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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2014 January 10 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

D. J. SOUTHWOOD, *President*
in the Chair

The President. Welcome. I have a lot to tell you, but on the whole it is something I rather like doing, and it's really partly what our Society is about — to recognize the scientific quality of the people in our community. I am pleased to announce the recipients of the Society's awards for 2014: the Gold Medal in Astronomy is awarded to Professor Carlos Frenk of the University of Durham; the Chapman Medal to Professor Louise Harra from UCL; the Eddington Medal to Professor Andrew King from the University of Leicester; the Herschel Medal to Professor Reinhard Genzel of the Max Planck Institute for Extraterrestrial Physics, Garching, and Berkeley, USA; the Price Medal to Professor Seth Stein from Northwestern University, USA; and the Jackson-Gwilt Medal to Professor George Fraser from the University of Leicester. The Gerald Whitrow Lecturer is Professor Ofer Lahav from UCL; and the Patrick Moore Medal is awarded to Hayley Flood for work at Long Eaton School. There are then two Fowler Awards: in Astronomy to Dr. Joanna Dunkley at the University of Oxford; and in Geophysics to Dr. Alex Coppley at the University of Cambridge. The Winton Capital Awards go to Dr. Benjamin Joachimi from UCL, in Astronomy, and to Dr. Chris Davies from the University of Leeds, in Geophysics. Group awards go to the *Herschel–SPIRE* consortium, led by Professor Matt Griffin from the University of Cardiff, and to the magnetometer team on the *Cassini* spacecraft, led by Professor Michele Dougherty. The Service Award goes to Professor Mark Lester from the University of Leicester.

Honorary Fellowships are awarded to Professor Alain Omont from the Institut d'Astrophysique in Paris; to Professor Roberta Humphreys from the University of Minnesota, USA; to Professor Joshua Frieman from the University of Chicago; and to Professor Rajmal Jain from the Physical Research Laboratory, Ahmedabad, India. The George Darwin Lecturer is Professor James Dunlop from the University of Edinburgh; the Harold Jeffreys Lecturer is Professor Alexander Halliday; the James Dungey Lecturer is to be Professor

Sandra Chapman. And we still have to award the Geophysics Gold Medal, which to goes to Professor John Zarnecki from the Open University. I hope I haven't missed anything else out!

I will now come to an even more enjoyable part of the programme, which is the science. Our first speaker is Allan Chapman, on 'Bishop John Wilkins, visionary of mechanical space travel and pioneer of popular astronomy: four hundred years on'.

Professor A. Chapman. This year, it is important for all astronomers to be aware that it is the 400th anniversary of the birth of John Wilkins: astronomer; English-language exponent of the ideas of Copernicus, Kepler, Galileo, and Bacon; and scientific educator. Wilkins was also a prophet of space travel by means of a mechanically-propelled 'Flying Chariot', and of the importance of an advancing technology for the improvement of the human condition. He was, furthermore, the *de facto* inspiration behind the founding of the Royal Society, a significant theologian, and finally, Lord Bishop of Chester. Indeed, the only thing that precluded Wilkins from becoming a Fellow of the Royal Astronomical Society was the fact that he was born 200 years too soon!

Wilkins' father Walter was a prosperous Oxford goldsmith, and his mother Jane Dod a lady of Northamptonshire, to whom John was born on 1614 January 1, probably near Canons Ashby, Northamptonshire. Educated at Magdalen Hall, Oxford (a daughter house of Magdalen College, which became Hertford College), he was ordained into the Anglican priesthood at 24, and presented with the living of Fawsley, Northants, which his maternal grandfather, the Revd. John Dod, obligingly looked after for him, thus enabling young Wilkins to travel.

Highly intelligent, well-off, well-connected, and blessed with charm and an ability to make friends and impress people, Wilkins' influential career began early. In 1638 and 1640, he published, in the English language, a pair of books that discussed the ideas of the 'New Astronomy', including heliocentricism and telescopic discoveries. Both his *Discovery of a New World … in the Moon* (1638) and *Discourse on a New Planet … that it is probable our Earth is one of the Planets* (1640) were published anonymously — a not uncommon literary convention of the day — although their true authorship was in no way concealed, and was soon widely known.

