface characteristics. By the early 20th Century science-fiction writers created fantasy worlds that brought great excitement to the first missions to Mars in the 1960s. But space missions reveal a dry, cold, barren world albeit with a wet and volcanically active past, so any life forms could have thrived only in the early years of Mars' history, that is billions of years ago. Any existing life on Mars is scarce and microbial in size, limited to those locations that allow liquid water to be periodically stable. Scientists are encouraged in their search by the diversity of hardy communities populating the most extreme environments on Earth. Despite the dead-planet model, a new series of missions is finding habitable zones that may yet contain clues to Martian life. The *Phoenix* mission is one such attempt to find habitable environments associated with the permafrost in the northern polar region.]

Mr. I. Ridpath. Is it now fully understood why the *Viking* experiments detected so much oxygen? For example, one of the experimenters continued to argue for years afterwards that he had discovered signs of life.

Dr. Smith. The reason he said that was that there were very strict boundaries on what would be a life signature, and that if there was more than a certain amount of ^{14}C, that would be a life signature; and that's exactly what he found. So there wasn't any wriggle room for him: he met a criterion that was set before the mission, having tested it many times on Earth. But when there were no organics found it was hard for people to understand how you could be releasing this carbon when there was no carbon there: they thought perhaps there were oxidants reacting with some of the nutrients in the experiment and making that release. So it left this big question mark over the whole mission — the lack of organics is what quashed this idea of life at the two *Viking* sites.

However, now we've found perchlorate — the attempt to detect organics was done by heating up the sample to as high as 500 degrees, and if there is perchlorate in with the sample, they can combust and give a release of CO_2 with no organics at all. So I think people are now looking back at the experiment and wondering if was really the right answer.

Rev. Barber. I thought there was a problem with one of the experiments anyway: there was a question as to whether the instrument was working correctly before launch.

Dr. Smith. I had not heard that the instrument was malfunctioning; there were several instruments, so perhaps we're not talking about the same one.

Professor D. W. Kurtz. Can you say something about the sub-surface temperature gradient and the potential for extremophile bacteria living off the internal heat of the planet?

Dr. Smith. As with any planet, the temperature does increase as you go towards the centre. On Mars, we tend to think of a cryosphere under the surface until you get to a temperature that is warm enough to melt the ice and form a hydrosphere, with the cryosphere acting as a cap that holds that water in. Some of the ideas about these huge flows that I showed, the large flood channels and river valleys, is that the ice cap has been breached and water has come out: there is almost certainly water at depth, and there are fractures all over Mars. And if you have warmth from volcanic activity, you could have very much more habitable regions at some depth under the surface — the problem is, how do you go and prove it?

Professor S. Miller. You were talking about cycles of about 10^5–10^6 years, and we know that bacteria can go into dormant states — are there any kind of limits as to how long bacteria can last for in those states?

Dr. Smith. The problem is that Mars does not have a magnetic field, so primary cosmic rays can hit the surface. So you have a much higher radiation flux on Mars than on Earth and that is going to break apart the DNA structure in any hibernating organisms. On Earth, some organisms have a way of waking up and repairing their DNA and then hibernating again; but if you don't have that repair process, an organism cannot remain viable for that long.

Professor Miller. Aren't there mini-magnetospheres on Mars — small, magnetically shieded areas?

Dr. Smith. Oh yes, you mean the remnant fields on the surface — perhaps that does act as a shield and protect some of these organisms. As we know on the Earth, some organisms are very clever in finding a way to survive; the real question is did they ever start? And you have to wonder that if life started on Mars, it would have started before life on the Earth because Mars cooled more rapidly than the Earth. We know that meteorites come from Mars to Earth, so the real question is, was there only one genesis, and are Martian and Earth life the same? I think in the next few decades — if I am bold enough to predict the future — we will start to find true evidence for life of some sort on Mars, either from methane, or from rovers, or planned missions. I recall that in the 1980s, I looked for planets around other stars, and people told me just to forget it, maybe there are just one or two; now we have over 400, and we're just geting started. I like to think that on the question of organics and life on Mars, we are in the pre-discovery phase!

The Vice-President. All good talks end on a note of optimism [laughter], so thanks very much indeed. [Applause.] Thank you all for coming; I shall now adjourn the meeting.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Thursday 2010 April 15 at 14^{h} 00^{m}
in the Bute Hall, University of Glasgow

A. C. FABIAN, *President*
in the Chair

The President. Welcome to the prize-giving ceremony, which is the best part of my job. We are going to start first with the Gold Medal for Geophysics to Professor John Woodhouse FRS from the University of Oxford. These notices will be read by Dr. Fiona Speirits and Mr. Fraser Watson, both from the University of Glasgow.

Dr. Fiona Speirits. The Gold Medal is the Society's highest honour. Professor Woodhouse is an exceptional theoretician who not only develops new theory, but also always uses his theory actually to learn something new about the Earth. His deep understanding of seismic data has led to ground-breaking developments including the discovery of inner-core anisotropy, the centroid-moment-tensor technique and the production of the first long-period tomographic models of the Earth's mantle and core.

The computational algorithm he developed to calculate the normal modes of the Earth is now a standard approach in the seismology of the Sun and certain kinds of stars. The centroid-moment-tensor catalogue contains thousands of earthquakes and is one of the most widely used resources by Earth scientists. Professor Woodhouse also helped produce the first believable maps of seismic velocity throughout the mantle and into the inner core. The impact of these maps of seismic structure cannot be overestimated: they provided the first pictures of what the interior of the Earth is like, and were crucial to understanding global dynamics and the internal thermal and mineral structure.

Professor Woodhouse is a Fellow and Inge Lehmann Medallist of the American Geophysical Union and a Beno Gutenberg Medallist of the European Geosciences Union. He was elected a FRS in 2000. He is one of the few seismologists whose name is known to all undergraduate students of the subject and whose work has been so often associated with memorable and important breakthroughs.

The award of the RAS Gold Medal to Professor Woodhouse is in recognition of his very significant contributions to the UK and worldwide geophysics community. [Applause.]

The President. The next medal we are awarding today is the Herschel Medal, to Professor James Hough of the University of Hertfordshire.

Mr. Watson. Professor James Hough is recognized as a leading world authority on astronomical polarimetry. He has made fundamental and wide-ranging contributions to this branch of astrophysics as an observational astronomer, an instrument builder, and a research leader. From small beginnings, he built his group at the University of Hertfordshire into an internationally recognized centre of excellence in such fields as the basic physics of scattering from dust and biological material.

His personal scientific contributions, including 13 papers in *Nature*, have ranged through processes such as grain alignment, star formation, and wind emission, with a special interest in the rôle that astronomical polarimetry can play in astrobiology. Professor Hough has been unselfish in his service to the community both in the UK and internationally, particularly Japan.

For all these reasons it is highly appropriate that Professor Hough is recognized by the award of the Herschel Medal. [Applause.]

The President. The Chapman Medal is awarded to Professor Bernard Roberts of the University of St. Andrews.

Dr. Speirits. Professor Roberts is one of the few creators of the subject of magnetohydrodynamic (MHD) wave theory and applications, whose papers on wave propagation in structured media have laid the foundations for the diagnostic tool of coronal seismology or (more generally) magneto-seismology. This work came to fruition when the space missions *SoHO* (launched in 1995) and *TRACE* (launched in 1998) permitted imaging of the solar corona actually to detect the MHD waves and determine their properties. The variety of MHD modes predicted by Professor Roberts have now all been identified in the corona, from both satellite and eclipse observations.

He has published over 180 highly cited papers in the field, has nurtured generations of students, and has played a leading rôle in the UK solar physics community through PPARC and the UK Solar Physics Group, of which he was Chair.

As a founder of the new discipline of magneto-seismology, Professor Roberts is an outstanding candidate for the Chapman Medal. [Applause.]

The President. The Jackson-Gwilt Medal is awarded to Professor Craig Mackay from the University of Cambridge.

Mr. Watson. Professor Craig Mackay, of the University of Cambridge, is one of the most innovative and productive researchers in the field of astronomical instrumentation in the UK; in particular he has helped bring the new electronic technology of the charge-coupled device into the mainstream of modern ground-based and space-based astronomy such that it is now the dominant detector technology for observational astronomy in the visible region of the spectrum.

His instrumental developments are fundamentally motivated by trying to solve problems in astrophysics but they have applications beyond astronomy as well. Progress in fields such as adaptive optics, interferometry, aperture synthesis, and infrared atmospheric-line suppression has been stimulated by his work.

On the basis of his innovative long-term contribution to astronomical instrument development, Professor Craig Mackay is a worthy recipient of the RAS Jackson-Gwilt Medal. [Applause.]

The President. The Award for Service to Astronomy goes to Professor Francisco Sánchez of the Institute of Astrophysics of the Canary Islands.

Dr. Speirits. Professor Francisco Sánchez is Director of the Instituto de Astrofísica de Canarias (IAC), and a leading figure in Spanish and European astronomy. He went to the Canary Islands in the 1960s in order to carry out research into the Zodiacal Light. The small astronomy group at the University of La Laguna at that time occupied temporary builders' cabins. Professor Sánchez soon recognized the quality of the Canary Islands' sky. To exploit it, since then, he has created leading international observatories on Tenerife and La Palma, housing instruments from more than sixty institutions in eighteen countries, which have had immense impact on astronomy, not least in the UK as well as in Spain, where astronomical research has been revitalized.

More recently, Professor Sánchez has been the driving force behind the world's largest optical telescope, the *Gran Telescopio Canarias*, which was inaugurated in 2009 July.

Besides being an Honorary Fellow of the RAS, Professor Sánchez has been honoured in France, Sweden, The Netherlands, Mexico, Denmark, and the USA.

For his political savvy, leadership, and commitment, spanning a period of more than 30 years, Professor Francisco Sánchez is a worthy recipient of the RAS Award for Service to Astronomy. [Applause.]

The President. The Award for Service to Geophysics is to Dr. Frank Lowes of the University of Newcastle-upon-Tyne.

Mr. Watson. It is often true in geomagnetism that 'the devil is in the detail', and Dr. Lowes' rigorous and tenacious approach has been ideally suited to gaining a deep and meaningful understanding of that detail, and working out how to deal with it.

Early in his career, for example, he made a fundamental contribution by building a working, self-exciting dynamo, where before there had been only theoretical existence proofs. Again, the 'Lowes power spectrum' has become a fundamental part of how the magnetic field is described, elucidating the regularizations used in modelling the field with spherical harmonics. A third example was when Dr. Lowes tracked down the source of magnetic noise arising from the Newcastle Metro system and indicated how to rectify the problem. In a long list of significant contributions, a final instance was how he meticulously resolved problems with the quinquennial magnetic field and secular (time) variation model, known as the International Geomagnetic Reference Field.

Dr. Lowes, of the University of Newcastle, has played a leading rôle in the community both nationally and internationally, particularly through IAGA, the International Association for Geomagnetism and Aeronomy, of which he was elected an Honorary Member, its highest award, in 2007, and he is a worthy recipient of the RAS Award for Service to Geophysics. [Applause.]

The President. The Group Achievement Award for Astronomy goes to the *SuperWASP* team, represented by Professor Don Pollacco of Queen's University, Belfast.

Dr. Speirits. Since they started operation in 2004 the *SuperWASP* (*Wide Angle Search for Planets*) high-performance cameras have been among the most successful discovery instruments in the world. They were developed and deployed by a consortium comprising the Universities of Cambridge, Keele, Leicester, the OU, St. Andrews, and Queen's, Belfast, along with the Instituto de Astrofísica de Canarias and the Isaac Newton Group of telescopes. With modest budgets, *SuperWASP*'s two continuously operating robotic observatories have allowed the team to discover a large number of exoplanets and to make a world-wide contribution to the initiation of exoplanet science. [Applause.]

The President. The Group Achievement Award for Geophysics goes to the CHIANTI consortium, represented by Professor Ken Dere of George Mason University, Virginia.

Mr. Watson. The CHIANTI consortium of scientists, from Italy, the UK, and the USA, over two decades developed the Atomic Database for Spectroscopic Diagnostics of Astrophysical Plasmas, a systematic, easy-to-use, and publicly-available database for spectroscopic observations used to estimate conditions in the Sun and other stars. This has allowed the community to exploit the rich range of solar spectroscopic datasets from missions such as *SoHO* and *Hinode* as well as, for example, to interpret observations of stellar coronae and stellar flares from the *XMM* and *Chandra* missions. The formal impact of the consortium's efforts can be measured by the more than 1000 citations to their papers describing the database and a corresponding level of use of the software in the published literature. [Applause.]

The President. An Honorary Fellowship is awarded to Dr. Wlodek Kofman.

Dr. Speirits. Dr. Wlodek Kofman is Director of the Laboratory of Planetology in Grenoble, France. Exploiting his skills in signal-processing engineering, he has made key contributions to understanding incoherent scatter from ionospheric plasma. His work on the physics of the auroral ionosphere and magnetosphere helps explain why the *EISCAT* radar facility, of whose Council he is a past Chair, has been so successful. More recently, Dr. Kofman has been involved in major space missions, including the *CONSERT* radar-sounding experiment on ESA's *Rosetta* mission, for which he is Principal Investigator. Scheduled to rendezvous with Comet 67P/Churyumov-Gerasimenko in 2014, this novel instrument will provide a detailed three-dimensional image of a cometary nucleus for the first time. Among his many services to the community, Dr. Kofman is a past Editor-in-Chief of *Annales Geophysicae*.

For his contributions to international science Dr. Wlodek Kofman is made an Honorary Fellow of the Society. [Applause.]

The President. The Winton Capital Award for Astronomy goes to Dr. Elizabeth Stanway, University of Bristol.

Mr. Watson. Using spectroscopy to get reliable samples, Dr. Stanway has found that distant star-forming galaxies are young, largely void of dust, and less abundant than expected, in comparison with closer galaxies. Using them as markers, she has pioneered the detection of otherwise dark galaxies through the emission of their molecular gas in radio and sub-mm bands, thus allowing for a much broader census of galaxy evolution and growth than would be afforded by concentrating on the optically luminous population alone. Dr. Stanway, of the University of Bristol, has built up an impressive record of achievement in her chosen field in the few years since she obtained her PhD, and is a worthy recipient of the Winton Capital Award for early-career scientists demonstrating exceptional promise. [Applause.]

The President. The Winton Capital Award for Geophysics goes to Dr. David Robinson, University of Oxford.

Dr. Speirits. Dr. Robinson's first-authored paper, based on his work on a large earthquake in the Indian Ocean, was published in *Science* in 2001 while he was still an undergraduate. This was followed by two more papers in the same journal, respectively, on the 2004 Boxing Day Sumatran earthquake, and on the direct relationship between the topography of the sub-ducting seafloor and the earthquake rupture process.

Dr. Robinson's research at the University of Oxford has modified our understanding of the mechanics and physics of earthquakes by developing a technique which provides a remarkably detailed image of their sources. He is a worthy recipient of the Winton Capital Award for early-career scientists demonstrating exceptional promise. [Applause.]

The President. There are several awardees who are unable to collect their awards today: the Gold Medal for Astronomy goes to Professor Douglas Gough of the University of Cambridge, the Fowler Prize for Geophysics to Dr. Ineke de Moortel of the University of St. Andrews, the Fowler Award for Astronomy to Dr. Barbara Ercolano of the University of Cambridge, and an Honorary Fellowship to Professor Conny Aerts of the University of Leuven and Radboud University, Nijmegen.

I also must talk about another issue. It is normally around this time of year we have the annual day meeting of Scottish Astronomers with the support of the Royal Society of Edinburgh Robert Cormack Bequest Fund, which also supports five summer-vacation scholarships, an undergraduate project prize, a best-postgraduate-paper prize, and a bi-annual Cormack lecture. This year the Cormack Meeting was put in advance because of the NAM meeting here. And they request, along with the CUP-funded poster prizes, to announce that there are currently project and paper prizes.

The best paper by a postgraduate in a Scottish department goes to Hazel Bain of Glasgow, Department of Physics and Astronomy. The best undergraduate project by a Cormack Vacation Scholar goes to Julie McCormick of St. Andrews, Department of Mathematics.

Mr. Watson. The NAM poster prize winners this year are Xu Wu, University of St. Andrews, Shenghua Yu of Armagh Observatory, Lieke van Spaandonk of Warwick University, and Lee Kelvin of the University of St. Andrews. [Applause.]

Dr. Speirits. The UK MIST prizes go to Santiago Vargas Dominguez of UCL and MSSL, Anthony Williams of Leicester University, and Heather Radcliffe of the University of Glasgow. [Applause.]

The President. So that concludes the awards ceremony. We now move on to the 2010 Darwin Lecture which is entitled 'The standard model of cosmogony: what next?' and is by Professor Carlos Frenk of Durham University.

Carlos Frenk is the Ogden Professor of Fundamental Physics and Director of the Institute for Computational Cosmology (ICC) at Durham University. He was instrumental in setting up that Institute and has worked tirelessly to maintain its forefront scientific programme and high international visibility. Since 1996 he has been the UK Principal Investigator of the Anglo–German Virgo Consortium, an international collaboration responsible for many of the largest and most sophisticated cosmological simulations in the world. His work with the Durham group over the last 15 years — carried out with simulations of cosmic structure formation by using the 'Cosmology Machine' — has created a world-leading capability for predicting the observable properties of galaxies and pioneered many of the developments which have resulted in the ΛCDM model becoming the standard paradigm for cosmic structure formation. He has also been heavily involved in the execution and analysis of large surveys of galaxies in our cosmic neighbourhood.

Professor C. Frenk. [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*.]

The President. Thank you, Carlos, for a splendid talk. Any questions?

Professor K. Horne. Can you say anything about the gravitational-lensing signature of the thousands of dark-matter haloes that don't have baryons in them?

Professor Frenk. As Keith correctly points out, I stress here how we can see the dark matter directly by detecting it or indirectly through the effects it has on galaxies. Of course, there is another way to see dark matter directly and that is the weak gravitational-lensing effect, and indeed the *Pan-STARRS* telescope, which I mentioned earlier, was designed to look into gravitational-lensing studies. So I think that is another area with a great future. At the moment there are already many measurements of gravitational lensing and I think the real golden era of lensing is about to come with the big surveys like *Pan-STARRS*, the Dark Energy Survey (DES), and eventually the *LSST*. It is clearly a fundamental part of the subject and one that I would have included if I had more time.

The President. Thank you, Carlos. [Applause.] Following the tea interval, we shall proceed to the STFC Community Forum.