In an easy style of writing, Wilkins described the 'earth-like' appearance of the Moon, with its craters, seas, and mountains, contra the pre-telescopic (*i.e.*, pre-1609–10) classical opinion that it was an unblemished albeit tarnished silvery sphere. He discussed the Moon's possible inhabitants — styled 'Selenites' from the Greek word for moon, *selēnē* — and then went on to talk of space travel. Dismissing any use of obliging spirits or fairies (beloved by contemporary fiction writers) as propellants, Wilkins opted for a 'Flying Chariot'. He favoured a mechanically (probably clockwork-) powered small ship, with great wings, the force of the large clockwork engine being communicated *via* step-up gears and levers (Wilkins, of course, in 1638–40 knew nothing of energy-conservation laws).

The lunar journey, Wilkins reckoned (for the size and distance of the Moon were known relatively accurately), would take around 180 days — no longer than it would have taken a ship to sail to the Far Eastern 'Spice Islands'. Indeed, Wilkins discussed the logistics of such a 'voyage' with considerable ingenuity.

Very significant, however, was Wilkins' genius as a scientific communicator, for Moon journeys notwithstanding, he was enthusiastic about teaching his fellow-countrymen that the Solar System was not the enclosed, geocentric cosmology that had been the academic orthodoxy since classical times. The telescope had changed all that, opening up an entirely new notion of the cosmos. Not only was the Moon mountainous and earth-like, but the stars might even be scattered across the vastness of space rather than being attached to a single sphere surrounding the Solar System!

Indeed, technology was crucial to Wilkins' entire understanding, and not just telescopes and scientific instruments, but also gears, springs, levers, magnets, cranes, ships, and 'energy' (as we would now call it) — all part of a whole vision of labour-saving machines that could make the world a better place. Such ideas found their initial inspiration in the writings of Sir Francis Bacon, such as the *Novum Organum* (1620) and *Sylva Sylvarum* (1627). (In fact, I have often wondered how the absence of slavery in post-classical mainland European civilization gave us a greater impetus towards labour-saving inventions than was the case in cultures where slavery was the norm and human life was cheap!)

In 1648, Parliament 'intruded' Wilkins into the Wardenship of Wadham College, Oxford: 'intruded' in so far as the increasingly autocratic government enforced him upon the College as part of a purge of Royalist dons. It was all the more ironic, therefore, that the new Warden turned out to be a man of remarkable liberality, quite un-puritanical, and who made Wadham into something of a haven for the sons of ostracized High Church Royalist families — such as the young Sir Christopher Wren, son of the expelled Dean of Windsor. The 'Philosophical (or scientific) Club' that Wilkins formed around himself at Wadham also included the layman Robert Hooke of Christ Church, and other non-Puritan undergraduates and dons who would go on after 1660, like Wilkins himself, to become Anglican Bishops.

Wilkins' 'Club' was not a formal College or University institution, but a society of friends, encompassing not only astronomers, but also medical men, naturalists, chemists, and 'antiquaries' (or historian-archaeologists), lay and ordained. And instruments were crucial to their perspective on Nature, for as Hooke would write in 1665, telescopes, microscopes, barometers, magnets, and suchlike, refined human sensory perception and gave insights into natural worlds inaccessible to our unaided five senses.

They met together, *c.* 1649–59, in Wilkins' Warden's Lodgings in Wadham to perform experiments, observe the heavens, and even, according to Hooke's subsequent 'Diary', to try out designs for flying machines! And all the evidence suggests that those meetings were extremely convivial, probably including dining, and on at least one occasion, in 1658, music.

After Wilkins left Oxford to become, for eleven months, Master of Trinity College, Cambridge, in 1659, and the death of Oliver Cromwell as Lord Protector which had occurred in 1658 September, the focus seemed to shift to London, and the group met at Gresham College, which was then in Bishopsgate. Following the Restoration of the Monarchy in 1660 May, those intellectually and politically astute gentlemen approached the new King, Charles II, for some sort of recognition. His Majesty gave them the title 'The Royal Society of London for the Promotion of Natural Knowledge', along with three privilege-bestowing charters and some ceremonial items.

On the other hand, the King gave them no money, and kept out of the new Royal Society's organizational and research affairs. Indeed, that was to create a momentous precedent, followed by other British learned societies which obtained Royal Charters, including the RAS: founded in 1820 and chartered in 1830. Societies created on that pattern declared loyalty to the Sovereign, drank loyal toasts at dinners, yet had total intellectual and organizational independence, unlike some of the new Continental scientific bodies, such as the French *Académie*, where the King and his ministers regarded it as their prerogative to interfere as they liked.