STFC COMMUNITY FORUM

A. C. Fabian, *President*
in the Chair

The President. This session will be rather truncated because of the Icelandic volcanic ash and the consequent disruption to travel. We don't have Bill Eason from NERC but Mike Hapgood has stepped in to show some of Bill Eason's slides, and we don't have Dave Parker from the UK Space Agency (UKSA) so John Womersley is going to tell us what he knows about the Space Agency and will also talk about STFC.

I want to start this session by pointing out where we are with the current situation. You'll be aware that we will soon have a new government and that there will be a spending review coming soon which will be very important for us. We really cannot take any more hits but we know that the main parties all mention science in their manifestos and claim that they will keep science funding at the current levels, which will be seen as a positive when you consider the talk about proposed cuts to public services. Groups like the RAS, Astronomy Forum, *etc.*, must press them to keep to those manifesto commitments. It is going to be a difficult time so we must be seen to be positive in what we are doing and where we are going. An important aspect of looking forward is students and postdocs. In my opening address on Monday I said that the RAS is going to have three new Fellowships, to be called the RAS 2010 Research Fellowships, each of which will last three years. They will be open to those based in the UK with less than three years of postdoctoral work. They will help to fill the gap left by the STFC postdoctoral research fellowships. I will now hand over to John Womersley who will tell us about the situation in STFC.

Professor J. Womersley. As we all know, we have been through a very painful period over the last three years which has resulted in a complete re-prioritization of STFC's programmes. As a result of significant consultation over the last year our programme has focussed on the highest-priority items in each area; that has resulted in painful reductions of support, which I acknowledge, and that policy has been applied to all areas of science supported by STFC. We can demonstrate that, as a Research Council, and as a research community, we can take tough decisions and carry them through, and have the ability to produce a programme which delivers excellent science *via* an affordable and therefore challenging budget. This both helps to prepare the way for the tough times to come but also to prepare the way for increases in funding. We are being as flexible as we can in implementing that plan. We have been able to restore more funding for the *UK Infrared Telescope*, and funding for *LOFAR* will come from the *SKA* envelope. I recognize that the university community is taking a lot of pain, as are the laboratories within STFC, but 20% of our savings are coming from within STFC. We should not expect the universities to shoulder the whole of the cuts and to that end we are expecting to make 2% efficiency savings per year for the next ten years, which will then be re-invested in science.

Grants have been issued at a lower level at the recommendation of the Grants Panel and STFC has accepted this. We are setting up a panel to look at this and a series of recommendations is being finalized. This is not intended as an attack on the grants but we recognize that the system is under stress. The allocation for 2010 is 235 studentships, which is a 10% reduction over the previous year. The postdoctoral-research-fellow (PDRF) programme was cancelled this year and that has raised quite a bit of unhappiness in the community, partly because applications had already been sent in before the decision was made to cancel the scheme. I apologize to those of you who were insulted by this decision but it was done in recognition that the studentships and advanced fellowships are the most valuable contributions we can make in this area and need to be protected. However, consultation is under way and we may re-introduce the PDRF programme in future years. At the end of all this there has been a huge reduction in the support flowing from STFC to the university physics and astronomy departments — something like 40% — which puts immense pressure on heads of department. This situation also applies to EPSRC where instrumentation-grant-application success has reduced by 50% over the last ten years. We will work with university and funding councils, EPSRC, and other stakeholders to see how this problem may be addressed. Another aspect which might be mentioned is that there is some thinking in the out-going government which believes that consolidation of research is a desirable thing, but it is not our policy.

The recent STFC review which has just ended was initiated by Lord Drayson on December 15 last year realizing that there were strong tensions in a single funding council responsible for grants, international subscriptions, and national facilities. On March 4 Drayson said that in 2010/11 for international subscriptions STFC will have to find the first £3 million of any increase in subscriptions, but we will be indemnified for levels above that. That has already been built into our planning and is the assumption which has held for the last 2 years, but Drayson may not be in post next month. For national facilities, on a 3-yearly basis, the Research Councils decided what collective capability and funding should be ring-fenced. This should be good news but the aim is to protect fundamental research. This will go a long way to satisfying the community feeling of two to three years ago about the ring-fencing of facility operation and other areas.

An implementation group is going to be set up by the Research Councils to fill in the details of this model which are not yet understood, *i.e.*, how to operate facilities, how to replace facilities, how to do R & D, how to pay users from outside the UK or inside the UK such as funding by our own universities, the Royal Society, or the Wellcome Trust. This new model is expected to start in 2011 April. Everywhere you set up a ring-fence you lose flexibility, but the intention here is to protect fundamental science against major swings in the cost of facilities operation.

The UK Space Agency (UKSA) was announced by Drayson in December and brings together the space-based aspects of STFC and NERC. It was hoped to come into operation on April 1. That has not happened but BNSC is standing in for the moment. Lord Mandelson also announced £12 million for the Space Innovation Centre at Harwell but this will not be part of the Space Agency. The UKSA will be a funding organ and will get its work done by bids from organizations such as the RAL Space Science and Technology Department, the UKATC, and others. UKSA will take over the payment of subscriptions to ESA, represent the UK at ESA meetings, and take over space-instrument projects such as *MIRI* for *JWST*. It will also have a rôle in issuing grants for space-science exploration but it will do this in tandem with STFC.

Looking forward to after the election, there will be a spending review soon or at least by next autumn. The Research Councils and STFC are actively discussing this issue and will develop both good and bad scenarios. A bad outcome would be a 20% cut. Talking about themes in the areas of world-class research, innovation, and skills, clearly astronomy has a strong rôle to play in both skills and attracting people to science, and in research areas where the UK achievement in science is second only to that of the USA. The Council has set up a working group chaired by Keith Burnett which will discuss how science can be involved in this process. There are, however, plenty of reasons to worry about the upcoming spending situation even if there is a flat settlement or a slight cash increase. There are lots of other demands on funds, including wind-turbine designs from the Carbon Trust, for instance. I hope that STFC will be able to present a coherent picture of a broad range of physics research with astronomy and fundamental physics at one end and applied science such as environmental applications at the other.

I want to close with some reasons for optimism. You have raised the visibility of science as an election issue and it is in the manifestos. The parties have taken a generally positive position. Most importantly, the funding modifications of ring-fencing of facilities-funding and the creation of UKSA means that we can argue that with a flat settlement fundamental science can be continued this year, and we feel that a 10% reduction should apply only to those smaller areas of the budget directly under STFC's control and not applied to international subscriptions or costs of facilities. We continue to have exciting and viable future projects such as *SKA*. [Applause.]

The President. Thank you, John. We'll go straight on with Mike Hapgood's presentation on behalf of Bill Eason and then we'll have questions.

Professor M. Hapgood. The origin of the changes that have been happening in the area of solar–terrestrial physics (STP) in STFC and NERC occurred between the Wakeham Review and the subsequent report. Funding of STP had been optimized and the transfer of STP to NERC was recommended about two years ago. Then there was a long period of discussions, and the outcome last November was an agreement between STFC and NERC, and in particular the transfer to NERC of 'Earth-orientated STP'. There are primarily two areas which have transferred across, most important of which is support for ground-based instruments working at Earth-orientated STP; *EISCAT* in particular has been the key facility about which discussions have been on-going. NERC will fund the actual research done with these facilities and STFC will retain funding for space-based facilities.

Examples of activities which NERC supports include long-term monitoring of the Earth's magnetic field, which is an area of STP which has always been with NERC, so there has always been some crossover between the two Councils. Then there is the impact of space weather on energy generation, and wind farms. Another area is the impact of cosmic rays and solar influence on climate. NERC is setting up a radar in the Falkland Islands to be operated by the University of Leicester and the British Antactic Survey. It will look at winds, gravity waves in the atmosphere, and tides, and also at the solar influence and effect of the Earth's radiation belts on the atmosphere because of what is known as the South Atlantic Anomaly. [Applause.]

The President. Thank you very much, Mike. Now is the time for questions.

Dr. M. Dominik. The Royal Society in March published a report on the scientific century and has made some interesting statements. I quote, "Science requires investment, infrastructure and an enabling policy environment, but its most important resource is people." Explicitly it recommends prioritizing investment in excellent people and increasing the number of postdoctoral fellowships. In this room I think we see a lot of people who are funded by STFC, and I think STFC should be very proud of them and their achievements. I would like to see us being proud of STFC as well and praising our Research Council. How could you make that happen?

Professor Womersley. Let me take that question in two parts because there is one about how we can make the case strongly for investment in scientific people as part of a national capability; I think it's partly because of their innovative research rôle which those people will carry out. I think the leverage most likely to work on governments in telling them to invest more in physics departments is about the undergraduate training that those physics departments are going to carry out. The leading researchers that we attract have a rôle in improving the quality of the universities, the universities then attract better students, who then attract in turn more students, so you create a virtuous system where the universities improve, the research quality improves, the teaching improves, and governments love it. I think governments are less likely to fund research groups purely for the research outputs — I think that is part of what the Royal Society report was getting at. You need to see the system — the education and research system and especially our universities system — as an enormous national capability. It has multi-millions of pounds turnover; it's one of the leading university research systems in the world. I think we have completely neglected it because of the very fragmented funding system which exists, of multiple sources of funding — education funding, HEFCE funding, research-council funding, none of which is actually looking at the system as a whole. Our funding criteria relate to the quality of the research proposal, and if the university is good and is able to support the researchers, then that does weigh heavily; but we do not tend to look at the number of undergraduates that those professors are teaching or the quality of the RAE rankings as anything which could or should affect the amount of funding. So there are multiple, different, independent, unconnected, incoherent sources of money, and one of the points that I think that report was trying to bring out was that we need to take a broader view about the sustainability of physics or even science as a broad subject area. So I think the

Royal Society report was very good and I am a little bit disappointed that it didn't create more waves in the media. It was not picked up as widely as it could and should have been, and that's a bit of a shame because most of what it said was very good.

In terms of what it will do to make you proud of us, let me say just one thing about it: one of the reasons why I think you have had doubts about whether you could or should be proud of the Research Council is that you were suspicious of the motivation and arguments that the Research Council was perceived to be making upwards to government. That is the interaction that the community has been concerned about. What I tried to do today was lay out the arguments that we would make. I cannot promise they will be successful, I cannot promise that anybody in any government we choose to elect will ever listen to them, but I want to try and give you some sense that we are arguing for investment in these science areas, that we are making the case not just for economic utility but also for research excellence, and that we see this as a very important national strength.

Professor D. Southwood. I think the big challenge is that we're in a market here, in NERC and in STFC and UKSA. There has always been a divide between NERC and whatever the other council was called (it kept changing its name, presumably out of shame!), there has always been a problem at that interface, and now we have a third interface. I really think that joined-up thinking is very important; and with peer review, I can tell you I have been involved with peer review both in NERC and in predecessors of STFC and it's different on account of the peers being different. And if you are judging against Earth science in NERC and judging against particle physics and astronomy in the other Council, I really think it's difficult to get joined-up thinking. If you then add to that the separation of the funding of development activities in space from the exploitation facilities in space in the same area, I am very glad I am a *retired* professor from Imperial College!

Professor Womersley. Let me just add one comment: one of the reasons I think Wakeham was correct in recommending this transfer of responsibility was to put the climate and Earth-orientated sciences into a system where the peers would care about that kind of science in the same way, not the technology used to do it but the scientific goals. It was trying to address your concerns, but I agree it has always suffered from some shared responsibility.

Professor Hapgood. I have had a lot of colleagues who have got involved with NERC peer review. For those of you who don't know, NERC has a system called the 'peer review college': it is quite a sophisticated process of peer review and everyone who has been involved with that has found that they really like moving from the former PPARC/STFC system into NERC. They just feel that people are looking more broadly at what science is being done and there is more crossover — that may represent diversity of disciplines within NERC, that you must look beyond to some deeper conceptual theme of what you're trying to do in terms of funding and studying the natural environment.

Professor Womersley. It is my understanding that UKSA plans to keep the current Space Science Advisory Committee as one of its science-advisory structures, which of course has membership which many of you are familiar with. It is chaired by John Zarnecki and we will have to have cross-membership between that group and the ground-based astronomy or other parts of STFC's process in terms of grant issues. I think lots of questions remain to be addressed about how to make sure that happens in an intelligent way because I know there are individual PI's who are funded to use multiple techniques, some of which will be under the purview of the space agency and some will be under STFC purview, and that's the kind of science we should encourage. It shouldn't be something that becomes harder to do. We should also remember that the space agency is not a scientific organization, or rather, it is not a purely scientific organization: it has a strong technological push, so it is not a research council; it will be more like a civil-service agency, and while I hope that they will use peer review as part of their decision-making process, it will not have quite the same centrality that you would expect it to have in a research council. And that's fine, that's one of the things government is trying to do when it sets it up.

Dr. W. Ho. As of late February, I was a year and a half through a three-year postdoc as part of Southampton's STFC rolling grant. At the end of February I was told that the funding for my position had been cut, and from direct communications from STFC I had about a month to clear out my desk and leave. I would like to be positive about the future of UK astronomy, but if I was asked by any of my colleagues, for example in the US, as to whether they should come to the UK, I would give them a definitive 'no' if their funding was coming from STFC because that funding could be cut at any time.

Professor Womersley. I think it's extremely unfortunate that you had such a short notice period. That is not the intent and we've tried — and we are still trying — to make sure that everybody who might be affected by a reduction of support has six months, which we think is a moral minimum, and if your university had chosen to argue for that then we might have been able to do something. I don't know the specific issues. One of the challenges that the astronomy grants panel has had to face is that there may not be sufficient funding available simply to keep all the existing positions, and it is awful to have to terminate people in any system at any time before the end of their contracts, but that was the recommendation to maximize the scientific output. It's not something I feel good about, I'm sorry this has happened; I hope it does not happen to others but I can't guarantee that it won't.

The President. I too am sorry about this. It is a very difficult situation, particularly when we look at other countries like America, Canada, Germany, France, and the Netherlands where they are putting increased funding into science, particularly in postdocs and the like. I think the UK is only going to lose in this system. I am worried that we are going to be crippled by what is going on. I want to be optimistic but it is very difficult. I think we also have this issue — it was touched on by the first question — and that is the career structure in astronomy is pretty shaky at the moment and we need to put a lot of thought and effort into that. But when we're standing on grounds that are shaky and the situation is changing year by year — possibly even month by month — over the next few months, it is going to be very difficult.

Professor M. Lester. John, over the last decade or so the government has actually increased spending on science, particularly research-council funding. And yet STFC and it predecessor PPARC have been unsuccessful, especially in last few years, in ensuring their fraction of that increase. How do you see us as a community helping you to reverse that trend? And how do you see your inviting us help you to do it, because it seems to me that there still is a disconnect between STFC executive and the community?

Professor Womersley. I think that a lot of reasons for the relative success or lack of success in different Research Councils in different areas in securing funding is not due to the individual excellence of the documents that they provide the year before the funding or the bid that goes in. It is due to a broader perception in government circles about the relevance and importance of that kind of science, and I think that this is a measure that over the last few years certainly, and maybe a few decades, there has been a sense that biomedical research has been the future. People have talked about the 20th Century being the century of physics and the 21st Century is the century of life sciences and so forth. Maybe there is some truth in that but if you look at research-council funding it certainly follows that pattern. There has also been a discussion about big issues and challenges in areas like energy and environment, health care, and novel security threats — funding has followed those things. And with no more knowledge than I have just imparted you could predict which Research Councils did well in the last spending reviews and which ones didn't. So how do we address that? We should make more apparent the contributions from our kind of research to the things society and the government care about. I see the rôle of universities as a national capability, the rôle of physics and science and technology and engineering as a key necessary capability, the rôle of astronomy as attracting students into physics who may after all go on to build wind turbines, but typically, when they are 8 years old, are more interested in astronomy and Brian Cox and particle physics than they are in materials science and engineering challenges. So we have to create a public perception about this kind of science; we have a great basis to start from because people really love this kind of stuff, but they tend to love it in a rather abstract way, about its cultural contribution to our knowledge of the Universe, and that's what drives most of us who are scientists in this area. Carlos being able to describe string landscapes is absolutely wonderful — we also have to point out that when Carlos does that he excites young people who go on to become scientists, and that contributes to solving the big problems of living in a knowledge-based economy in a relatively small country with relatively expensive industries in the north-west part of Europe in the 21st Century.

There is no single answer, there is no wonderful thing we can find and put on the table and government will suddenly change its mind. But we have to create a climate in which it seems forward-looking for future governments to invest more in these areas. Public support is part of that but governments are typically investing in things because they are afraid of not investing in them and because they see some opportunities to look good and appear forward-looking. No one is worried about losing the next election because there won't be enough physics undergraduates, but they are worried that they may lose the next election if they appear to have destroyed the universities system or failed to make sufficient provisions for the future knowledge-based economy. The research excellence is key because it is a shorthand for having really good universities, really good scientists, scientists being central to the economy, all of those things. So I think we have to argue much more broadly, we have to argue about the physical sciences and engineering or maybe about science in general. We have to argue about the special rôle that this kind of science can have as being the most exciting, the most inspiring, the thing that gets young people hooked. We must keep getting this message out to everyone at every opportunity because you know it takes a long time to change perceptions in this way.

Professor Hapgood. One important thing I think we ought to bring out of astronomy in general, and in particular Solar System science, is the idea embedded in Brian Cox's programme. If we cut away all the glitzy stuff there is a very simple science idea, that we should not consider the Earth in isolation from the rest of the Universe, the Solar System in particular, but understand that even the more distant Universe affects the Earth. Getting that over actually makes this science more important because it influences lives down here and you don't need astrology to do that — there is real physics there.

Professor Frenk. In a hospital ward, one sign that a patient is terminally ill is that the consultant reappears more and more frequently. So this comes back to the point about the grants system: when a procedure is terminally ill, it gets reviewed and reviewed time and again. We're worried about the fact that there is going to be another review of the grants system, although the current system we have was reviewed three years ago when all the guidelines were changed. Prior to that there was the spending review which George Efstathiou chaired, that changed the way the rolling grants were going to be managed. So this would be yet another review of the system that's been reviewed continuously, and that's a cause for concern. We were talking earlier about how UK astronomy really punches above its weight and how for a pound invested we get a lot more science than most of our competitors. The reason for that, I'm convinced, is the way the resources are distributed here, of which grants are a key part. The reason why astronomy in the UK is so strong is because resources are apportioned in a very specific way, which no European country or even the USA has.

So my question is this: what is the background to yet another review of the grants system, who instigated this, what is the time-scale, and what do you think is going to be the outcome?

Professor Womersley. I am going to try and answer briefly, to avoid getting myself into too much trouble. If you can all keep a secret, I would like this review to protect and reaffirm the value of the grants system similar to the one we already have, but I think there are enough people questioning it and its viability that simply not to have this review would probably lead to a worse outcome. So this is a system that has been questioned and criticized. It is necessary to evaluate whether it still brings value, but I believe myself that if you look at the way science is funded in places that do it successfully, like the National Science Foundation, or DOE, for example, they have things similar to rolling grants — they have a system similar to the one we have here.

Professor A. Lawrence. The Space Innovation and Growth Team were pushing the idea that the total space economy would quadruple. Now most of that is in telecommunications and Astrium, *etc.* But is there room for a small-missions programme along the lines of what France, Italy, and Germany have? If there is, how do we lobby for it? Whom do we lobby? Will STFC have a part in that or will we have to find out who the new UKSA CEO is and push it forward?

Professor Womersley. You can, and the people who have already been involved with BNSC are receptive to those ideas; the Technology Strategy Board is a potential contributor to a small-satellite programme and there was interest in a recent spending review when STFC was considering a national space-technology programme that would have supported some of those things. So I think one might take that as a relatively receptive message, but the future space agency would be expected to make the case for that and would probably wish to do so because it seems like an idea which has been kicking about for a while. So it's a shame Dave Parker is not here today, because I know he is interested in these ideas. So if you want someone to contact, Dave Parker would be a good place to start.

Professor Lawrence. Just to add something that struck me as annoying almost to the point of scandalous, both on the BNSC web pages, and in the material for the Innovation Growth Team report, which is all fantastic stuff. It was just plastered with PR material that has its origins in space science and astronomy but also in solar–terrestrial physics. The report itself, however, did not contain a word about astronomy or space science, which is very worrying; maybe this was just a mistake.

Professor Womersley. I don't know anyone who was involved with that who would like to comment, but I wasn't, so I won't.

Dr. Helen Mason. We've had a fantastic meeting here in Glasgow, or, at least the solar-physics community has, and I assume everyone else has also. We've got a very vibrant community of solar physicists and astronomers, many young and enthusiastic people here, and many good students. I know we're losing them; many of them have no jobs, others have gone to the USA. Cancelling postdoctoral fellowships gives the message that we don't care about the individuals. I want to know at the end what hope you can give us. Say some words of optimism, please, to encourage them to stay. [Applause.]

Professor Womersley. Reasons for optimism, I believe, are that we stand on the verge of a decade of discoveries about the Universe, which I hope we can use collectively to re-invigorate and re-excite people; interest in the *Large Hadron Collider* is just one example. We ought to detect gravitational waves, we ought to detect dark matter, we ought to be able to exploit *Herschel* and *Planck* to understand new things about the origins of the Universe in fundamental ways. We ought to learn much more about the planets from the range of missions we are currently funding. If we continue to make advances in science, we have a base from which to rebuild funding to a more appropriate level — funding of this science is presently below the appropriate level. Let me just say that so you don't have to argue with me. It is obvious that we are not putting enough money into these areas of research. You could then assume that the government is not giving us enough money, but of course I never said that. We want to get more, we want to use the science, we want to use the contributions to research that the UK is making, woefully under-supported though you are as researchers. UK universities are still enormously respected internationally, and are still, amazingly, able to attract the best researchers in the world despite the very poor funding prospects that currently exist. The science is exciting — this is one of the best environments to do science in the world when the funding is there. And I strongly hope that that means the funding will be there, that we will have politicians that understand this, that we will have an economic climate which enables greater investment to be there. The science is exciting, the science should be the reward, but it needs adequate support to be done and I very much hope that we can get back to a situation where that can happen, because people deserve it.

The President. The Astronomy Forum and the RAS are trying very hard to tell everyone about what is happening, how everything works, and also to try and make sure that we can all think about these things and try and engage with the people who do the funding: the people in business and the Treasury and Science Minister, so that they do understand how we work and why it is worth funding us. I know from talking to some of them that it is difficult but it will be a new bunch in about a month or so, and we will really try and engage and push forward.

Professor Monica Grady. This is a completely separate question. I just wondered what is happening for NAM 2011?

The President. NAM 2011, we are uncertain about. I will be frank about it; Sheffield was slated to do the next NAM but is unable to do it since one of its groups has pulled out. It's going to be in Manchester in 2012, and the RAS Council is considering using a conference venue in 2011. It's possible that David Elliott may want to say something about that. We have asked all departments whether they are prepared to do it, but nobody has volunteered; it is a lot of work. I'm sure the people from Glasgow will tell you how much work it is —

they have done a fantastic job and we'll get to that in a minute. But maybe what we'll do is go to a conference hotel or something like that and organize it there. I hope people will bear with us and watch this space: there *will* be a NAM next year.

Mr. D. Elliott. I had hoped that I would, by now, have had the costed proposal from a conference centre in Llandudno. I hope that it will be with us next week. If that does not materialize, we'll need to find somewhere else, but we will, obviously.

The President. I think we will now close this community session and I thank you all for coming. Let me then thank our organizers from the Vice-Chancellor and Principal, Professor Muscatelli, to the Local Organizing Committee, that's Lyndsay Fletcher, the chair, and all her colleagues, and the Scientific Organizing Committee, chair Martin Hendry, and his colleagues, and all the other helpers who are too numerous to mention. So let us close this meeting today with a round of applause to everyone who has helped make this meeting so successful. [Applause.]

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 214: HR 6790, HR 6886, HR 6901, AND HR 7137

By R. F. Griffin
Cambridge Observatories

The four objects are quite close together in the sky, and are all single-lined systems whose observable components are late-type giants. Their orbits are of modest eccentricities; the periods are about 3·4, 1·0, 6·4, and 2·7 years, respectively.

Introduction

The four stars treated in this paper are bright enough to be in the *Bright Star Catalogue*[1], but none of them has a constellation designation. HR 7137 is of fifth magnitude; the other three are $6^{m}\cdot 3$ to $6^{m}\cdot 4$, near the faint limit of the *Catalogue*. They are all to be found in a small area of sky in the south-following corner of Draco and in the adjacent constellation of Lyra. They are between 18 and 19 hours of right ascension; HR 6901 is near +39° declination, about 2½° directly preceding Vega (whose HR number is exactly 100 higher), while the other three objects are all near +50° and are roughly 2, 4, and 9 degrees from γ Draconis, near a line extending towards Deneb.

HR 6790 (HD 166207)

The *UBV* magnitudes of HR 6790 have been measured by Eggen[2]; V and $(B-V)$ have also been reported by the Mermilliods[3] and by *Simbad* to have been provided privately by Häggkvist & Oja, who must also have supplied those data for entry into the *Bright Star Catalogue*, although they received no acknowledgement in that volume. The results are close to $V = 6^{m}\cdot31$, $(B-V) = 1^{m}\cdot05$, $(U-B) = 0^{m}\cdot96$. The star was classified K0 III at the David Dunlap Observatory (DDO) by Halliday[4], who also used a microphotometer-based scheme to derive a numerical luminosity class of 2·9, whereas Hossack[5], with whom he was evidently in collaboration, had initially found it to be 2·2 — too bright. Eggen[6] at one time listed a type of K0 IV, without saying where he got it from, in the context of suggesting that HR 6790 might belong to his 'ζ Her group', but later[7] he seems to have drawn back from that suggestion. Wilson[8] derived $M_V = +0^{m}\cdot6$ from the width of the K-line emission. The parallax[9] is equivalent to a distance modulus of $5^{m}\cdot37 \pm 0^{m}\cdot15$, putting the absolute magnitude at $+0^{m}\cdot94$, with the same uncertainty, and placing the star in the 'clump' region (luminosity class IIIb) in Keenan & Barnbaum's diagram[10]. Efforts[11–13] in Cambridge and Denmark to estimate chemical abundances from narrow-band spectrometry led to slightly sub-solar values.

The radial velocity of HR 6790 was first measured at the David Dunlap Observatory, probably in the early 1940s, with a prism spectrograph giving 25 Å mm^{-1} at Hγ on the 74-inch reflector. The mean velocity from four plates was listed by Young[14] as −56·1 km s^{-1} with a 'probable error' of 1·7 km s^{-1}; the result was flagged to indicate that it was "more uncertain than for the general run of stars". The total range was noted as 12 km s^{-1}, and it is clear that Young suspected velocity variation but did not consider the evidence to be strong enough to warrant a specific assertion about it. The individual DDO plate velocities have never been published.

In the early 1980s, McClure and his colleagues at the Dominion Astrophysical Observatory (DAO) progressively established the finding that barium stars were members of binary systems. An initial paper[15] by McClure, Fletcher & Nemec compared the incidence of variable velocities between a sample of barium stars and a control sample of "random K giants", which happened to include HR 6790. Their six measurements of that star exhibited a spread that would be quite abnormally large for a star that was actually of constant velocity; the velocities were not given individually but were plotted, and it could be seen that they were monotonically increasing. In a second paper[16], an increased spread of velocities was reported for HR 6790, but no further information was given. But then, in 1983, Harris & McClure[17] published the individual radial velocities as well as the duplicity statistics for a sample of K giants, and they included 16 observations of HR 6790. Those data cover 85% of a complete cycle and could have supported an orbital solution of sorts, but their authors did not put one forward. De Medeiros & Mayor[18] subsequently noted a discordance between their own two OHP radial-velocity measurements of the star, and later made the actual data available through the Centre de Données Stellaires; they also gave a $v \sin i$ estimate of 1·6 km s^{-1}. De Medeiros, da Silva & Maia[19] later gave the same information again. *Hipparcos*[7] suspected the star of astrometric duplicity, finding itself obliged to adopt an 'acceleration solution', but Mason *et al.*[20], following up by speckle interferometry such *Hipparcos* indications for a lot of stars, did not find it resolved.

TABLE I

Radial-velocity observations of HR 6790

The sources of the observations are as follows:
1979–1982 — DAO[17] (weighted ⅛ in orbital solution);
1988/9 — OHP Coravel[18] (weight ½); 2004–2010 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O–C) km s⁻¹*
1979 May 18·49	44011·49	−54·3	$\overline{8}$·773	−0·5
June 2·46	026·46	−53·2	·785	+0·2
14·41	038·41	−52·8	·794	+0·2
July 19·32	073·32	−51·6	·822	+0·4
31·36	085·36	−51·2	·832	+0·4
Aug. 25·38	110·38	−50·7	·852	+0·2
Oct. 3·30	149·30	−49·8	·883	−0·2
Nov. 7·26	184·26	−49·1	·911	−0·5
1980 Mar. 6·43	44304·43	−47·0	$\overline{7}$·007	+0·1
Apr. 2·43	331·43	−47·9	·029	−0·4
July 8·30	428·30	−50·8	·106	−0·1
Sept. 16·25	498·25	−52·4	·162	+0·7
1981 Mar. 20·41	44683·41	−57·7	$\overline{7}$·311	−0·6
Sept. 29·23	876·23	−59·2	·465	−1·0
1982 Mar. 19·54	45047·54	−57·9	$\overline{7}$·602	−0·5
Apr. 9·47	068·47	−56·7	·619	+0·4
1988 July 17·92	47359·92	−58·6	$\overline{5}$·455	−0·4
1989 Apr. 20·15	47636·15	−56·2	$\overline{5}$·676	0·0
2004 Dec. 21·72	53360·72	−55·8	0·261	+0·4
2005 June 1·06	53522·06	−57·8	0·390	+0·2
Aug. 21·98	603·98	−58·0	·456	+0·2
Oct. 25·84	668·84	−58·0	·508	+0·1
Dec. 8·70	712·70	−57·9	·543	0·0
2006 Mar. 1·25	53795·25	−57·4	0·609	−0·1
Apr. 9·11	834·11	−56·8	·640	0·0
June 4·06	890·06	−56·0	·685	0·0
July 3·00	919·00	−55·4	·708	+0·1
Aug. 15·95	962·95	−54·8	·743	−0·2
28·92	975·92	−54·4	·754	0·0
Sept. 22·85	54000·85	−53·7	·774	0·0
Oct. 24·82	032·82	−52·8	·799	+0·1
Nov. 25·74	064·74	−51·6	·825	+0·4
2007 Jan. 14·30	54114·30	−50·7	0·864	−0·3
Feb. 15·26	146·26	−49·5	·890	−0·1
Apr. 2·20	192·20	−47·9	·927	+0·1
May 1·12	221·12	−47·6	·950	−0·2
June 1·07	252·07	−46·8	·975	+0·2
July 7·05	288·05	−46·9	1·004	+0·2
Aug. 6·01	318·01	−47·4	·028	+0·1
Sept. 7·89	350·89	−48·6	·054	−0·2
Oct. 4·87	377·87	−49·2	·075	+0·1
Nov. 14·77	418·77	−50·9	·108	−0·1
Dec. 12·77	446·77	−51·8	·131	0·0

TABLE I (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2008 Feb. 16·24	54512·24	−53·8	1·183	+0·1
Mar. 31·18	556·18	−55·5	·218	−0·4
Apr. 24·16	580·16	−55·7	·238	−0·1
June 26·06	643·06	−56·6	·288	+0·1
July 21·98	668·98	−56·9	·309	+0·2
Aug. 30·92	708·92	−57·5	·341	0·0
Sept. 26·91	735·91	−57·9	·362	−0·1
Oct. 22·83	761·83	−57·9	·383	0·0
Nov. 18·70	788·70	−58·3	·405	−0·2
2009 June 17·09	54999·09	−57·8	1·573	−0·1
2010 Apr. 18·17	55304·17	−52·3	1·817	−0·1

HR 6790 was placed on the radial-velocity observing programme of the Cambridge *Coravel* at the end of 2004, and has been measured 36 times. The star (like the others discussed in this paper) is favourably placed for observation, passing near the Cambridge zenith and being in opposition near the summer solstice, so seasonal gaps in data coverage can be avoided; indeed, in 2007 the object was measured in every calendar month except March. The observations, including those from the DAO and OHP, are listed in Table I. In the solution of the orbit, the DAO measures have received an empirical adjustment of +1·2 km s⁻¹ and a weighting of ⅛; the OHP ones have received what is for

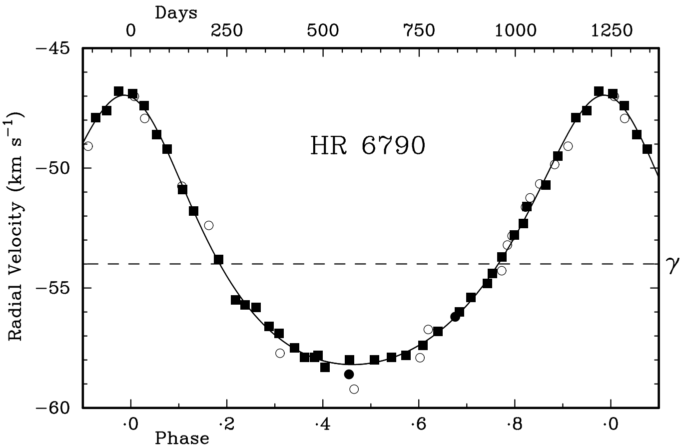

FIG. 1

The observed radial velocities of HR 6790 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The Cambridge velocities are plotted as filled squares; there are two observations from OHP[18] (weight ½), plotted as filled circles, and 16 from the DAO[17] (weight ⅛), plotted as open circles.

them the usual adjustment of +0·8 km s^{-1} and have been weighted ½. Since the Cambridge observations carry 92% of the total weight, the solution that incorporates the earlier measures scarcely differs from that derived from the Cambridge data alone, either in respect of the elements themselves or their standard errors, except in the case of the period, where the great increase in the time base obtained by the addition of the early velocities refines the value from 1244 ± 6 days to 1248·5 ± 0·7 days. The adopted elements are collected with those of the other three stars and their listing is deferred till Table V, after those stars have been introduced; the orbit is illustrated in Fig. 1.

HR 6886 (*HD 169221*)

HR 6886 has been remarkably neglected for a bright star. The only ordinary photometry available for it is the $V = 6^{m}·40$, $(B-V) = 1^{m}·07$ that Häggkvist & Oja supplied privately for publication in the *Bright Star Catalogue* and by the Mermilliods[3]; the $(U-B)$ colour index is still unknown. The object was on the above-described experimental programme of classification, carried out at the DDO by Hossack[5] and Halliday[4]; they respectively derived luminosity classes of 3·2 and 2·7 for the star, which Halliday classified in the normal way as K1 III. He deduced an absolute magnitude of $-0^{m}·16$, which is *exactly* the value derived from the *Hipparcos* parallax, whose uncertainty represents about $0^{m}·22$.

Just as in the case of HR 6790, the radial velocity of the star was first determined at the DDO, from the same plates as were utilized by Hossack and Halliday; in Young's compilation[14] the mean velocity from four plates is given as −16·0 km s^{-1} with a 'probable error' of 0·8 km s^{-1}; no suspicion of variability arose. Again in analogy with HR 6790, HR 6886 was observed twice with the OHP *Coravel*, and the results — amounting to a modest discordance between the two velocities, and a $v \sin i$ of 2·0 ± 1·0 km s^{-1} — were published twice by de Medeiros *et al.*[18,19]; the two velocities have since been made available through the Centre de Données Stellaires, and it was from that listing that HR 6886 was selected for observation at Cambridge.

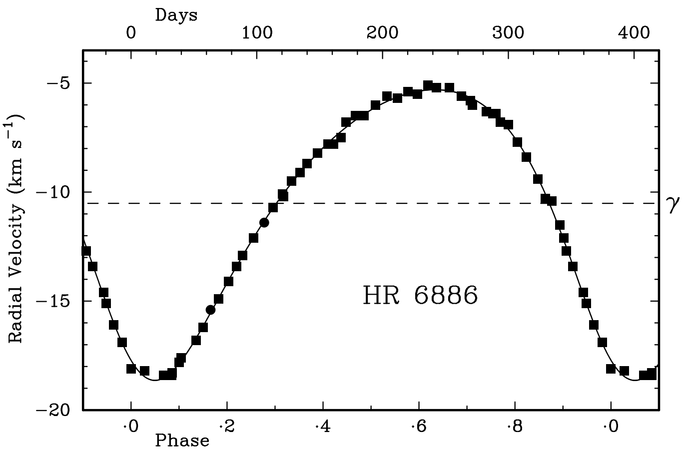

FIG. 2

As Fig. 1, but for HR 6886, and with the same coding of the plotting symbols. In this case the two OHP observations[18] received full weight.