I believe that John Wilkins and his 'Club' played a major role in defining that format of loyalty combined with intellectual independence of what in future would become the hallmark of British learned societies.

Following the Restoration in 1660, Wilkins — like several old 'Club' members — was promoted to senior ecclesiastical appointments. Wilkins himself held a major City of London benefice, the Deanery of Ripon, and then in 1668 became Lord Bishop of Chester. Other Oxford, Cambridge, and London protégés and Fellows of the Royal Society became Bishops: Seth Ward (Salisbury), Thomas Sprat (Rochester), and John Tillotson (Archbishop of Canterbury) — Robert Hooke's good friend, who in 1691 would confer a Lambeth MD degree upon him.

The idea that the Christian Church was axiomatically at odds with the new science is a myth, countered by plain factual evidence. Galileo had been the darling of Cardinals and Popes until his 'cockiness' and increasingly offensive rhetoric won him enemies. Indeed, it had been Jesuit astronomers such as Christopher Clavius who applauded and confirmed Galileo's 1610–11 telescopic discoveries. Nor should we forget that the overtly Copernican and much-published Johannes Kepler was a devout German Lutheran in the senior employ of two deeply Catholic Holy Roman Emperors in Prague. And with not so much as a rebuke — let alone any persecution! And what had sent Giordano Bruno to the stake in Rome in 1600 was not his Copernicanism so much as his ridicule of key aspects of Christian belief: not what a former Dominican Friar should have been doing!

We should also remember that until James Bradley's discovery of the aberration of light in 1728, and J. F. W. Bessel's clinching measurement of a stellar parallax in 1838, there was no clear-cut proof that the Earth moved around the Sun. And if discussion were conducted in a non-confrontational, non-offensive way, then no one suffered — Catholic or Protestant. Being a 16th- or 17th-Century Copernican may have been deemed somewhat eccentric and running counter to available observed evidence, but it did not get you into trouble.

And that, I would suggest, is why a charming, sociable, and intellectually powerful man like Wilkins was able to play such a vital role as an apostle of the 'New Astronomy' to people who read English, but not Latin or Italian.

Like Galileo, and like St. Augustine, St. Thomas Aquinas, and the leading intellects of the Christian tradition over the previous 1600 years, Wilkins was not a fundamentalist. For he, like they, argued that Scripture had to be understood in the light of what was known to the Israelites in *c.* 1500 BC when it came to interpreting 'natural phenomena' in the Old Testament, such as an implied flat Earth, or what rotated around what. God spoke to the ancient Jews in plain common-sense language, not in exact scientific terms; but He had given us the brains to work out the physics for ourselves as knowledge advanced. What was central in the Bible was God's moral message to the human race, not the astronomy. Indeed, in 1615 Galileo cited his contemporary Cardinal Boronius who, a few years before, had said the purpose of Scripture was to 'teach us how to go to Heaven', and not 'how the Heavens go'.

That way of thinking was shared by John Wilkins, which enables us to appreciate how his science and his theology could blend so easily together. It was also a view shared by the overwhelming majority of Fellows of the Royal Society.

Finally, I have been so bold as to suggest that — theology apart — Wilkins and the late Sir Patrick Moore FRS shared a good deal in common. Both were 'Moon men', both were fascinated by the idea of space travel, and both were inspired users of the media of their day to take the latest discoveries in astronomy to the wider public. Both men, moreover, were famously convivial, with wide circles of friends and admirers.

[For a fuller account of Wilkins and his context, see Professor Chapman's article, 'Fly me to the Moon', in *Astronomy and Geophysics*, **55**, 26, 2014.]

The President. One or two questions?

Professor R. Holme. I was interested in your comments about Wilkins filling empty spaces with lots of people, because in geomagnetism, we are used to the idea of Halley coming up with the model for westward drift and putting people in the gap. And we all laughed at him for that. But it seems as if he is part of the tradition.

Professor Chapman. It was part of a whole series of debated arguments. There were people who had comic laughs at Wilkins. There was a poet in the late 17th Century who spoke of "flying to the moon on Wilkins' wings". This is of course an open society. It is a society where you say something and somebody may shoot you down. You may get parodied or laughed at. In 1676, an absolute box-office success opened in London called *The Virtuoso*, which was a parody of the Royal Society. They were taking all the novel experiments from the Royal Society. It invents the model of the mad scientist, Sir Nicholas Gimcrack, who spent his entire days doing mad experiments. So you have the science, you have the discoveries, you have a laugh, but that is the nature of an open society; and Wilkins was within that society. Halley too was inspired by Wilkins.