TABLE II

Radial-velocity observations of HR 6886

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

Date (UT)			*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O–C)* *km s*$^{-1}$
1987	Aug.	13·94*	47020·94	−11·4	$\overline{14}$·278	−0·1
1988	July	17·93*	47359·93	−15·4	$\overline{13}$·166	+0·1
2002	May	31·05	52425·05	−7·5	0·438	−0·3
	July	14·99	469·99	−5·7	·555	−0·1
	Aug.	14·95	500·95	−5·2	·637	+0·1
	Sept.	11·00	528·00	−5·8	·707	−0·1
	Oct.	4·88	551·88	−6·8	·770	−0·1
	Nov.	14·78	592·78	−10·4	·877	+0·4
	Dec.	9·75	617·75	−14·6	·943	+0·1
2003	Feb.	21·24	52691·24	−16·8	1·135	−0·1
	Mar.	19·16	717·16	−14·1	·203	0·0
	Apr.	8·15	737·15	−12·1	·255	0·0
	May	1·12	760·12	−10·1	·316	0·0
		15·10	774·10	−9·1	·352	0·0
		29·04	788·04	−8·2	·389	0·0
	June	28·05	818·05	−6·5	·467	+0·2
	July	4·97	824·97	−6·5	·486	−0·1
		13·99	833·99	−6·0	·509	+0·1
	Aug.	8·88	859·88	−5·4	·577	+0·1
		24·87	875·87	−5·1	·619	+0·2
	Sept.	10·89	892·89	−5·2	·664	+0·2
		28·96	910·96	−6·0	·711	−0·3
	Oct.	17·82	929·82	−6·4	·760	+0·1
		27·76	939·76	−6·9	·786	+0·2
	Nov.	3·79	946·79	−7·7	·805	0·0
	Dec.	7·70	980·70	−11·5	·894	+0·2
		17·77	990·77	−13·4	·920	−0·1
2004	Jan.	17·29	53021·29	−18·1	2·000	−0·4
	Feb.	26·25	061·25	−17·6	2·105	+0·1
	Apr.	15·13	110·13	−12·9	·233	0·0
	June	5·07	161·07	−8·7	·366	+0·1
		22·04	178·04	−7·8	·411	−0·1
	July	6·02	192·02	−6·8	·447	+0·2
	Aug.	7·91	224·91	−5·6	·534	+0·2
		31·98	248·98	−5·5	·597	−0·1
	Oct.	5·86	283·86	−5·6	·688	−0·1
		25·84	303·84	−6·3	·740	−0·2
	Nov.	26·75	335·75	−8·4	·824	0·0
	Dec.	5·73	344·73	−9·4	·847	−0·1
		11·72	350·72	−10·3	·863	−0·2
		26·29	365·29	−12·1	·901	+0·1
2005	Jan.	13·30	53383·30	−15·1	2·949	0·0
		19·23	389·23	−16·1	·964	−0·1
	Mar.	12·22	441·22	−17·8	3·100	+0·1
	Nov.	16·73	690·73	−6·4	·754	0·0
2006	Mar.	1·24	53795·24	−18·2	4·028	+0·3
		23·19	817·19	−18·3	·085	−0·1
2007	Apr.	2·20	54192·20	−18·4	5·068	+0·1
	May	30·12	250·12	−13·4	·220	0·0
	June	28·03	279·03	−10·7	·296	0·0
	July	13·01	294·01	−9·5	·335	+0·1

TABLE II (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2007 Apr. 2·20	54192·20	−18·4	5·068	+0·1
May 30·12	250·12	−13·4	·220	0·0
June 28·03	279·03	−10·7	·296	0·0
July 13·01	294·01	−9·5	·335	+0·1
2008 Feb. 16·25	54512·25	−12·7	5·907	−0·2
Apr. 24·16	580·16	−18·4	6·085	−0·1
May 19·10	605·10	−16·2	·150	0·0
July 21·98	668·98	−10·2	·317	−0·1
Aug. 30·93	708·93	−7·8	·422	−0·3
2009 June 17·10	54999·10	−14·9	7·182	0·0
2010 Apr. 18·17	55304·17	−16·9	7·982	0·0

*Observed with Haute–Provence *Coravel* (weight 1).

The writer's observations were begun in 2002 and now number 56; they are set out in Table II, with the two OHP measurements obtained through the Centre de Données Stellaires at the head. Although the orbital period is close to one year, owing to the favourable position of the star on the celestial sphere there are no gaps in phase coverage; indeed, observations were made in 13 consecutive months in 2003/4. The orbital period determined from the Cambridge observations alone is 381·56 ± 0·13 days; it is modestly refined to 381·64 ± 0·07 days by the incorporation, with equal weight, of the two OHP data. The orbit is shown in Fig. 2, and the final elements are included in Table V below.

HR 6901 (*HD 169646*)

HR 6901 has entries in the principal double-star catalogues, as BDS[21] 8532 and ADS[22] 11320, but only on account of the measurements by Hough[23] (the first of which was in 1891) with the Dearborn 18½-inch refractor of a very faint star 17″ away from it. It seems as if the only set of *UBV* magnitudes of the star is that by Oja[24], who found $V = 6^{m}\cdot37$, $(B-V) = 1^{m}\cdot44$, $(U-B) = 1^{m}\cdot68$, and the only MK classification is that by Abt[25], of K4 III.

The star was one of several that were asserted to be variable by Weber in a very brief item[26] in the *Information Bulletin on Variable Stars* in 1966. His listing simply said that its photographic magnitude varied from $8^{m}\cdot1$ to $8^{m}\cdot7$ and that the variation was 'irregular'. He promised that details would be published in *le Bulletin de la Station Astrophotographique de Mainterne*, of whose existence no evidence has been found. On the other hand there is abundant evidence that the star is not appreciably variable at all. *Hipparcos* (which found the distance modulus to be $7^{m}\cdot1 \pm 0^{m}\cdot3$ and thus $M_V \sim -0^{m}\cdot7 \pm 0^{m}\cdot3$) records that the 130 transits that it observed had an r.m.s. photometric spread of $0^{m}\cdot008$; among the other 99 stars reported on the same page (1811) of the catalogue, there are only ten with smaller spreads, and all of them refer to stars brighter than HR 6901. Percy *et al.*[27], perhaps rather incautiously, used HR 6901 as a comparison star for photometry of HR 6872, which they intended to test for variability, but they found the difference to have $\sigma = 0^{m}\cdot006$. Thus the suggestion that HR 6901 is variable has been thoroughly discredited. The star should be omitted from lists of suspected variables, and it seems remarkably unhelpful, indeed mischievous, of *Simbad* to adopt, as its headline identification for HR 6901 no matter under

TABLE III

Radial-velocity observations of HR 6901

The sources of the observations are as follows:
1978–1983 Ames[29] (*weighted 1/10 in orbital solution*);
1993–1998 — OHP Coravel (*weight 1*); *1999–2009 — Cambridge Coravel* (*weight 1*)

Date (*UT*)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	(*O – C*) $km\ s^{-1}$
1978 June 8·37	43667·37	−54·6	0·233	−0·4
1979 Mar. 15·44	43947·44	−50·9	0·352	+0·4
1980 May 23·32*	44382·32	−48·1	0·537	−3·5
26·35	385·35	−43·3	·538	+1·2
July 28·17	448·17	−44·3	·565	−0·6
Aug. 15·12	466·12	−43·5	·573	−0·1
18·13	469·13	−43·9	·574	−0·5
1981 May 20·30	44744·30	−40·1	0·691	+0·5
1982 June 2·32	45122·32	−41·0	0·852	+0·9
8·31	128·31	−41·7	·855	+0·3
29·21	149·21	−41·6	·864	+0·7
Aug. 12·13	193·13	−43·3	·883	−0·3
17·13	198·13	−43·4	·885	−0·4
1983 May 26·35	45480·35	−48·3	1·005	+0·7
June 22·27	507·27	−49·2	·016	+0·4
July 8·23	523·23	−49·3	·023	+0·6
Sept. 9·08	586·08	−51·3	·050	−0·1
1993 Feb. 13·23	49031·23	−45·1	2·517	+0·2
Mar. 19·20	065·20	−44·7	·532	+0·1
July 8·99	176·99	−42·9	·579	+0·3
Sept. 11·78	241·78	−42·0	·607	+0·4
Dec. 30·72	351·72	−41·1	·654	+0·2
1994 Feb. 21·24	49404·24	−41·1	2·676	−0·3
May 1·12	473·12	−40·2	·705	+0·3
Aug. 3·98	567·98	−40·5	·746	−0·3
Dec. 11·74	697·74	−40·6	·801	+0·1
1995 Jan. 5·26	49722·26	−40·8	2·812	+0·1
June 5·08	873·08	−42·5	·876	+0·2
Dec. 27·25	50078·25	−46·4	·963	+0·4
1996 Mar. 29·16	50171·16	−48·8	3·003	+0·1
Apr. 25·12	198·12	−49·5	·014	0·0
Nov. 18·74	405·74	−53·3	·103	−0·2
Dec. 17·70	434·70	−53·8	·115	−0·3
1997 Jan. 26·24	50474·24	−53·8	3·132	+0·1
Mar. 1·17	508·17	−54·2	·146	−0·1
Apr. 1·15	539·15	−54·4	·159	−0·1
May 1·13	569·13	−54·5	·172	−0·1
June 20·10	619·10	−54·7	·194	−0·3
July 21·02	650·02	−54·3	·207	+0·1
Sept. 9·85	700·85	−54·2	·228	0·0
Dec. 21·22	803·22	−53·6	·272	−0·1
1998 Apr. 29·09	50932·09	−52·2	3·327	−0·1
July 8·98	51002·98	−50·9	·357	+0·2

TABLE III (*continued*)

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O–C)* *km s*$^{-1}$
1999 Dec. 19·72	51531·72	−43·6	3·582	−0·5
2000 Jan. 8·71	51551·71	−42·7	3·591	+0·2
Apr. 7·15	641·15	−42·4	·629	−0·6
June 11·99	706·99	−41·3	·657	−0·1
Aug. 2·97	758·97	−40·9	·679	−0·1
Oct. 5·78	822·78	−40·2	·706	+0·2
Dec. 2·76	880·76	−40·1	·731	+0·2
2001 Feb. 14·22	51954·22	−41·0	3·762	−0·7
May 12·10	52041·10	−40·3	·799	+0·3
July 5·01	095·01	−40·8	·822	+0·3
Sept. 25·85	177·85	−42·1	·857	−0·1
Nov. 1·78	214·78	−42·5	·873	+0·1
2002 Jan. 4·30	52278·30	−44·6	3·900	−0·9
Feb. 23·25	328·25	−44·5	·921	+0·2
Mar. 27·14	360·14	−45·5	·935	−0·2
Apr. 20·11	384·11	−46·3	·945	−0·4
May 16·07	410·07	−46·6	·956	−0·2
June 2·99	427·99	−47·2	·964	−0·4
July 14·99	469·99	−47·5	·982	+0·3
Aug. 14·94	500·94	−48·2	·995	+0·3
Sept. 8·98	525·98	−49·0	4·006	0·0
Oct. 4·81	551·81	−49·4	·017	+0·2
Nov. 4·82	582·82	−50·2	·030	+0·1
Dec. 9·71	617·71	−50·7	·045	+0·3
2003 Feb. 18·24	52688·24	−52·1	4·075	+0·1
Mar. 19·16	717·16	−52·9	·087	−0·2
Apr. 19·10	748·10	−53·0	·100	+0·1
May 8·07	767·07	−53·4	·108	−0·1
2004 Mar. 31·16	53095·16	−53·7	4·248	+0·3
May 19·13	144·13	−53·7	·269	−0·1
June 22·04	178·04	−53·1	·283	+0·2
Aug. 11·00	228·00	−52·5	·305	+0·2
Sept. 3·92	251·92	−52·0	·315	+0·5
Oct. 5·86	283·86	−52·0	·329	+0·1
Nov. 4·82	313·82	−51·7	·341	0·0
Dec. 16·71	355·71	−51·4	·359	−0·3
2005 Jan. 23·30	53393·30	−50·6	4·375	−0·1
Mar. 23·21	452·21	−49·8	·400	−0·2
May 8·09	498·09	−48·9	·420	0·0
June 14·03	535·03	−48·2	·435	+0·1
July 18·04	569·04	−47·9	·450	−0·1
Aug. 15·02	597·02	−47·4	·462	−0·1
Sept. 7·87	620·87	−47·1	·472	−0·1
Oct. 4·80	647·80	−46·4	·484	+0·1
15·78	658·78	−46·2	·488	+0·2
Nov. 17·80	691·80	−46·2	·502	−0·4
29·74	703·74	−45·7	·507	0·0
2006 Mar. 23·19	53817·19	−44·1	4·556	−0·1
Sept. 10·96	988·96	−41·7	·629	+0·1
2007 July 7·05	54288·05	−40·0	4·756	+0·3
Aug. 26·96	338·96	−40·2	·778	+0·2

TABLE III (*concluded*)

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O – C) km s⁻¹
2008 Aug. 12·98	54690·98	−45·2	4·928	−0·2
2009 May 30·10	54981·10	−51·1	5·051	+0·1
June 26·07	55008·07	−51·7	·063	0·0
Aug. 7·99	050·99	−52·3	·081	+0·1

*Rejected

what designation one brings up its data, such an arcane (as well as erroneous) heading as "Basic data: **SV* WR 164** — Variable Star of Irregular type".

HR 6901 is yet another star whose radial velocity was first observed at the DDO, in the same programme[14] as HR 6790 and 6886; the mean value, from four plates, was −39·2 km s^{-1} with a 'probable error' of 1·2 km s^{-1}. The measurements must have been clustered around the maximum-velocity node of the orbit, since the mean value is slightly higher (*i.e.*, less negative) than the maximal limit of the orbit found here. The object was observed rather systematically at the Fick Observatory of Iowa State University at Ames, where a photoelectric radial-velocity spectrometer[28] was brought into use on the 24-inch *Mather* reflector as early as 1976. In 1986 Beavers & Eitter[29] published 17 Ames measurements of HR 6901; they cover most of an orbital cycle but it does not seem possible to derive orbital elements from them as they stand — the solution runs away to excessive periods and finally diverges. The observers evidently maintained the observations, because a brief abstract[30] of a presentation by them to a 1988 meeting of the American Astronomical Society refers to orbital elements for 18 stars, whose identities (only) are given in the abstract and one of which was HR 6901; but the results seem never to have been published.

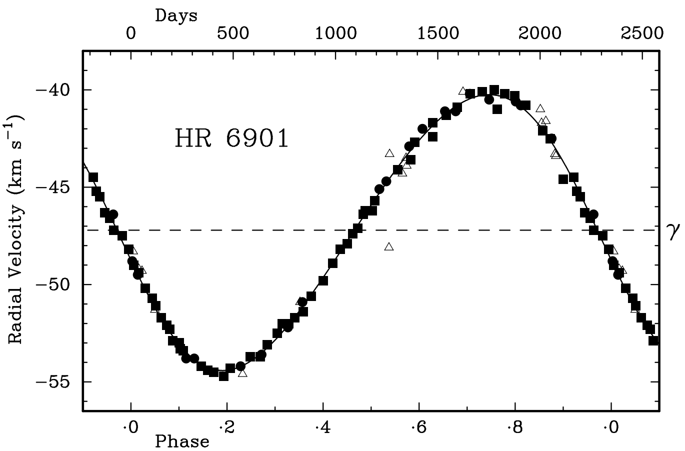

FIG. 3

As Fig. 2, but for HR 6901. The OHP observations in this case are the writer's own. Open triangles represent measurements made by Beavers & Eitter[29], which (except for the 'bad' one, which was rejected) were weighted 1/10 in the solution of the orbit.

The star was placed on the Cambridge observing programme (pursued then, however, at OHP in the absence of an operational spectrometer at Cambridge at that time) in 1993, and has remained under observation ever since. There are 21 observations from OHP and 60 made with the Cambridge spectrometer, making a total of 98 including the published velocities from Ames. They are recorded in Table III. The OHP and Ames velocities have been adjusted by +0·8 km s^{-1}, and the Ames ones have been weighted 0·1; the latter are also classified at source into three qualities, A, B, and C, which are weighted here by factors of 1, 0·5, and 0·2, multiplicatively with the overall weighting. On that basis an initial set of orbital elements was calculated. A troublesome feature of the solution was that there was one outlandish residual among the Ames velocities, and it belonged to one of the eight class-A, full-weight, measurements. It was about 2½ times as great as any other residual, and six times the r.m.s. value of the other 16 from Ames, even when no account was taken of the lower weights of most of them. The decision was taken to reject that datum. The global weighting of the remaining Ames velocities ought then logically to be increased considerably to restore approximate equality of their weighted variance to that of the other data sources; but we have demurred at that, owing to uncertainty as to whether the rejected observation was really defective or was merely at the extreme tail of the error distribution, in which case an excessive weight attributed to the Ames data set would lead to a spuriously high precision for the finally derived orbital period. The final orbit is plotted in Fig. 3, and its elements are included in Table V below.

HR 7137 (*HD 175535*)

This star is brighter than the other three described above and has received a little more attention. Its broad-band magnitudes have been measured by Argue[31], Johnson *et al.*[32], and (for V and $(B-V)$ only) by Häggkvist & Oja[33], and Moffett & Barnes[34]. The results were close to $V = 4^{m}{\cdot}92$, $(B-V) = 0^{m}{\cdot}90$, $(U-B) = 0^{m}{\cdot}57$. The spectral type was first classified in the original *Draper Catalogue*[35] of 1890, in which it appeared as type I (letter I, not roman one). Such a classification now seems an anachronism, but after all it is halfway between G and K and so can be seen as equivalent to G5, which is indeed the type given much later (1922) in the *Henry Draper Catalogue*[36]. The type was re-considered by the Mount Wilson observers[37] who estimated spectroscopic parallaxes, and put at G4; they gave the absolute magnitude of the star as $+0^{m}{\cdot}8$, whereas Rimmer[38] had previously put it at $0^{m}{\cdot}0$ and the corresponding π_{sp} at $0''{\cdot}010$, in complete agreement with the recent *Hipparcos* conclusions. The *Hipparcos* parallax is equivalent to a distance modulus of $5^{m}{\cdot}07 \pm 0^{m}{\cdot}13$, indicating an absolute magnitude of $-0^{m}{\cdot}15$, with the same uncertainty.