The President. I am going to draw this to a close with the remark that Robert Goddard was made fun of by the *New York Times*, who finally issued an apology in 1969 on July 23! Thank you very much, Allan. [Applause.]

Now I should introduce the next speaker, Professor Richard Holme, from the University of Liverpool, speaking on 'Characterization and implications of intradecadal variations in length of day'.

Professor Holme. I would like to report on work that I have been doing with Olivier de Viron, of the Institute de Physique du Globe de Paris. The rotation rate of the Earth is a powerful but often overlooked geophysical probe of Earth structure and processes. Variations are driven either by external torques on the Earth or by exchange of angular momentum between different elements of the Earth system. Variations are observed on time-scales of billions of years down to seconds, and there is an enormous range of probes of its behaviour, depending on the time-scale considered. On a long time-scale, the geological record provides sedimentalogical (in particular, tidalite deposits) and palaeontological (in particular stromatolite fossils) records which suggest that Earth rotation has been steadily slowing over time — there were apparently 400 days per year during the Devonian period. This is due to tidal torque from the Moon, and the increase in size of the Moon's orbit, confirmed by lunar laser ranging. Historical astronomical observations, particularly of eclipses, give details for the last few thousand years, with more detailed information from stellar occultations over the last 500 years. Recent variations are much better resolved as a result of VLBI and GPS measurements (variations in rotation give rise to a systematic, system-wide error in GPS positions). Annual and semi-annual variations of about a millisecond in length of day are well-explained by exchange of angular momentum between the atmosphere and solid Earth (with smaller contributions from the oceans) — recent models for the 1960s onwards explain annual variations particularly well, leaving a residual 6-month signal as the dominant unexplained short-period variation.

On intermediate time scales, length-of-day variation is dominated by angular-momentum exchange between the solid Earth and fluid core, confirmed by modelling core angular momentum carried by uniform motion on cylinders (torsional oscillations) within the core from core surface flows modelled from variations in geomagnetic field. Careful correction of the length-of-day signal for the atmospheric contribution along with a simple 6-month running average reveals that the core signal can be explained with a combination of a large decadally varying signal with amplitude a few milliseconds, but with the addition of a simple oscillatory variation of constant amplitude (about 0·12 milliseconds), constant period (approximately 6 years), and constant phase. Evidence for this signal can also be inferred back to at least 1920 from the occultation observations. It has been known for some years that the observed length-of-day evidenced power on intradecadal time-scales, but the uniformity of the periodic signal in this model argues against an origin external to the Earth, for example, to solar activity. Instead, the periodic variation is likely to result from core dynamics — gravitational coupling between the mantle and an oscillating solid inner core has been suggested. Its core origin is further supported by examination of geomagnetic jerks, observed sharp changes in the second time derivative of the geomagnetic field. The times of those events match closely the 6-year length-of-day variation, as can be predicted from the magnetic induction equation, from which a change in slope in secular variation would be caused by a change in rate of core flow. Smaller-scale discontinuities are also present in the length of day between the peaks of the 6-year variation; those features suggest jumps in the length of day itself, which would follow from a jump in the moment of inertia of the Earth. Such jumps have been observed as the result of large earthquakes, although the signal observed there is an order of magnitude larger. A possible alternative cause is abrupt, almost instantaneous, coupling (perhaps electromagnetic) between the fluid core and solid mantle, helping to excite torsional oscillations in the core fluid.

As well as supporting a core origin for those features, the closeness in time of the features in both the length-of-day series and the geomagnetic jerks has further implications. If the mantle had a substantial electrical conductivity, then magnetic signals would be delayed in passage from the core–mantle boundary to where we can observe them at Earth's surface. That that delay is small (for several geomagnetic jerks constrained from satellite observations, at most a couple of months) provides a strong limiting constraint on the electrical conductivity of the deep mantle. The new ESA multi-satellite magnetic mission *Swarm*, successfully launched in November of last year, provides the opportunity for a much more detailed magnetic probing of these rapid variations, and therefore for more exact constraint of mantle conductivity, and what that value might tell us about the composition and mineralogy of the deep Earth.

The President. Any quick questions?

Dr. A. Jackson. Richard, if you were to do a spherical-harmonic analysis of the jerks, as many people have done, you would find that there is a strong axisymmetric or zonal component to the jerks. You probably agree that the torsional oscillations are not capable of creating any zonal components. So do you still want to argue that the jerks are really linked to torsional oscillations?

Professor Holme. I argued that they were linked but they weren't caused by them. I argued that the torsional oscillations were in fact a consequence rather than a cause. If you have such upwelling and flux expulsion, then the flux expulsion would be the primary driving mechanism. That would certainly give signals that weren't just zonal effects or produced by torsional oscillations.

Dr. Jackson. Is a flux expulsion likely to give you an axisymmetric signal as well?

Professor Holme. I am happy to entertain an alternative explanation — I am confident in the data analysis, but the explanation is only a suggestion. You are certainly right that the signal isn't just torsional oscillations.

Mr. M. F. Osmaston. In 1967, I published a letter in *Nature* suggesting that there could be a link between magnetic activity and core convection, which would transfer angular momentum in and out. This would change the oblateness of the core–mantle boundary, which would change the moment of inertia of the Earth and therefore would possibly account for the length-of-day changes. If you do a little sum, you only have to change the core oblateness by six inches to do it.

Professor Holme. There are also signals correlated with geomagnetic jerks related to Chandler wobble and changes in phase. They are the components we haven't talked about. On an overall change in the core–mantle boundary even of only six inches — a localized change seems more plausible.

Mr. Osmaston. The crucial point is that you don't actually need any forced transfer between the core and the mantle to do that.

The President. Thank you very much, Richard. [Applause.] It is now a pleasure to introduce Professor Mike Barlow from UCL, and his title is 'Detection of a noble-gas molecule in the Crab Nebula'.

Professor M. Barlow. I would like to report the first detection of a noble-gas molecule in space, *via* the detection of two rotational transitions of the ArH^+ molecular ion, in *Herschel–SPIRE* spectra of the Crab Nebula that had been obtained by a *SPIRE* Guaranteed-Time team.

The *SPIRE Fourier Transform Spectrometer* provided spatial coverage of a significant fraction of this 5-arcminute-diameter nebula, with 35 Short Wavelength (SSW) detectors (beam-width 18 arcsec) covering the 959–1544-GHz frequency range (194–313 microns) and 19 Long Wavelength (SLW) detectors (beam-width 37-arcsec) covering the 447–989-GHz frequency range (303–671 microns). Examination of the spectra showed the presence of only three clear emission lines, two being unidentified, with the third being identified as the $J = 2–1$, $F = 5/2–3/2$ line of OH^+ at 971·8038 GHz, a transition that had previously been observed from a wide range of astrophysical environments by *SPIRE*.

Fortuitously, this OH^+ line fell within the frequency coverage of the SLW detectors and of the SSW detectors. Since the clumps and filaments of the Crab Nebula can have radial velocities anywhere between ±1200 km s^{-1}, we used the measured radial velocities of the OH^+ line, in detector spectra in which both it and the unidentified lines were observed as single unblended components, to correct the observed frequencies of the two unidentified lines to 'rest' frequencies. For the unidentified line in the SLW spectra, four spectra yielded a mean rest frequency of 617·554 ± 0·209 GHz, while three SSW spectra yielded a mean rest frequency of 1234·78 ± 0·643 GHz for the other unidentified line. The ratio of these two frequencies is 1·9995 ± 0·0012, suggesting that we were observing the 2–1 and 1–0 transitions of a simple diatomic molecule. Molecular-line databases provided us with identifications with the $J = 1–0$ 617·525 GHz and $J = 2–1$ 1234·603 GHz transitions of $^{36}ArH^+$, representing the first detection outside a laboratory of a noble-gas molecule. The spectral resolution of the *SPIRE* spectrometer was sufficient to rule out an identification with the ^{40}Ar or ^{38}Ar isotopic variants of ArH^+.

In the Earth's atmosphere ^{40}Ar is the third most abundant species after molecular nitrogen and oxygen, but that ^{40}Ar originates from the radioactive decay of ^{40}K in rocks. In the cosmos, ^{36}Ar is predicted to be the most abundant isotope of argon, created by explosive nucleosynthesis during core-collapse supernova events, of which the Crab supernova is believed to have been an example. The ArH^+ molecular ion can be formed in the laboratory by the reaction $H_2 + Ar^+ \rightarrow H + ArH^+$, releasing 1·49 eV.