The first MK classification was Roman's[39] "G8 III st-l" where the 'strong-line' suffix was actually intended to mean more or less the reverse of what it says. Keenan & Yorka[40] published a type of G7 IIIa Fe-1 in 1985; Keenan rather uncharacteristically omitted it from his subsequent listings. Hansen & Kjærgaard[13] found $M_V = +1^{m}{\cdot}5$ and [Fe/H] = −0·24 from Strömgren indices, which also gave the quantity *res*(*k*) as $0^{m}{\cdot}037$, very close to the point ($0^{m}{\cdot}04$) at which it flags up the object as either peculiar in some way or as consisting of two sources at different temperatures, thereby indicating a binary nature. Wilson[8] found an absolute magnitude of $+0^{m}{\cdot}6$ by his *K*-line method. *Hipparcos* fitted the star's position with an 'acceleration solution', so it was presumably seeing the orbital motion, but when Mason *et al.*[20] took that as a cue to attempt to resolve it by speckle interferometry they were unsuccessful.

The radial velocity of HR 7137 was measured at Lick Observatory in the early years of the last century in the course of a systematic programme of observation of all stars brighter than $5^{m}\cdot51$ according to photometry available at the time. It was announced as a binary in 1911 in an item by Campbell[41] giving the evidence for considering no fewer than 94 stars as binaries; among them were 56 and 70 Peg, already treated[42,43] in the series of papers of which *this* one is a member, but also γ Tau, Betelgeuse, and κ Cyg, whose binary natures have not been confirmed, although Betelgeuse certainly does vary in radial velocity. In Campbell's paper HR 7137 was identified by its BD[44] designation +50° 2686, since neither the *Bright Star Catalogue* nor the *Henry Draper Catalogue* had yet been published; seven velocity measurements, having a range of nearly 10 km s^{-1}, were given. In 1913 the star featured in a preliminary listing[45] of the mean velocities of the stars that had so far been observed on the Lick programme. It was identified there as D.C. 8457, from its entry in the *Draper Catalogue*[35]; the mean velocity was given as "+7.:", with the note, "Sp. bin.; estimated velocity of the center of mass." (The estimate agrees with our finding here to within 0·03 km s^{-1}!)

In the final catalogue[46] of Lick velocities the seven observations listed in 1911 are given, with slightly changed velocities owing to various corrections that had been applied, plus just one later one. One of the original seven, however — the one that was most discordant with the rest and was responsible for about half the total range of the velocities — appears in brackets. The introduction to the catalogue spells out that "In general, measures rendered quite uncertain by serious underexposure of the plates, or by large temperature changes or other causes have been excluded; but a few have been quoted when we felt that even an approximate velocity at the recorded epoch of observation might have value at some later date. Such measures have been enclosed in brackets, but not used in obtaining the mean of the observed velocities." Ironically, the offending observation (1909 September 7) fits the orbit adopted here almost perfectly! After its rejection, the range of the remaining velocities was much reduced, and their listing is followed by the deprecating remark, "The evidence of variability rests on the range of only 4·8 shown by the values for two spectrograms taken on plates having a very coarse grain." There are in general no annotations to inform the reader as to differences in the quality or character of the plates, but the remark should probably be read as indicating that the two plates concerned had unusually coarse grain rather than as an oblique means of saying that all plates had very coarse grain. In any case, it appears that the authors of the catalogue were doing their best to back-pedal on the 1911 attribution of variability to the velocity of HR 7137.

Beavers & Eitter[29] published just one radial-velocity measurement of HR 7137. Like the Lick observations, it is included in the listing of velocity data in Table IV.

De Medeiros & Mayor[18] reported that six observations of HR 7137 had been made with the OHP *Coravel* over a span of 2579 days, that they were discordant with one another, and that the mean $v \sin i$ was 2·3 ± 1·0 km s^{-1}. De Medeiros, da Silva & Maia[19] reported exactly the same information; but when the former authors lodged their individual observations with the Centre de Données Stellaires, the number of measurements listed for HR 7137 was nil, so unfortunately the OHP work cannot be included in the data set here.

The 2002 paper[19] by de Medeiros, da Silva & Maia, which is entitled *The rotation of binary systems with evolved components*, has a tabulation of 134 such systems, all but five of which are *Bright Star Catalogue* stars. Seventy-four of the systems have orbits, which are referenced; the references show that 30 of the 74

TABLE IV

Radial-velocity observations of HR 7137

The sources of the observations are as follows:
1908–1926 — Lick[46] *(weighted 0·02 in orbital solution);*
1980 — Ames[29] *(weight 0·1); 2004–2009 — Cambridge Coravel (weight 1)*

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
1908 June 24·43	18116·43	+8·9	$\overline{36}$·446	–2·0
July 29·31	151·31	+9·7	·481	–1·2
Aug. 6·20	159·20	+11·5	·490	+0·7
1909 June 23·32	18480·32	+6·7	$\overline{36}$·820	+1·2
Sept. 7·22	556·22	+2·3	·898	+0·1
1910 May 19·43	18810·43	+7·9	$\overline{35}$·159	+1·2
31·40	822·40	+7·9	·171	+0·7
1926 Oct. 14·21	24802·21	+10·2	$\overline{29}$·318	–0·1
1980 July 29·21	44449·21	+10·8	$\overline{9}$·513	0·0
2004 Dec. 21·72	53360·72	+9·5	0·674	+0·3
2005 June 1·08	53522·08	+4·9	0·840	+0·1
Aug. 21·99	603·99	+1·1	·924	+0·2
Sept. 16·94	629·94	–0·2	·950	–0·1
Oct. 25·83	668·83	–0·7	·990	+0·1
Dec. 8·74	712·74	+0·3	1·036	–0·1
2006 Apr. 4·19	53829·19	+6·5	1·155	–0·1
May 11·11	866·11	+7·9	·193	0·0
June 4·07	890·07	+8·6	·218	0·0
July 3·01	919·01	+9·5	·248	+0·2
Aug. 7·98	954·98	+9·8	·285	–0·1
Sept. 7·99	985·99	+10·5	·316	+0·2
Oct. 4·95	54012·95	+10·6	·344	+0·1
Nov. 3·80	042·80	+10·7	·375	0·0
Dec. 2·70	071·70	+11·0	·405	+0·2
2007 Jan. 14·74	54114·74	+11·0	1·449	+0·1
Mar. 2·24	161·24	+10·7	·497	–0·1
Apr. 2·20	192·20	+10·6	·528	–0·1
May 1·14	221·14	+10·2	·558	–0·3
June 1·08	252·08	+10·2	·590	–0·1
Aug. 4·94	316·94	+9·7	·657	+0·2
Sept. 7·89	350·89	+8·8	·691	–0·1
Oct. 4·87	377·87	+8·5	·719	+0·1
Nov. 14·78	418·78	+7·3	·761	–0·1
Dec. 5·77	439·77	+6·7	·783	–0·1
2008 Feb. 16·25	54512·25	+4·2	1·857	+0·2
Mar. 5·24	530·24	+3·0	·876	–0·2
31·18	556·18	+1·7	·903	–0·2
July 21·99	668·99	–0·2	2·018	0·0
Aug. 19·02	697·02	+1·1	·047	+0·1
Sept. 12·92	721·92	+2·4	·073	0·0
26·91	735·91	+3·3	·087	+0·1
Oct. 5·85	744·85	+3·8	·096	+0·1
16·82	755·82	+4·4	·108	0·0
31·81	770·81	+4·8	·123	–0·3
Nov. 7·78	777·78	+5·5	·130	0·0

TABLE IV (*concluded*)

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O – C)* $km\ s^{-1}$
2008 Nov. 22·73	54792·73	+6·2	2·146	0·0
Dec. 17·75	817·75	+7·1	·171	−0·1
2009 Aug. 25·02	55068·02	+10·8	2·429	−0·1
Oct. 8·85	112·85	+10·7	·475	−0·2

orbits were published by the writer (with collaborators in a few cases). Many of the remaining stars were already on the Cambridge observing programme, from which orbits have since been published for 15 of the 60 stars that were lacking them in 2002. Certain others were actually added to the programme as a result

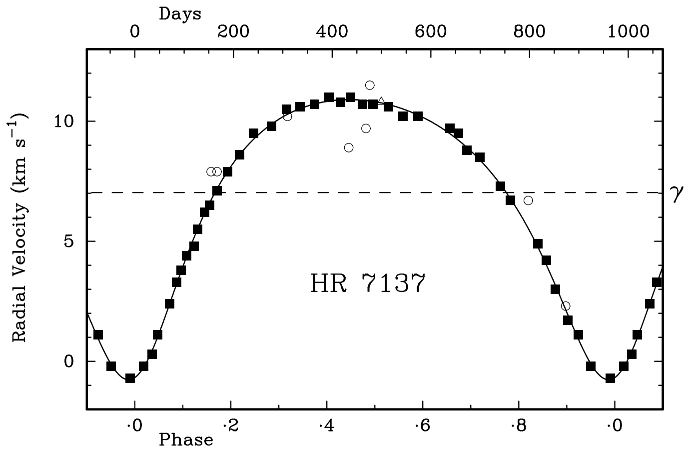

FIG. 4

As Fig. 3, but for HR 7137. The open circles plot Lick observations[46]; they are about 100 years old, and by enormously increasing the time base they refine the orbital period substantially despite being weighted only 0·02.

TABLE V

Orbital elements for the four stars

Element	*HR 6790*	*HR 6886*	*HR 6901*	*HR 7137*
P (days)	1248·5 ± 0·7	381·64 ± 0·07	2347·9 ± 2·6	972·84 ± 0·35
T (MJD)	53035 ± 6	53021·3 ± 1·0	52513 ± 23	53678·2 ± 2·4
γ (km s^{-1})	−54·00 ± 0·03	−10·51 ± 0·03	−47·21 ± 0·03	+7·03 ± 0·03
K_1 (km s^{-1})	5·62 ± 0·05	6·67 ± 0·04	7·08 ± 0·04	5·83 ± 0·04
e	0·255 ± 0·007	0·253 ± 0·005	0·088 ± 0·006	0·342 ± 0·006
ω (degrees)	8·6 ± 1·7	149·4 ± 1·0	101·5 ± 3·6	190·0 ± 1·1
$a_1 \sin i$ (Gm)	93·3 ± 0·8	33·85 ± 0·18	227·9 ± 1·3	73·4 ± 0·6
$f(m_1)$ ($M_\odot$)	0·0208 ± 0·0005	0·01064 ± 0·00017	0·0857 ± 0·0015	0·0167 ± 0·0004
R.m.s. residual (wt. 1) (km s^{-1})	0·18	0·15	0·24	0·14

of a scrutiny of the de Medeiros *et al.* paper; one of them was HR 7137, for which Cambridge observations started in late 2004 and now number 40. They are set out in Table IV after those from Lick and Ames, which have both been adjusted by adding 0·8 km s^{-1} to the published values in an effort to make them homogeneous with the Cambridge data.

The Cambridge measurements alone yield an orbit with a period of 970·7 ± 1·7 days. Addition of the Lick and Ames data — Lick with a weighting of 0·02 to equalize the weighted variances, with no attempt made to distinguish between the reliabilities of the observations severally, and Ames weighted 0·1 on the basis of experience — refines the period to 972·84 ± 0·35 days. Fig. 4 illustrates the orbit, and Table V gives the final elements, not only for HR 7137 but for the other three stars as well.

Discussion

There is little that can be said about these four single-lined binaries apart from assessing the prospects for detecting the secondaries and of determining the orbits in the third dimension by astrometric methods.

We can start by using the mass functions to indicate minimum masses for the secondary components, on the basis of an arbitrary estimate of 2 $M_{\odot}$ for the masses of the primaries. For the four stars, in the order of right ascension (or HR number) in which they have been treated above, those minimum masses are about 0·5, 0·4, 0·9, and 0·5 $M_{\odot}$, respectively. If they belong to main-sequence stars, the corresponding secondaries may be as much as 9, 10, 6, and 9 magnitudes, respectively, fainter than their primaries; if they were white dwarfs they would be fainter still. Thus they are liable to be very difficult to detect, although in the absence of information about the orbital inclinations there is no means of telling how far above the minimum values the actual masses may be.

Next, we can consider the angular sizes of the orbits and the angular separations of the components by reference to the values of $a_1 \sin i$ in conjunction with the parallaxes. The quantity $a_1 \sin i$ represents a minimum value for the semi-major axis of the orbit of the primary star around the centre of gravity of the system. The actual values of $a_1 \sin i$, taken from Table V above and converted from Gm into astronomical units (1 AU ~ 149·6 Gm) are about 0·62, 0·23, 1·52, and 0·49 AU, respectively. Because $a_1 \sin i$ refers to the projection *onto the line of sight* of the semi-major axis measured in the orbit plane, whereas to find the angular distance requires its projection *onto the plane of the sky* (which is normal to the line of sight), we cannot derive accurate values for the angular separation. Since all four orbits are of low or very moderate eccentricity, however, the projection on the sky must, at any rate at certain times, be at least comparable with $a_1 \sin i$ and may (because of the sin i term) be significantly larger. We can therefore obtain representative (but probably nearly minimal) values for the angular distances that the stars can reach from the centres of gravity of their respective orbits simply by multiplying their $a_1 \sin i$ values (expressed in AU) by their parallaxes, which by definition are the angles subtended by 1 AU at the distances of the stars concerned. Those angles are about 5·5, 1·1, 5·8, and 4·7 milliseconds of arc. All except the second one (that of HR 6886) are large enough that *Hipparcos* recognized the non-linearity of the apparent proper motion and was obliged to fall back on an 'acceleration solution'; presumably, therefore, now that the spectroscopic orbits are known, some approximation to the astrometric orbits could be wrung from the *Hipparcos* data.

Since the secondary stars can be expected to be less massive than the primaries, by up to a factor between two and five as indicated above, the separations of the components are likely to be larger, by factors of well over two and, except in the case of HR 6901, perhaps as large as five or so, than the distances we have just calculated with reference to the primary stars alone. Even so, it is scarcely to be expected that any of the systems could be resolved by speckle inteferometry with telescopes of the apertures that have routinely been used with that technique; on the other hand, these are all bright stars and the putative separations are easily resolved by systems with separated apertures, for which the principal difficulty is likely to be the magnitude differences between the components.

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CORRESPONDENCE

To the Editors of 'The Observatory'

John Wheatley

I thought your readers might be interested in some information I have unearthed about the Bluntisham carpenter and amateur astronomer John Wheatley (who lived from 1812 or 1813 to 1888). There was an account of Wheatley's astronomical activities published in *The Observatory* in 1958[1] which reproduces very closely the description of him given earlier in a local history book in 1941[2]. However, that account has two amusing quirks which might possibly be explained by the oral transmission of the story, although they were not queried in later issues of *The Observatory*. The first refers to Wheatley studying "Gardene's *Treatise on Optics*". I can find no evidence of there having been a writer on optics named "Gardene". I suggest that this might be the Rev. W. N. Griffin, whose *A Treatise on Optics* was first published in 1838[3]. More remarkably, the account recalls how Wheatley was involved with "…the re-discovery of Belaugh's Comet". Again, I can find no evidence of there ever being a comet named "Belaugh". I think it more likely that the comet concerned was Biela's Comet, which famously returned in two parts in 1846 and 1852 and then was lost.

I can add that the 18-inch-diameter mirror cast and figured by Wheatley in 1865 survives at the Norris Museum in St. Ives[4] and a letter from Wheatley describing it can be found in the John Couch Adams papers at St. John's College, Cambridge[5]. There are also two photographs of Wheatley, one with a collection of the telescopes, musical instruments, and a table that he had built[6], the other showing him with a large refractor in the yard of his cottage in Bluntisham[7].

Yours faithfully
MARK HURN

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2010 May 11

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Public Reaction to a V = –12·5 Supernova

The letter[1] from Thomas Hockey & Virginia Trimble in the June issue of *The Observatory*, concerning the public reaction to a nearby supernova, raises several interesting questions. But first I should emphasize (as the writers were well aware) that astronomers making observations and predictions about social matters do so as laymen, and as such are no more to be believed than the person next to you at the pub. Indeed, astronomers are unusual in several respects, and can be less in touch with 'the public' than most. An example at hand is Sir James Jeans[2], who asserts in *The Universe Around Us* that as soon as astronomers gained some inkling of the true size of the Universe "... astrology died a natural and inevitable death." It's fairly clear to anyone working in public outreach that astrology is still very much with us.

In spite of having thus dismissed any claim I might have to special authority in the matter, I think it is pretty certain that a supernova as bright as the full Moon would result in the sale of bracelets guaranteed to protect the wearer against harmful radiation by 'energy fields' or something of the sort, as well as other equivalents of anti-earthquake pills.

I do see a possible danger for astronomers if they loudly and repeatedly reassure the public that there is nothing to be feared from the supernova, and then some unexpected effect proves them wrong. It is very hard to guard against things that just haven't been thought of. And astronomers are not used to their science having practical consequences (as opposed to medical researchers, for instance), and so might be less careful to emphasize potential problems or uncertainties in their predictions. Even if nothing of this sort happens, I can foresee teachers telling their students not to look at the star, just to avoid the danger of a lawsuit (as I understand has happened with solar eclipses).

Turning to something more quantitative, I recall a discussion in a science-fiction novel from the late 1960s or early 1970s (one of Sir Fred Hoyle's, I think, though I cannot recall the title) in which a nearby nova or supernova occurs. Several scientists are trying to work out whether people might be permanently blinded by it. Of course the full Moon doesn't blind anyone (medically), but the same total light concentrated in a starlike point would have much higher surface brightness. As a rough calculation, a human eye seeing a point source as a disc 3 minutes of arc in diameter would find our supernova a hundred times the surface brightness of the Moon. Giving the Moon an albedo of 10%, the supernova would have ten times the surface brightness of a completely reflecting landscape at noon. Taking into account the fact that much of the full Moon is not under vertical illumination from the Sun, this number should be reduced. I suspect it would be painful but not enough to cause permanent blindness. (Those with better eyesight would be more in danger of damage, of course, as the image would be more concentrated.)

If the supernova progenitor were already an apparently bright star, like Antares or Betelgeuse, it would ironically be harder to detect its brightening early on. All current and planned automatic surveys of the sky of which I am aware are saturated by first-magnitude stars and so cannot measure them. The notice would have to come from an alert naked-eye visual observer, as was the case, for instance, with the brightening of delta Scorpii in 2000, and even then would be delayed if the progenitor were not on someone's regular observing programme. (Betelgeuse is a known variable of roughly one magnitude amplitude, and the AAVSO web site shows quite a few people keeping track of it.) Delta Scorpii was caught apparently when it had brightened by only a few tenths of a magnitude[3], but there were stars close in brightness quite nearby, making any change easily visible. A (currently) first-magnitude star would present more difficulties to visual photometry, with the only useful comparison stars far away in the sky. I suspect, though, that a brightening of a half-magnitude or more would be noticed, which would allow observation of most of the rising branch of the light curve.