ArH^+ is relatively stable, with a dissociation energy of 3·9 eV. The clumps and filaments of the Crab Nebula are known to contain molecular hydrogen and we found the strongest ArH^+ emission to be coincident with regions showing strong H_2 emission and enhanced ionized argon emission, suggesting that the observed ArH^+ is formed in transition zones between ionized and molecular regions of the nebula. Our identification of ArH^+ in the Crab Nebula has also allowed the identification of a broad unidentified absorption feature that had already been seen between 617 and 618 GHz in *Herschel HIFI* spectra of several interstellar sightlines. That feature appears consistent with absorption in the J = 0–1 rotational transition of $^{36}ArH^+$, from multiple interstellar components.

Further details about the detection of ArH^+ in the Crab Nebula can be found in the discovery paper in *Science* (Barlow *et al.*, **342**, 1343, 2013).

The President. Questions or comments?

Professor I. Crawford. The quarter of a solar mass of dust in the Crab Nebula — was it all produced by the supernova?

Professor Barlow. Yes. As you know it is only 960 years old, spotted in 1054. It hasn't swept up any interstellar gas at all. In fact, it's in a very-low-background region. That is one of the reasons it is so easy to measure the dust spectrum, as there is no contamination.

Professor Crawford. What was the mass of the progenitor star?

Professor Barlow. It is estimated at between nine and 15 solar masses. It was a core-collapse supernova.

The President. Thank you very much. [Applause.] The final talk is by Dr. Helen Fraser from the Open University, on 'Icy Collisions: the art of planet building beyond the snow line'.

Dr. Helen Fraser. [No summary was received at the time of going to press.]

The President. Thank you Helen. Questions or comments?

Professor A. Fitzsimmons. I see you're dealing with relative velocities of order centimetres per second. I was under the impression that the dust-grain velocities would be much higher than that in a protoplanetary disc. Is that right?

Dr. Fraser. In protoplanetary discs, the relative velocities between particles are very small at those kinds of sizes. If you have a kilometre-sized body, then there's a different velocity régime. At these size régimes, where you're really doing the building process, the relative velocities are very tiny, even if the absolute velocities are very high. You absolutely can't extrapolate because you go from regimes where sticking can occur at much lower velocities, to velocities where fragmentation occurs. It's the middle range we are trying to understand, where the physics is very complicated.

Rev. G. Barber. Might electrostatic forces explain why particles might stick?

Dr. Fraser. It's certainly true, people have questioned electrostatic forces. I have a collaborator in Germany who works with cool traps so we can see. We were concerned we would get charging in our experiments but we don't. With micron-sized particles, they could play a role but if you look at the slightly larger particles, the electrostatic forces aren't strong enough.

A Fellow. I would urge everybody here to go on YouTube and search for

Rupert drops. That is where molten glass is dropped into cold water. It sets up tensile stresses within the drops which cause a kind of hardening effect on the surface of the glass. Is it possible that the process of hyperquenching you are using here is hardening the surface of your ice grains, preventing them from sticking?

Dr. Fraser. Having tested our hyperquenched ice against ordinary crushed ice, we find the results are the same, so we are fairly certain they are hexagonal ice. There is quite a lot of condensed-matter literature that explains that if you want to hyperquench water so that the ice crystallizes and hardens, your droplet needs to be smaller than 3 μm. We do have a hard sphere, but of normal, hexagonal ice.

Dr. L. Whiteway. I imagine the parabolic flights are fun but probably expensive. Your film doesn't look as if it lasts 22 seconds so why don't you do the experiment in a lift shaft?

Dr. Fraser. It's a very good question. In a parabolic flight we do three or four collisions per parabola and we have 30 parabolae. In Germany, there is access through *ELIPS* to a drop tower. We could use the drop tower and there are some advantages, such as you are in a lab all the time. The disadvantage is that it is between two and four seconds and it has to withstand a deceleration of 20 G at the end. Things like turbo pumps don't like that! We have additional technological problems when doing the experiment in a drop tower. My collaborator in Germany does do some experiments in drop towers but not with ices because of some of the limitations we have. If we could build a 200-m-tall tower then we could do the experiment on the ground. So whichever way you go there are technological challenges.

The President. Thank you very much. [Applause.] I will now bring the meeting to a close, and invite you to a drinks reception in the RAS library. Finally I give notice that the next A&G open meeting of the Society will be on Friday, 2014 February 14th.

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in the Geological Society Lecture Theatre, Burlington House

M. A. Barstow, *President-Elect*
in the Chair

The President-Elect. The incumbent President is away at a meeting and he has asked me to stand in for him this afternoon to take the Ordinary Meeting. It will be a pleasure because there are some medals and prizes to give away. One of the major items of business for this afternoon is the award of the Price Medal for Geophysics. This is presented to Professor Seth Stein. I was involved in giving the prizes at the NAM in St. Andrews. That was great fun as I got to read out the citations. However, David got to hand over the medals. I get to do both this afternoon! Professor Seth Stein has a 35-year history of ground-breaking achievements in Earth sciences of global importance in numerous fields including plate tectonics, seismology, and space geodesy. In addition to an extraordinary plethora of service on international committees, he is an outstanding teacher, with much of his influence having been through his popular graduate-level geophysics textbook, *Introduction to Seismology, Earthquakes, and Earth Structure*. Perhaps one of his most influential recent scientific contributions has been his decade-long project to investigate intra-continental deformation and its relation to continental seismicity, focussing initially on the New Madrid zone in the Mississippi river valley in the United States. His observations led to a new model for intra-continental earthquakes and of aftershock productivity, changing our views of earthquake risk to the general public. It's for these reasons, Professor Seth Stein is awarded the Royal Astronomical Society's Price Medal. [Applause.]

Professor S. Stein. I'm honoured. Thank you very much.

The President-Elect. Now on to the main programme of the afternoon. We have a series of talks, the first of which is from Professor James Jackson of Cambridge: 'Field trips of the mind: modern and historical earthquakes and the legacy of Professor N. N. Ambraseys'.

Professor J. Jackson. We have just had a two-day meeting on earthquake science and hazard and I would like to celebrate the achievements of someone who has made a great contribution to this subject. Nick Ambraseys was, by profession, an earthquake engineer who spent much of his working life at Imperial College, but he had a separate life looking at the history of earthquakes. This talk is by way of a personal reflection on his qualities and the sort of man he was. He was an extraordinarily influential scientist in this area and was a huge inspiration to the younger generation, including me.

Of the ten largest earthquakes in the last 100 years, four have occurred in the last decade. Those ten are all on plate boundaries in the ocean where the ocean slides under adjacent islands and land. However, they are not the sort of earthquakes that kill most people. It is those events in the continental interiors which are most lethal. This correlates with increasing population growth, which is why several recent continental events have been so catastrophic. Nick Ambraseys is largely responsible for what we know about the earthquake history of the Mediterranean, Middle East, and western Asia.

He did his national service in the Greek Navy in 1954, and the biggest earthquake of the last 100 years in the Aegean occurred in 1956 on Amorgos. He studied the effect of the resulting tsunami — specifically how far it reached into the islands of the central Aegean. He then became interested in the earlier history of tsunamis in the Aegean going back to 1400 BC and wrote a paper on that topic in 1960 whilst at Imperial College. The facts about those historical events were not at all clear because of errors and confusions in geographic names, dates, and linguistic transliterations, often repeated and perpetuated from one study to the next. As a result, he established a work ethic by which he would make it his job to return to the original sources and establish the facts himself. His extensive knowledge of languages helped to bring the disparate sources together, and he paid particular attention to the dating of each event, which could be variously recorded in the Julian calendar, the Gregorian calendar, the Islamic and lunar calendars.

He also began to carry out field work and to record in great detail the physical effects and the results of ground rupture, faulting, and landslides after earthquakes. The process of finding those features was never easy and often made more difficult because maps tended to be available only to military authorities in those days. His faithful recording of those observations has allowed us to return to the study of those earthquakes with modern understanding and modern imaging tools, and greatly clarify what happened in them. His interest in earthquake faulting was far-sighted, and predated the proof that slip on faults produced the seismic radiation pattern seen in earthquakes, which was only achieved in 1964.

He also looked at earthquake damage as a function of building type in the affected areas, which could vary greatly, from complete destruction of adobe houses in Iran to almost complete resilience for timber-framed structures in Turkey. His familiarity with building performance in places where construction types hadn't changed for centuries was an important yardstick for calibrating and interpreting written accounts of historical earthquakes.