Even after detection, precise photometry, and indeed all sorts of observations, would be difficult because many (perhaps most) instruments would be saturated in short order. Perhaps someone involved with early observations of SN 1987A could provide more detail, and extrapolate to the brightness we are considering in this case.

In any event, a programme of precise photometry of bright stars would be useful for other reasons, and would not require large or expensive equipment. It only needs someone at a good site to take an interest. Indeed, perhaps some enterprising amateurs are already taking care of it.

Yours faithfully,
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REVIEWS

Under the Radar. The First Woman in Radio Astronomy: Ruby Payne-Scott, by W. M. Goss & R. X. McGee (Springer, Heidelberg), 2010. Pp. 354, 24 × 16 cm. Price £108/$159/€125 (hardbound; ISBN 978 3 642 03140 3).

Ruby Payne-Scott was a pioneer, a pace-setter, and a personality. As the first woman radio astronomer she created a precedent which made it that little bit easier for other women to follow. As a brilliant physicist with a highly mathematical mind she pursued research relentlessly, both learning and teaching as she went, displaying a curious mix of a feisty nature and a deep affection for her immediate family. Even so, little has been written about just who and what she was and her all-too-brief years of research, and this book is to be welcomed as one which finally fills that gap.

Australian by birth, Payne-Scott (as the book labels her throughout) entered "radio physics" (as it was then called) somewhat by accident; her skills as a trained radio engineer became needed when WWII engulfed the South Pacific, and she obtained a position in the Radio Physics Laboratory (RPL) division of the CSIRO in Sydney. When her expertise in receiver technology and noise analysis was transferred to observations of the Sun, the research which then flourished became one of the core themes around which world radio astronomy was beginning to nucleate; her mathematical abilities were of paramount importance in formulating the concept of radio interferometry and Fourier synthesis. However, the book goes considerably further than Payne-Scott's own contributions, and the several chapters which describe her years at RPL are in fact a detailed history of the RPL group itself. One senses the competition that was developing between Australia and the UK, and has to admire the dogged determination of the central players to maintain the ideals of scientific excellence. It is therefore the more surprising that when nature (in the form of motherhood) brought Payne-Scott's research career to a sudden halt at age 39 she appeared to be remarkably unemotional about it.

The material for this book has been very thoroughly researched, leaving little archival material unread. Adding in what are described as "extensive" interviews by telephone and personal visit, the authors have amassed about as much information on and around the subject as could be possible. The photos which are reproduced are not of high quality, but are probably as good as the originals could support. The book commences encouragingly with an outline of Payne-Scott's career and concludes with a rationale plus numerous Appendices. It is well written and contains very few typing errors — but it left me dissatisfied on two counts.

Chapters 5 to 9 (out of 16) are given over to details of the radio astronomy carried out at the various sites where Payne-Scott worked, but encompassing the activities and the correspondence of the whole group. They are too technical for those not trained in the field (the authors even invite the non-scientist reader to skip them); moreover, the central figure fades from the limelight a little too often, thus making the book seem a bit like an excuse to explain the technicalities of early radio astronomy. My other point is also serious but in a different sense. The co-authors have clearly put considerable effort into the preparation of their material, but without (or not recognizing the need for) distilling from it the essence of Ruby Payne-Scott. All the ingredients for this highly complex fare are assembled, but are served up raw — they still need to be combined into a palatable dish. What we have here is a detailed technical document rather than the biography of a particular individual. The Preface quotes from a discussion on the pitfalls of scientists attempting to write history, and it was a pity that advice was not heeded. Circumstance, temperament, and culture combined to influence very significantly how the new science of radio astronomy developed in Australia and who the essential players were, but it shouldn't be left entirely to the reader to work it all out; that was the biographers' task.

Payne-Scott's involvements in scientific research, her political leanings, and her personal life are treated as separate topics, with no apparent recognition that the mixture of all those things added indelible hues to the subject's outlook, reactions, and decisions. There is a separate sub-chapter entitled 'The character of Ruby Payne-Scott', but it is merely a one-paragraph report of a brief conversation which showed how highly her main antagonist in the research years actually rated her scientific abilities. Nowhere do the authors reflect on the obvious effects which prevailing culture must have had upon a person who was overtly going against the grain. They note (frequently) that Payne-Scott was said to be effective at arguing, could be forthright to the point of aggressive, and didn't suffer fools gladly, but place a young, spirited, intelligent, and gifted woman in the straightjacket of the culture of that era, and think it extraordinary if she does *not* try to re-shape the world around her. Payne-Scott was born within a year of my own mother, and many of the changes which have since swept through the workplace did their cleansing before those in today's workforce were even around, so it would have added much to the context of the biography had it dwelt more on the unavoidable influences of background and less on the specialized science. Her success as a member of the illustrious Sydney Bush Walkers implied an ability get along with comrades under difficult physical conditions, but we are left to guess if that experience was of value in her rôle as a team leader in world-class physics.

A related and also slightly unsatisfactory feature of the book is the way it hives off a large amount of material, some more relevant than the rest, into a hotchpotch of Appendices. Interesting anecdotes, often the most human snippets, are relegated to footnotes though they add importantly to understanding how and why things turned out as they did. Presenting a summary gave away the juicy parts right at the start, so there was no 'story' left for the rest of the book to tell. One personal incident on which the authors dwell perhaps too much is the fact that Payne-Scott suffered a miscarriage, but the date was not documented, causing them to speculate repeatedly on the event yet never once to consider the likely repercussions for Australian or even world radio astronomy had that first baby been carried successfully to term.

Notwithstanding, it is high time that the record on yet another woman pioneer be set straight, and Goss & McGee are to be warmly congratulated on the major effort which this book represents. It should be on the shelves of every astronomical library, even though at £108 it is not cheap. — ELIZABETH GRIFFIN.

The Principles of Astronomical Telescope Design, by J. Cheng (Springer, Heidelberg), 2009. Pp. 631, 24 × 16 cm. Price £118·50/$179/€129·95 (hardbound; ISBN 978 0 387 88790 6).

This 630-page book provides a very comprehensive engineering and science study of telescopes used for astronomy, covering the collection and focussing of electromagnetic radiation, from gamma rays through to radio waves. The technical level of the book is for graduate engineers and astronomers, and it has an up-to-date and very extensive list of references. I reviewed some of the algebra in detail and found it to be complete and understandable.

Chapter 1 reviews the fundamentals of optical telescopes. The astronomical requirements of angular resolution, light-collecting power, field of view, and atmospheric windows for ground-based astronomy are presented. Cheng then presents fundamentals of astronomical optics with a review of basic principles, including aberration theory and corrector designs, and system-merit functions such as the modulation-transfer function. Chapter 2 then describes how a telescope mirror is specified, designed, and built. Properties of mirror materials are reviewed and methods for polishing and coating mirrors are described. Astronomical seeing and stray-light control are presented.

Moving on to more mechanical aspects, Chapter 3 covers telescope structures and control systems for telescope mounting, tubes, drives, and controls, and provides a structural dynamic analysis for telescope systems. For ground-based systems, Chapter 4 presents advanced techniques for optical telescopes. Active and adaptive optics and optical interferometers are described, showing the reader that the new optics technologies of wavefront sensing, speckle interferometry, amplitude interferometry, and intensity interferometry provide exciting new windows on the Universe for astronomical research.

Chapter 6 reviews the fundamentals of radio telescopes, by providing first a brief history and then reviewing the scientific requirements for them. Exploring radio-astronomical telescopes in more detail, Chapter 7 covers telescope design by examining antenna tolerancing, radio-telescope structure design, and radio interferometers. Coming to the shorter wavelengths, Chapter 8 provides a review of millimetre- and submillimetre-wavelength telescopes, starting with thermal effects, structural design, and carbon-fibre composite materials. Methods to measure the performance of submillimetre-wave telescopes are described along with a review of 'Quasi-Optics'.

Catering for space-based and 'new' branches of astronomy, Chapter 5 outlines the status of space-telescope projects, such as *Hubble*, *James Webb*, and the *Space Interferometry Mission*; Chapter 9 provides a discussion of infrared, ultraviolet, X-ray, and gamma-ray telescopes; and Chapter 10 covers gravitational-wave, cosmic-ray, and dark-matter telescopes.

Finally, Chapter 11 covers a series of rather disconnected topics including electromagnetic-wave and atmospheric transmission, non-electromagnetic telescopes, and man's missions to image the planets in our Solar System.

The book was originally written and published in Chinese and has been updated for this edition in English. Chapter 10 is new, while chapters 1, 4, 7, and 9 were reworked and updated. Unfortunately many of the drawings are poor and not legible in some cases. The book could have been better organized and the continuity between chapters improved. Cutting-edge modern astronomical research is a team effort between scientists and engineers who build ever more sensitive telescope and instruments. I predict that the book will find broad use among the engineering and astronomical communities for years into the future, and I recommend this book to astronomers and engineers who build astronomical telescopes and instruments. — JAMES B. BRECKINRIDGE.

At the Edge of the Solar System: Icy New Worlds Unveiled, by A. Doressoundiram & E. Lellouch (Springer, Heidelberg), 2010. Pp. 224, 24 × 17 cm. Price £29·99/$34·95/€34·95 (paperback; ISBN 978 1 4419 0864 3).

Evidently intended for a popular readership, this is an English translation of *Aux confins du système solaire*, written by two Parisian astronomers in 2008. Although in some respects this is yet another book about the 2006 IAU change in the status of Pluto, the authors also have much to say about the more recent discoveries of objects in the outer Solar System, their orbits, and their physical structure.

The chapters on the physical composition and likely origin of the "icy new worlds unveiled" beyond Neptune are the most detailed and informative in the book and represent a useful introduction to what modern photometry and spectroscopy of very faint moving objects can tell us about conditions in the outer System; and, coupled with knowledge of orbital statistics and ideas on the long-term changes in the orbits of the giant planets, how the present conditions have evolved from those just after the Solar System began to form.

Doressoundiram & Lellouch express their approval of the 2006 decisions in Prague ("a good decision", "the dynamicists win the battle") concerning the meaning of the terms 'planet' and 'dwarf planet'. This reviewer was particularly pleased to see their description of the strength of the 'clearing the neighbourhood' criterion (pp. 142–143) and how even Mars is more effective than Pluto is at this by five orders of magnitude, in contrast to the difficulty of applying the 'hydrostatic equilibrium' criterion (pp. 132–134) that has so far permitted only Pluto, three other transneptunian objects, and Ceres to be included in the dwarf-planet category. Indeed, in allowing Haumea and Makemake to be added to the Pluto–Eris pair in 2008, the IAU quite brilliantly stated that the incorporation of transneptunian objects brighter than absolute magnitude +1·0 was (only) "for the purpose of naming" such objects. *After* they have been named, who knows which objects qualify as dwarf planets?

One criticism I have of the book is that occasional brief facts are given but are neither followed up nor accompanied by references. On page 15, for example, in discussing the serious attempts to grapple with the idea that supposed irregularities in the motion of Uranus were due to the presence of one or more transneptunian planets, the name of "Indian astronomer V. B. Ketakar (who has received little recognition for his contribution)" is added to those of W. H. Pickering and Percival Lowell. Whereas the well-known ideas of the two Americans are then described in some detail, absolutely nothing more is said about the poor Indian (not even his dates). Then, on page 169, as evidence of the success of the "potentially very powerful method" of finding TNOs from stellar occultations, Figure 8.6 purports to show such an occultation "as seen by the William Herschel telescope in the Canary Islands", said occulter being "320 metres in diameter at a distance of 140 AU". I, for one, should like to know more!

And the book is not without errors. Contrary to the statement (p. 8) that Piazzi "was not involved in the project" (*i.e.*, the 'celestial police'), he had just not been *told* he was a member by the time he discovered Ceres. It is not the diameter of Charon that was measured as 603·5 km (p. 37) but the radius. There is no 'Journal of the Astronomical Society of the Pacific' (p. 63): Leonard's remarks were in that Society's 1930 August *Leaflet*. The first letter in a provisional designation (p. 76) indicates not the fortnight in the stated year but the half-month. While its diameter may not have been precisely measured, Sedna clearly ranks among the 12 largest known TNOs, yet it is missing from the display in Figure 5.9 (p. 112). — Brian G. Marsden.

Astrophysics of Planet Formation, by Philip J. Armitage (Cambridge University Press), 2009. Pp. 284, 25·5 × 18 cm. Price £40/$65 (hardbound; ISBN 978 0 521 88745 8).

I have always been surprised by the disparity between the number of astronomers studying the origin of the Universe and the number studying the origin of the planets. The latter subject, cosmogony, seems more relevant, is so much closer to hand, and the physics is more fun. Cosmogony has also been given a considerable boost by the discovery, in the last few decades, of nebular dust clouds around distant stars, and more than four hundred extra-solar planets to add to our well-known eight. And now we not only have to explain celestial segregation, in which the vast majority of mass ends up in the star but the vast majority of angular momentum in the planets, but we also have the problem of migration. Instead of the majority of planets being well behaved and being born close to their present orbits, planets now wander about, some moving out and producing Edgeworth–Kuiper Belts and others diving in to the stellar potential wells and ending up with Jovian masses in Mercury-like orbits.

Cosmogonic problems abound. Why is the Solar System so unusual? Was the accretion process dominated by gravity or did dusty plasmas play a significant rôle? Are all planets formed in the same way or do near-stellar collisions have a rôle to play? Were many migration processes so efficient that many planets ended up consumed by the central stars? And just how common are planetary systems anyway?

Philip J. Armitage is a professor at the University of Colorado, Boulder. The important combination of having to do research and having to teach advanced students has resulted in *Astrophysics of Planet Formation* being a textbook of admirable clarity and succinctness. This is just the sort of textbook needed to boost the cosmogony/cosmology ratio. The first two chapters concentrate on the characteristics of both the Solar System and the new planetary systems found around other stars. We then delve into the properties of protoplanetary discs and the evolution of their surface densities. Much is made of angular-momentum transport and the effect of possible partial ionization. Then comes a chapter on dust coagulation and planetesimal formation, followed by a review of accretion and the temperature-dependent production of terrestrial planets and gas giants. The final chapter concentrates on the effects of migration and resonances, and tackles the delicate problem of stability.

This excellent book is a superb introduction to modern cosmogony, beautifully produced and with an extremely useful and up-to-date reference section. I was a bit surprised about the history. There is very little, and many of the old favourites on the cosmogony library shelf do not even get a mention. I was also slightly worried about the concentration on Sun-like stars. Just how does the mass, metallicity, and angular momentum per unit mass of the protoplanetary nebula and the central star affect the form of the final planetary collection? And what happens in the case of binary stars? There is plenty of work still to be done and Armitage's book is a good place to start. — DAVID W. HUGHES.

Protoplanetary Dust: Astrophysical and Cosmochemical Perspectives, edited by D. Apai & D. S. Lauretta (Cambridge University Press), 2010. Pp. 377, 25 × 18 cm. Price £70/$120 (hardbound; ISBN 978 0 521 51772 0).

This book discusses cosmic dust from the perspective of planet formation *via* ten multiple-author chapters. It is an excellent read, very much at the research edge in the field, and very up to date in the sources used. I would recommend it highly to graduate students, but also for the bookshelves of professionals in the field.

The novel aspect is that each chapter is authored by two or three different people from the fields of astronomy, Solar System analysis, and laboratory experiment. This occasionally makes the text a bit jumpy, but mostly is very successful in testing astronomical ideas by comparison with the formation of the Sun's planets, and with measured material properties. The book is very comprehensive, including discussing areas of ignorance (*e.g.*, why circumstellar discs are viscous, and why oxygen isotopic ratios are anomalous). Some recent results were new to me (for example, that dust originally forms in very static layers of AGB stars) and some were surprising, such as where lab results in CO, CO_2 fractionization do not match preconceptions. The book is mostly very even-handed in presenting rival ideas, though I would have liked to see a bit more discussion of the controversy over whether the Sun formed near a supernova, and the recent suggestion of lightning happening within discs. More-well-established ideas are solidly presented, including relevant equations, and the authors have taken good care to explaining their terminology (though an even longer glossary would help readers from diverse backgrounds).

The astronomical side of this field often suffers from theoretical ideas being presented as fact, in the absence of observed data, and one of the particular values of this book is the testing of ideas by 'sanity-checking' against properties of the Solar System, including discussion of why it might be atypical. Overall it's a very thorough work with an original approach, and very self-consistent from chapter to chapter, for which the editors are commended. — JANE GREAVES.

Stellar Evolution and Nucleosynthesis, by S. Ryan & A. Norton (Cambridge University Press), 2010. Pp. 236, 26·5 × 21·5 cm. Price £75/$130 (hardbound; ISBN 978 0 521 19609 3), £35/$60 (paperback; ISBN 978 0 521 13320 3).

As I write this review on the eve of the May 6 UK election, I recall the heady days in 1964 when Harold Wilson sought to harness "the white hot heat of the technological revolution" following the Labour party's win at that election. The Open University, which enrolled its first students in 1971 January, was an outstanding product of that revolution, possibly the sole surviving product. Astronomy is one highlight of the OU. This textbook, published by CUP in association with the OU, sets a high standard for what I hope will be a series of books for distance learners in the UK and elsewhere pursuing a passion for astronomy.

A strength of the book is a comprehensive set of worked examples and a rich array of other exercises for "astrophysics and physics majors looking to move on from the introductory texts". The text is delightfully free of multiple-choice questions that have infested even university courses on the eastern side of the Atlantic and which are surely a certain way to lose the next technology revolution. However, the level of treatment is not always uniform. For example, five analogies are introduced to illustrate the emptiness of an atom, but the equation of radiative diffusion is stated without explanation.

Stellar evolution and nucleosynthesis has proven a fascinating field of endeavour for me for all the years since 1964. To a considerable extent, the fascination of the subject is the breadth of disciplines that contribute to understanding and progress in the field. Very little of this breadth is realized in this otherwise fine book. In terms of nuclear reactions, Gamow peak and S-factors are covered but not a word on how nuclear-reaction rates of astrophysical interest are measured or calculated. The opportunity to highlight solar neutrinos is not taken. Observations pertinent to stellar evolution and nucleosynthesis by low-mass stars are barely discussed; would not mention of the discovery of technetium stars spike the interest of readers in their living-rooms as they read about synthesis by neutron capture? How do we know, the same readers might ask, that supernovae are the element factories and delivery systems that it is claimed they are? Perhaps the next edition — surely there should be one — will address those and other omissions and the general imbalance in the presentation in favour of theoretical ideas. — DAVID L. LAMBERT.

Star Clusters: Basic Galactic Building Blocks Throughout Time and Space (IAU Symposium No. 266), edited by R. de Grijs & J. Lépine (Cambridge University Press), 2010. Pp. 575, 25 × 18 cm. Price £70/$125 (hardbound; ISBN 978 0 521 76499 5).

This book provides a wide-ranging look at star clusters, both open and globular, and how they are used as laboratories for studying star formation and evolution.

These are the conference proceedings of IAU Symposium 266, held in Rio de Janeiro in 2009 August. They are neatly structured into sections concentrating on the sessions held, with a large section at the rear for the poster presentations. The sessions were wide-ranging to cover such a broad range of interest, and ranged from star formation to cluster formation, dynamics, and evolution. Within each session, many individual areas of interest were covered; for example, in the session on cluster dynamics there was work presented on the formation on brown dwarfs and on searching for intermediate-mass black holes.

The cluster research presented here all starts with the premise that star formation does not occur in isolation, and almost all stars are formed within clusters and group together in hierarchical structures. Throughout the sections there are interesting papers that support this view both theoretically and through multi-wavelength surveys.

Overall, I feel the book is a useful overview for those studying clusters, but is perhaps a little too wide-ranging for most people to use on a regular basis. — SARAH CASEWELL.

Star Clusters as Tracers of Galactic Star-Formation Histories, edited by R. de Grijs (Royal Society Publishing, London), 2010. Pp. 214, 24·5 × 17·5 cm. Price £58 (paperback; ISBN 978 0 85403 803 9).

This special issue of the *Phil. Trans. Royal Soc. A* carries a number of self-contained scientific review papers centred on the theme described by the title. It has been compiled and edited by Richard de Grijs, a leading researcher in this field, who writes the first introductory review to set the scene and motivate the work that follows. Taken together, they provide a comprehensive review of contemporary star-cluster research (modulo my comments below) aimed at the academic-level astronomical community. No attempt is made to make this book understandable at the public level. I will therefore continue this review under the assumption that the reader is reasonably knowledgeable in contemporary astrophysics.

Some of the reviews are fairly short and focus on specific recent advances or particularly thorny questions (*e.g.*, Bruzual or Harris), whereas others are more comprehensive (*e.g.*, Kalirai & Richer, van Loon). The Lada and Clarke double-bill makes for excellent reading, providing a compact and concise, yet stimulating, review on the subject of star-cluster formation. Although the two authors come at the topic from the opposing directions of observations and simulations, the two works are well dovetailed together, and, in contrast to much of the rest of the book, are very well cross-referenced. This brings me to a small gripe: I felt that the review authors could have done with communicating a little more with one another; in places there is a little too much repetition (particularly in the introductions) and too little cross-referencing.

The topic of this special issue — star clusters and their use as tracers of the star-formation histories of galaxies — has necessarily biassed the reviews towards studies of globular clusters, as they are the oldest and most populous category of star cluster and can trace star-formation histories right back to the epoch of galaxy formation. The interesting recent discovery of multiple-age populations in some globular clusters features in a number of reviews, namely those of Bruzual, who discusses what evolutionary-synthesis modelling is telling us, and van Loon, who details the chemical effects and observational evidence. The reviews of Kalirai & Richer and Verperini give insight into the complexities of star-cluster dynamics, and Goodwin succinctly discusses the more specific problem of the formation, evolution, and effects of the binary-star population. Finally, Larsen and Harris take wide-angle views of young and old cluster populations.

As comprehensive as this special edition is, I felt two key issues/topics were not addressed at all. First is the form of the stellar initial mass function (IMF), a contentious issue which has been driven by the study of star clusters. Fortunately this topic has very recently been reviewed by Bastian, Covey & Meyer (*Ann. Rev. A&A*, in press, 2010). Second is the subject of star-cluster-driven feedback, an omission of particular pertinence in the context of Galactic star-formation histories. Interested readers should refer to the review of Galactic winds by Veilleux, Cecil & Bland-Hawthorn (*Ann. Rev. A&A*, **43**, 769, 2005).

For a complementary review of young and massive star clusters (the younger cousins — and perhaps modern-day progenitors — of globular clusters), the interested reader should certainly get hold of the recent review by Portegies Zwart, McMillan & Gieles (*Ann. Rev. A&A*, in press, 2010). — MARK WESTMOQUETTE.

High Energy Radiation from Black Holes: Gamma Rays, Cosmic Rays, and Neutrinos, by C. D. Dermer & G. Menon (Princeton University Press, Woodstock), 2009. Pp. 538, 23·5 × 15·5 cm. Price £52 (paperback; ISBN 978 0 691 14408 5).

This book is a very timely review of non-thermal processes in astrophysics, complementing the dramatic increase in our knowledge of the non-thermal Universe over the past decade. *Swift* has revolutionized the number and quality of datasets on gamma-ray bursts, motivating much more detailed models of the transient jet produced in the explosive blast wave from a collapsing massive star as the black hole forms. Similarly, there has been a vast increase in data from the *Fermi* satellite on steady jets from accreting black holes. Both these types of jet clearly contain ultra-high-energy electrons, which are themselves carried along at relativistic velocities by the out-flowing jet. This book pulls together all the required radiation processes to describe the spectrum produced by this combination of non-thermal electrons with relativistic bulk velocity distributed spatially through the jet. This is an invaluable resource for anyone starting in the field, as it takes a step-by-step approach, showing clearly the underlying physics which leads to the final spectrum.

The existence of highly energetic electrons in the jet is unambiguous, so leading to the obvious question of how they are accelerated to such high energies. The book works through particle-acceleration processes, many of which should equally or even preferentially accelerate ions. This links again to recent observational breakthroughs, this time from data on ultra-relativistic cosmic rays from the *Pierre Auger Observatory*. The cosmic-ray spectrum is described in detail, with AGN jets being the most likely sites for production of the highest-energy ions. The possible energy-loss channels for these ions are discussed systematically, including pair-production on cosmic-infrared-background photons, which limits the distance that the highest-energy cosmic rays can travel, producing the observed high-energy cut-off (the GZK effect).

High-energy protons can also lose energy in the acceleration region itself by colliding with protons, electrons, or photons. All these processes are described, many of which lead to neutrino production *via* pion decay. Unlike the ions, neutrinos will not be easily absorbed so give a potential future observing window on the highest-energy acceleration sites across the entire Universe.

The book is very self-contained, including General Relativity for both cosmology and black holes, together with Special Relativity required for the high-energy processes. All in all, it is a tremendously useful resource for researchers in high-energy astrophysics. — CHRIS DONE.

Mysteries of Galaxy Formation, by F. Combes (Springer, Heidelberg), 2010. Pp. 218, 24 × 17 cm. Price £24·99/$29·95/€29·95 (paperback; ISBN 978 1 4419 0867 4).

The formation of galaxies, or more generally cosmic structure, has become a major theme of modern astronomy. Like all active subjects, it is replete not only with contingent facts, but with phenomenology that makes it hard for the uninitiated to get started. The newcomer has to grasp a range of often contradictory or opposing ideas. These usually invoke a wide spectrum of physics, and frequently a degree of blind faith. Even for experts this mixture can make the original papers hard to read.

This book will be enormously useful to anyone wanting to know about this field and facing these types of problems. It provides a concise and very readable introduction to the observational facts and the ideas currently vying to explain them. Although it uses no mathematics, it is careful to explain and stress the rôle of the underlying physics throughout. The author is a distinguished figure in this field, and gives apt and succinct characterizations of complex theoretical ideas, as well as the difficulties with which successful observational tests must contend. The book is well illustrated and the author and her translator have produced a lucid text. Ideal for students, and an excellent reference for everyone else. — ANDREW KING.

AKARI, a Light to Illuminate the Misty Universe (ASP Conference Series, Vol. 418), edited by T. Onaka, G. J. White, T. Nakagawa & I. Yamamura (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 546, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 716 2).

This is the proceedings of an international symposium held in 2009 to report initial results from the *AKARI* (*ASTRO-F*) mission. The publication is most timely: the review copy arrived within a week of the first public data release (http://darts.isas.jaxa.jp/astro/akari) of the all-sky-survey point-source catalogues and will serve to illustrate the wide range of science being done with *AKARI*. Besides the all-sky surveys with *Far-Infrared Surveyor* (at 65, 90, 140, and 160 μm) and the *Infrared Camera* (9 and 18 μm), which took priority during the early part of the mission, *AKARI* was used for pointed observations, including spectroscopy, for open-time projects. The public surveys are described in the first two papers and we are then given an astronomical tour from zodiacal light to cosmic background radiation *via* star formation, evolved stars, and galaxies near and far. The range of topics covered is most impressive. This is a remarkable time for infrared-satellite missions, with *Spitzer*, *Herschel*, and *WISE* also in orbit, and the volume includes contributions describing projects with these, often synergetic with *AKARI*.

The contributions, including poster summaries, generally run to 4–8 pages, enough to give the authors space to report their results and the reader an assessment of what to look out for in the journals. With very few exceptions, the discussion is not reported. The book is well produced, with clear figures and photographs, but it is pity that those of participants sprinkled through the volume are not captioned. Even if you don't normally use infrared data, look at this book to see what *AKARI* might do for your research. — P. M. WILLIAMS.

Particle Dark Matter: Observations, Models and Searches, edited by G. Bertone (Cambridge University Press), 2010. Pp. 738, 25·5 × 18 cm. Price £70/$115 (hardbound; ISBN 978 0 521 76368 4).

Dark matter has become a central topic of modern cosmology. Despite this, there are still relatively few good books providing in-depth, comprehensive coverage of the subject. Into this void *Particle Dark Matter* is a very welcome addition. Virtually every aspect of modern dark-matter research is covered, with the wide authorship providing detailed but consistently readable contributions. As the preface claims, this is far more than a collection of review papers.

The subject coverage is good, well organized, and avoids too many repetitions. The first section of the book explores the observational need for an additional (non-baryonic) matter component to the Universe, and the consistency of dark-matter numerical simulations with those observations. The modified-gravity hypothesis is also presented. The second section explores in detail the wide range of candidate dark-matter particles, linking to physics beyond the standard model. Section 3 then considers opportunities for dark-matter and related searches at accelerators, with particular emphasis on the *LHC*. The progress towards a terrestrial direct detection is the subject of Section 4, while the final section explores the possibilities for indirect detection and astrophysical constraints. Throughout the book, the care taken with citations is impressive, although the index is a little too brief.

This is an excellent book, ideally suited to graduate students in the field and any others wishing to familiarize themselves with one of the most exciting and pressing challenges presently available in science. I can report that my colleagues, on seeing the book on my desk, have more often than not attempted to steal it away to lose themselves in its depths. — ALEXANDER MURPHY.

2nd Crisis in Cosmology Conference, CCC-2 (ASP Conference Series, Vol. 413), edited by F. Potter (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 323, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 706 3).

Perhaps the strangest thing about this proceedings volume is that none of the papers cites anything by Tom van Flandern, to whose memory it is dedicated and who convened the conference of which it is a record. I say "Perhaps" because there are other unusual features. None of the authors of the 30 included papers (some other speakers did not submit their manuscripts) is female, though there are four women among the other 30-plus participants (three with surnames matching those of male authors). Ten of the papers come from authors associated with universities or major observatories.

Of the more-or-less discrete 30 ideas, the authors have previously presented four in major journals (*Astronomy & Astrophysics*, *Monthly Notices*, *Physical Review*). Expansion of the publication inventory to include *Bulletin of the American Physical Society*, *Acta Physica Polonia*, *Physics Essays*, *Journal of Astrophysics and Astronomy*, *Physica Scripta*, AIP conference proceedings, and the

Journal of Quantitative Spectroscopy and Radiative Transfer brings in eight more of the ideas. The rest made their debuts in less-well-known journals, books, or only on-line. In a few cases, authors cite none of their previous work.

You will by now have deduced that 'Second crisis' deals (apart from a couple of observational summaries) almost entirely with non-conventional cosmologies, which, variously, deny cosmic expansion, finite age, General Relativity, non-centrality of our position, dark matter, dark energy, and strings. Another curiosity, again perhaps, is that two of the best-known non-standard viewpoints (M. Milgrom's MoND and J. Bekenstein's TeVeS) are not represented by papers or even in the references, though R. L. Oldershaw (another unconventional cosmologist) and Emil Wolf (who found laboratory evidence for a source of small redshifts not attributable to motion, expansion, or gravitation) do turn up in the references.

Probably most valuable to the conventional cosmologist is the last paper, by Louis Marmot (a former co-author with Grote Reber), which gives analytical expressions for angular-diameter distance, luminosity distance, and time-dilation factors for 12 redshift mechanisms (including ΛCDM). All but two of the time-dilation factors are $(1 + z)$. The exceptions are a complicated relation for gravity nullification (represented elsewhere in the book) and $F_{t.} = 1$ for the Heisenberg Effect (not elsewhere explained).

Conflict of interest statement: one of the alternatives, Quantum Celestial Mechanics, came from old friends (and very close friends of my late husband, Joe Weber) Howard Preston and Franklin Potter. The latter also took over the editing of the volume after the death of Tom van Flandern. Van Flandern's work does appear in the book reviewed in *The Observatory* (**129**, 32, 2009) by Elizabeth Griffin and further discussed in these pages (**129**, 156, 2009) by me. — VIRGINIA TRIMBLE.

How It Ends: From You to the Universe, by C. Impey (W. W. Norton, London), 2010. Pp. 352, 24 × 16 cm. Price £18·99 (hardbound; ISBN 978 0 393 06985 3).

Astronomers come in both optimistic (*Surviving 1000 Centuries*, according to Roger-Maurice Bonnet and Lodewijk Woltjer) and pessimistic (*Our Final Hour*, or in other editions, *Our Final Century*, according to Martin Rees) subspecies. Impey is, in a sense, a pessimist, in that he is quite sure that individual humans, species, biospheres, planetary systems, stars, galaxies, and universes will all eventually die or cease to be habitable. The only question is when. You are unlikely to outlive Jeanne Louise Calment: (1875–1997; misprinted in the text as 1977, which would have been less interesting). Even before the red-giant Sun boils away our oceans, increased weathering of rocks will reduce atmospheric carbon dioxide below the level needed to support any known plants. And on the cosmic scale, both big crunches and big rips are bad for anyone still around 100 Gyr into the future when these might happen; and even eternal, slowing expansion finds its denizens more and more starved for high-grade energy sources.

That CO_2 factoid was one of my "aha's" from the book — that is, things I hadn't known before and am glad to add to permanent memory. Others are that we are more genetically different from people living 5000 years ago than they were different from Neanderthals, that a bolide is a fireball seen by a geologist, and that Danish cartoonist Storm P is at least a competitor with Yogi Berra and Niels Bohr for a remark about the danger or difficulty in making predictions, "especially about the future". A few items hover between "aha" and "oops." On

p. 26 the author tells us that most of the people who have ever lived are alive now, while p. 313 says only 5–6 %.

Naturally, I also accumulated a fine collection of "no's", "oopses", "eh?s", "ums", "oys", "hoo-hee?s", and "are you sure, sure, sure?s". Listing them all would be misleading, since the author is an expert on many of the topics he addresses and has consulted other experts from other fields. But here is roughly one of each, if only to clarify how an "oy" differs from an "oops".

"Princeton astrophysicist Ed Salpeter" (who spent his entire post-PhD career at Cornell) is definitely an "oy", while "Katy" Pilachowski (in the preface but correct in text and index) is merely an "oops", as is "the surface of a red dwarf is hundreds of degrees".

A classic "hoo-hee?" is the "Strir", appearing in Figure 12·3 with no explanation in caption or text or index entry. "Could the mayfly figure out the pattern of germination of planets and pollination of flowers?" is merely an "um" (presumably plants is meant, though who am I to swear that planets don't germinate and mayflies don't figure this out?). The order in which an observer in Los Angeles is said to become aware of various phenomena caused by a 10-km asteroid hitting San Francisco is an "eh?", with radiation first, earthquake second, fragments third, and an atmospheric "blast wave travelling at hundreds of kilometers per second", a distant last after half an hour. SF to LA is a smidge more than 500 km. Query marks went next to the "tenuous oxygen atmosphere" of Europa, male sex assigned to a Koi fish named Hanako, and the 76-year age of Cheeta, who, according to a recent column filler in the *LA Times* was actually several chimpanzees over the years, like Lassie (well, Lassie was several collies, mostly male, with long hair).

I have thought of two possible endpoints for these comments. One is a brief quiz, in which the reader is asked to identify the distinguished colleagues whom Impey describes as "avuncular, long-haired ... with counterculture-vibe", "an aging Lothario", "a small man with gentle eyes and the cadence of a preacher from Southern England", "slender ... head framed by a halo of dark curls", "very soft-spoken and gracious", and "a boxer, an athlete, and an attorney". Oh, sorry, that last is Edwin Hubble, with recent scholarship suggesting that the description is at least an "um".

Alternatively, the contribution of proton decay to the luminosities of all stars at all times was a definite "aha!" for me. But efforts to reproduce the combination of one solar mass (or a bit less), a lifetime of 10^{35} yr, and a luminosity of 400 Watts, also ends in an "um". Now, you please do the calculation and figure out where I went astray (as I still cannot!). But the pions that come directly from proton decay must be π^{+}, while only π^{0} decay directly into gamma rays. Score: author minus 1, reviewer minus 1? — VIRGINIA TRIMBLE.

Astronomical Data Analysis Software and Systems XVIII (ASP Conference Series, Vol. 411), edited by D. A. Bohlender, D. Durand & P. Dowler (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 588, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 702 5).

Every autumn the astronomical-computing tribe gathers at the ADASS conference. This is the proceedings from its 2008 gathering and includes papers relating to more than 30 talks and over 80 posters presented at the conference, together with summaries of the demonstrations and 'Birds of a Feather' discussions.

People question the value of conference proceedings that (like this one) appear more than a year after the meeting, but the argument that they provide no more than an out-of-date snapshot is less applicable here. The articles in ADASS proceedings will typically not be superseded by journal papers that might well have appeared before the proceedings volume. In most cases, an ADASS proceedings paper is the most formal way in which this material will appear; too technical for a mainstream astronomy journal, it may appear on a project website, but is unlikely to find another long-term, citeable home in the literature.

Does that matter? To other members of the ADASS tribe, clearly yes, since they will want to make use of the lessons learned by others, but what about those within the wider astronomical community? The argument for answering "yes" to that has strengthened as the ADASS tribe has attracted new members, *e.g.*, research astronomers engaging with computer scientists to develop novel approaches to data-analysis problems, as well as the traditional writers of telescope-control and data-reduction software.

The latter will retain their rightful place at ADASS, but the topics the conference covers are becoming more main-stream within astronomy as astronomers need more computational tools for their research. Few may read this volume from cover to cover, but it should be found within all serious astronomy libraries, available for reference by those needing information about the state-of-the-art in a domain of increasing importance to astronomy. — BOB MANN.

Small Telescopes and Astronomical Research, edited by R. M. Genet, J. M. Johnson & V. Wallen (Collins Foundation Press, Santa Margarita, CA), 2009. Pp. 327, 23 × 15 cm. Price \$19·95 (plus shipping; about £12·50) (paperback; ISBN 978 0 9788441 3 4).

The funding for the publication of this book has come from the Collins Family Foundation and this has allowed a more eclectic choice of papers than would normally be found in a book of this type. To some extent the book is a celebration of the lives of two people who have done much to allow or encourage the use of small telescopes in astronomical research. The first of these is Thomas Johnson, the inventor and creator of Celestron telescopes. It can be argued that his development of the Schmidt-Cassegrain telescope, which allows a small tube length to be combined with a relatively large aperture, has done more than almost anything else to provide part of what is needed to allow the serious use of small-aperture telescopes. The second person is Russ Genet himself, one of the editors of the book and a mercurial guiding light whose influence can be seen in much of the work described in this book.

The papers contained in these pages vary from two short contributions, which are meant as pleasant diversions and can best be described as science fiction/fantasy, to a very serious discussion, the longest paper in the book, on the chirality of details associated with solar flares and other features. The interpretation of the word 'small' in the title of the book will surprise some professional astronomers. A paper on the use of 50-mm-diameter lenses from binoculars, together with modern digital detectors and recording media, shows with remarkable effect the accuracy which can be achieved in determining the shapes and sizes of asteroids during occultations. It will also be salutary to some double-star observers to see what can be achieved with a 3-inch diameter Tasco telescope. (Included is a contribution on double stars by one of the Editors of

The Observatory, R.W. Argyle.) The range of subjects covered includes variable stars, exo-planets, double stars, proper motions, observational projects which can be carried out by students in one term at college, and much more. The book is made particularly useful to those undertaking astronomical education as it not only covers the projects but in many cases describes in detail the 'off-the-shelf' hardware and software which make the projects possible.

One particular pleasure with this book is the quality of the editing. This reviewer did not find a single error or typo. The book will be of little interest to those who feel that they need a 10-metre-diameter telescope for their research, but to both professional educators at the undergraduate (or lower) level and amateur astronomers it can be heartily recommended. — E. Norman Walker.

Starlight: An Introduction to Stellar Physics for Amateurs, by K. Robinson (Springer, Heidelberg), 2009, Pp. 286, 23·5 × 15·5 cm. Price £22·99/$34·95/€34·95 (paperback; ISBN 978 1 4419 0707 3).

Keith Robinson's recent publication presents a good, easily accessible account of basic stellar physics. Some mathematical detail is included for the more interested reader, but the level is pitched well so as not to overwhelm those less gifted in that department.

The book is part of Patrick Moore's *Practical Astronomy Series*, and complements this series' catalogue well. Other introductory stellar astrophysics books tend to be for a more advanced reader; but this book serves to bridge the gap between the reader with a basic scientific knowledge and those more advanced texts. This volume is priced at £22·99, in keeping with the rest of the series' typical price of around £20–£30. More advanced texts are often more highly priced, making this book good value for money for the amateur astronomer.

Starlight starts with a basic outline of some of the mathematical rules used in stellar astrophysics, and goes on to cover areas such as the electromagnetic spectrum and radiation fields, magnitude systems, radiative transfer, atmospheric physics, stellar structure, the interstellar medium, and stellar evolution. This provides ample coverage of the basics of stellar astrophysics, though I do feel that the mathematical run-through at the beginning would benefit from the explicit inclusion of some basic trigonometry, as this is used frequently in the text. There are no mistakes in the scientific material, though a couple of minor typos are present. However, these do not detract from the value of the book in a major way.

The author's writing style is very easy to follow, making extensive and effective use of everyday analogies to explain the more-complicated concepts. The figures are well presented and are in black and white. Though some would have been more attractive in colour, they still effectively communicate the concepts they illustrate. All make good use of caption boxes, and the end of each chapter contains a bullet-point summary of key points. This allows the really main points of the material to come through, so a complete beginner can follow the various concepts easily. Some equations are presented for those readers who may be interested in making a few calculations themselves, but those less inclined may move past these sections and still follow the material.

Back when my interest in stellar astrophysics was forming at school, this would have provided an interesting, informative, and insightful introduction. It would be a good resource for, say, a GCSE-level or amateur astronomer, and I would recommend it to that readership. For those studying at a higher level, *i.e.*, an undergraduate, the mathematical depth is too shallow and I would recommend something more advanced. However, the book's aim of communicating the basics of stellar astrophysics at a beginner's level is achieved.

All in all, Robinson's book is a well-put-together resource for the amateur astronomer, explaining the basic concepts and equations pertinent to the study of the stars. — N. J. DICKINSON.

A Spectroscopic Atlas of Bright Stars: A Pocket Field Guide, by Jack Martin (Springer, Heidelberg), 2010. Pp. 214, 20·5 × 12·5 cm. Price £24·99/$29·95/€29·95 (paperback; ISBN 978 1 4419 0704 2).

This pocket guide is a noble attempt to introduce practical stellar spectroscopy into backyard star-gazing. Imaging the spectra of bright stars is a hobby which Martin has pursued for many years, and is now offering to share with those who could easily follow but who may have been put off by the cloak of professionalism and mathematics which traditionally shrouds it. Sensibly limiting his objective to instruction on stellar classification, he devotes a few pages to history and to scientific and technical explanation, with the rest of the book given over to the *Atlas* itself, displaying his own spectra of 72 stars. The end contains an extensive glossary, and an index of terms used and stars named.

The *Atlas* has a two-page spread per object. One page shows a photographed image of the spectrum; a scan of it is ranged above, with the most prominent features marked. The other page identifies the star in its constellation, and tabulates HD number, 2000 co-ordinates, V magnitude, distance, spectral classification, $(B - V)$, effective temperature, and radial velocity. A second table gives the wavelengths of the identified lines indicated on the opposite page.

The actual purpose of the book is not entirely clear. To teach spectral classification? Although the spectra are normalized to their highest point, and one can appreciate how the energy distribution alters with temperature, the intrinsic characteristics of the film have not been removed so inevitably there will be differences between what is shown here and what another person obtains with a different instrument set-up. Nor does it demonstrate well the changing nature of spectra with temperature, because at low resolution the wealth of absorption lines in a cool star cannot be appreciated. No mention is made of the fact that some bright stars (*e.g.*, α Aurigae and α Geminorum) are double, nor that composition differences mean that other objects too will be unreliable as standards for their quoted spectral type and temperature.

The presentation of the material lacks certain basics. It lists the 72 stars in order of spectral type and then in order of R.A., but does not give page numbers for cross-referencing in the *Atlas*. Writing in note-form still requires commas, and the sense of what is thus presented is sometimes elusive. Occasionally the grammar leaves something to be desired; clauses are placed where they describe unintended subjects. A number of typos were not picked up. The glossary is not spared from grammatical and punctuation errors, sometimes seriously affecting the meaning; one entry is duplicated in the wrong place, and several give definitions that are inversions of the actual concepts. Both the index and the tables contain redundant information which dilutes their effectiveness. The format of the *Atlas* is not well planned. Though it is literally pocket-sized, much of each page is actually blank; the spectra could therefore have been twice as big, and the tables enlarged so that it doesn't require a magnifying glass to read them. These are mostly grumbles about presentation rather than content, but presentation, after all, is a substantial element of an atlas.

With expanding ranges of celestial objects to investigate nowadays and shrinking resources to do any of that properly, there is a crying need to involve willing participation in areas such as this, by those not formally trained. This book is a brave start, and if its author consults a little more widely when preparing a second edition then he could produce a really solid handbook to engage and help instruct the non-professional. — ELIZABETH GRIFFIN.

The Monthly Sky Guide, by I. Ridpath & W. Tirion (Cambridge University Press), 2009. Pp. 72, 31 × 21 cm. Price £10·99/$17 (paperback; ISBN 978 0 521 13369 2).

This book's cover is attractive, showing an observer with earthly birds and Cygnus shaded as a swan, although the number of stars can look like dust! The first five sections are a fairly general guide to observing, mostly words with diagrams although the last of these, about the Moon, does include photographs and some useful Moon maps (orientated, as are all the maps, for visual observing) with slightly over half the Moon as an image on one side and the same area as a labelled diagram on the other. The last twelve sections consider each month individually, usually in four pages. Each of these has an all-sky chart, then 'key stars', planets, eclipses (solar and lunar), meteors, and other events (such as the Venus transit) as appropriate for the time span covered (2010 to 2014). There then follow detailed descriptions of one or two constellations with suitable maps and usually a boxed section about a feature in one of the constellations. Finally there is a one-page index although no glossary.

A good feature is that nothing overlaps the page. Most of the maps have a fist marked to give an idea of scale, which works well. The maps are readable by the light of a red torch, so it is odd that the use of red light is not mentioned. In fact it is a little difficult to decide at whom this book is aimed: the first chapters give a fairly basic introduction to many aspects of astronomy but there is not enough information for a beginner and the level would be too basic for a more experienced user. I could see it being quite useful for someone who has a casual interest and just wants something to give them inspiration as to what to look at if they suddenly find a bit of time to go outside, or possibly a parent trying to keep one step ahead of an enthusiastic child! Most of the objects described are for the naked-eye, with some use of binoculars or small telescopes.

The style is clear enough for beginners but there are some points that could cause frustration; for example, some stars referred to in the text are marked but not identified on the charts. The word 'asterism' does not appear, although the Plough is mentioned often. Southern-hemisphere residents are not catered for (the limit of 20° north is not revealed until page 12) but casual northern-hemisphere astronomers should be able to find something of interest in this book. — RITA WHITING.

A Question and Answer Guide to Astronomy, by P.-Y. Bely, C. Christian & J.-R. Roy (Cambridge University Press), 2010. Pp. 280, 24·5 × 17·5 cm. Price £18·99/$28·99 (paperback; ISBN 978 0 521 18066 5).

In my job, there are times when you are asked a question, particularly by the general public, that requires a simple and easily-digestible response. How often have you tried to answer a question and then found yourself using technical jargon which then only serves to obscure your explanation? Perhaps help is at hand in the form of *A Question and Answer Guide to Astronomy* which goes some way to helping answer those sorts of questions in a way that can be easily understood by the non-scientist. This guide contains what the authors consider to be the 250 questions that are most likely to pique the curiosity of the general public.

The categories covered in the book are 'Stars', 'The Solar System', 'The Earth', 'The Moon', 'Celestial phenomena', 'The Universe', 'Life in the Universe', 'History of astronomy', 'Telescopes', and 'Amateur astronomy'. The book's aim is to summarize current astronomical knowledge, which is quite an ambitious target using only 250 questions. Reading through the book, most of the answers are quite reasonable although the explanation of why Pluto is no longer a planet in Q.56 did cause me some qualms, having been present during the many sessions on that topic during the 2006 International Astronomical Union General Assembly in Prague. The choice of questions answered in the book may not be quite the selection I would have chosen, but that is probably a moot point; I would have preferred more questions in categories such as 'Celestial phenomena'.

In one sense, the authors have achieved part of their aim: there is a desire to pursue some of the topics addressed in this book. I have to say I did learn something from this book, namely that Phobos and Deimos translate to Fear and Dread, respectively. All in all, I think it would go down well with people interested in astronomy who do not necessarily have a scientific background, and it would make a good stocking-filler come Christmas time. It is well illustrated and at an attractive price. I also feel certain that there is scope in the future for more questions to be addressed in follow-up volumes to this book, preferably using a variety of authors to represent different areas of astronomical expertise. — STEVE BELL.

OTHER BOOKS RECEIVED

Power Exhaust in Fusion Plasmas, by W. Fundamenski (Cambridge University Press), 2009. Pp. 431, 25·5 × 18 cm. Price £80/$125 (hardbound; ISBN 978 0 521 85171 8).

'Power exhaust' is the safe removal of power from a burning plasma and is at the heart of attempts to derive energy from fusion reactors, particularly, but not exclusively, of the tokamak variety. This textbook for advanced graduates and researchers contains chapters on basic plasma processes that will also be of more than passing interest to those working on fusion in astrophysical environments.

Quantum Chromodynamics: Perturbative and Nonperturbative Aspects, by B. L. Ioffe, V. S. Fadin & L. N. Lipatov (Cambridge University Press), 2010. Pp. 585, 25·5 × 18 cm. Price £110/$180 (hardbound; ISBN 978 0 521 63148 8).

This volume in the *Cambridge Monograph* series is directed at graduates and researchers concerned with the modern approach to the theory of strong interaction, and covers chiral effective theory, anomalies, vacuum tunnel transitions, and QCD sum rules amongst its many topics. It is an essential read for students concerned with hadronic properties.

OBITUARY

Christopher Moss (*1946–2010*)

Chris Moss was a remarkable man. Some people have two careers or even more, but most undertake them sequentially. Chris had parallel careers in theology and astrophysics. He began Jesuit training after leaving school, and had already completed degrees in theology and philosophy when he took his physics degree at Oxford. In the early 1970s he moved to Sussex and to the Royal Greenwich Observatory, where he worked with Bob Dickens on clusters of galaxies, obtaining redshifts from the *Isaac Newton Telescope* before its move from Herstmonceux to La Palma. His great interest was, and remained, star-forming galaxies in clusters, and the mechanisms by which star formation is triggered. His PhD led to two well-cited and highly regarded papers, on Abell 1367 and Abell 262. Subsequently he spent periods at Steward Observatory and at the Vatican Observatory; among his close collaborators were Mark Whittle and Gerard de Vaucouleurs. Chris returned to the UK as Dean of St. Edmunds College, Cambridge, where he devoted much of his energy into setting up two institutes. The first, in 1987, was the Von Hugel Institute, dedicated to study of the relationship between Christianity and society. The second, in 1989, was the Margaret Beaufort Institute for Women in Theology. Today, both Von Hugel and Margaret Beaufort Institutes are thriving.

Alongside his considerable administrative duties at St. Edmunds, Chris continued his research career at the Institute of Astronomy in Cambridge. He continued to research star formation in cluster galaxies, where in a series of papers with Mark Whittle and others he advocated that gravitational tidal interactions, in particular during mergers in subclusters, were a major factor in driving star formation, more important than the rival mechanism of ram-pressure effects.

Following a brief period as principal of Heythrop College in London, Chris turned his attention fully to astronomy, and moved back to Arizona as a guest of the Vatican Observatory.

Around 2000 Chris began yet another career, as salesman and contract negotiator for Telescope Technologies Limited, manufacturer of research-class telescopes on Merseyside. He was a principal negotiator for the sale by TTL of a 2·4-metre telescope to the Yunnan National Observatory in China. As recently as March he was able to use the newly installed, and now very successful, Yunnan telescope at its site near Lijiang, to obtain some observations in support of his theory that gravitational effects, rather than ram-pressure stripping, triggered star formation, in this case in some galaxies in the Abell 1367 and Coma clusters.

Following the sale of TTL to a US company, Chris moved full-time into the Astrophysics Research Institute of Liverpool John Moores University, where he acted as *Liverpool Telescope* support astronomer, organizing the time-allocation process, making sure that telescope users had the correct information to carry out their observations effectively, and acting as advocate for the users to the *LT* operations and technical groups. He continued his research career, taking part in the supervision of two research students, and forming new collaborations through his knowledge of the *Liverpool Telescope*. In addition he was an effective and popular teacher of undergraduates.

Throughout his life Chris was always concerned with the welfare of the underprivileged in society, and worked tirelessly to improve their lot, whether they were in a deprived environment on an Indian reservation in Arizona, refugees from Latin America fleeing political persecution, or the homeless on the streets of Manchester. Chris had time for them all. He also had a great affinity with eastern cultures, and a network of friends in the Far East. At the time of his death on 2010 May 12, he was working to build up partnerships for LJMU with astronomical institutes in China and Thailand. He was a very private person, and yet a friend to everyone he met, and will be greatly missed. — DAVE CARTER.

CORRIGENDUM

PROFESSOR STIBBS' OBITUARY

In my obituary for Professor Stibbs (**130**, 272, 2010), I erroneously stated that he was the star of a cricket match played at Herstmonceux during the RGO tercentenary celebrations (in 1975). Of course, the occasion was four years earlier at the time of Sir Richard Woolley's retirement in 1971, as I was reminded by Tom Lloyd-Evans' fine tribute to Stibbs in *Astronomy & Geophysics* (**51**, 4.41, 2010). I apologise for this memory lapse, which is quite inexcusable since I was at Herstmonceux throughout that period! — DAVID STICKLAND.

EDITORIAL

PRICES FOR 2011

The Editors are pleased to announce that there will be no change to prices for 2011. They will remain: £70 for institutional subscribers in the UK; £75 or US$140 for institutional subscribers outside the UK; and £15 or US$30 for personal subscribers who undertake not to sell or donate their copies to libraries. Back issues may be bought for £10 or US$20 per copy, although discounts may be requested for bulk orders. All these prices include postage (including airmail delivery for overseas subscribers).

Here and There

THE REALLY LOCAL GROUP

The survey looked at 225 galaxies at distances of between about 2·8 and 3·4 parsecs from Earth. — *Nature*, 2009 October 29, p. 1177.

PRACTISE WHAT YOU PREACH

Submitted articles should be written … conforming to … spelling rules as commonly practiced in Canada. Canadian spelling can be found in the Oxford Dictionary of Canadian English. — From *Instructions to Authors for JRAS Canada*. [The ODCE gives the spelling "practised" for the verb.]

CELESTIAL GO-SLOW

M 31 is approaching us at about 900 ft per second. — *Daily Telegraph*, December Night Sky.

NEW PHYSICS IN A FERTILE FIELD

… equivalence principle testes are the most sensitive probes of new physics … — *The Cosmology of Extra Dimensions and Varying Fundamental Constants* (Kluwer, Dordrecht), 2003, p. 440.