In 1982 he published with Charles Melville a book called *A History of Persian Earthquakes*. Melville did his degree in mediaeval Persian and they wrote about the history of earthquakes in Iran from about 600 AD. The great achievement of the book was that it showed what could be done by going back to original sources, tracking down errors in dates, place-name spelling errors, and so on. Their work extended the knowledge of earthquake occurrence much further back than the 100-year instrumental record, and produced several important insights. In some places it became clear that the 20th-Century record was completely unrepresentative of longer periods; in others it showed an apparent oscillation between seismic quiesence and activity in adjacent regions (such as between the North and East Anatolian fault systems in Turkey, and between the Alborz and Khorassan in Iran); while many earthquakes seemed to have occurred on unknown structures. With modern GPS measurements clarifying the overall motions, we can now ask whether the historical record contains enough earthquakes to account for what must be happening.

Ambraseys's books are a remarkable achievement of scholarship, needing the skills of an historian and linguist as well as those of a seismologist, engineer, and field geologist. Without a profound knowledge of the context, the historical record, and particularly silence, is difficult to interpret and potentially misleading. Thus at the time of the Baghdad Caliphate the quality of historical information from Iraq was relatively good and complete, but much more sketchy from other parts of Iran. When Genghis Khan came along and trade routes switched to the north of Iran, Baghdad became a relative backwater, poorly covered by the chroniclers. Then, when Shah Abbas in the 17th Century moved the capital to Isfahan from Tabriz, the routes again became viable in the south, and consequently well recorded. He was insistent that the historical record of earthquakes is just that — a record, and lack of information does not imply that earthquakes will not occur in a region, as several recent examples have shown.

He retired from teaching in 1998, but showed no real decline in his research activity. Towards the end of his life he became particularly concerned that although he had spent much of his career talking to people in countries affected by earthquakes it was having little effect. Some modern countries are very resilient and build structures that do not fall down during earthquakes, but old countries with a large legacy of historic buildings are more vulnerable. The danger is often increased by a lack of regard for building regulations, and he made notable efforts to emphasize the importance of tackling corruption in the building industry. His main legacy is his books on historical seismicity, which remain enormously valuable sources of information, and provide a very high standard of quality and scholarship that defined this field. To live up to that standard is the challenge facing those who want to take this subject forward.

The President-Elect. Thank you very much. That was a fascinating talk with some very important lessons. We have time for a couple of questions.

Reverend G. Barber. Perhaps I missed it but was there a reason why the earthquakes appear to follow the trade routes?

Professor Jackson. No, I only showed the ones that killed more than 10 000 people, which really need to be in a city or large town, and they are often on trade routes. Precise casualty figures are never obtainable for historical events, but the ones killing more than 10 000 can usually be identified with some confidence.

Mr. M. Hepburn. In the Mexico earthquake, the thing that was noticeable was that the buildings of the colonial era mostly stayed up; it was the ones of modern Mexico that fell down.

Professor Jackson. Yes, well this is part of what he would refer to as corruption; people cutting corners to cut costs. It's quite clear in the world that there are perfectly adequate building designs, standards, and codes. For example, Tehran has the same building code as California, but it doesn't mean it's as safe as California.

The President-Elect. Thank you very much. [Applause.] The next speaker is Dr. Lindsay Glesener from Berkeley. She is also the Tomkins Prize winner, so I will present her with her certificate. [Applause.] Those of you who know me will realize that I am a great fan of rockets. I did my PhD on rockets and I still fly them so I am really interested to hear the talk that is to come: 'Studying hard X-rays from solar flares with the *FOXSI* rocket'.

Dr. Lindsay Glesener. Particle acceleration in solar flares has proven puzzling for generations, especially in regard to the mechanisms to transfer so efficiently energy from the Sun's magnetic fields into particle kinetic energy. For the last 12 years, the *Reuven Ramaty High-Energy Solar Spectroscopic Imager* (*RHESSI*) spacecraft has studied flare-accelerated particles with greater sensitivity and resolution than any previous solar mission. *RHESSI* uses an indirect Fourier-based imaging technique, which, when combined with its fine-resolution spectroscopy, provides detailed information on flare-accelerated electrons and ions. These studies, spanning energies of 3 keV to 17 MeV, can help to answer outstanding questions about how huge numbers of particles are energized to such high energies (MeV and GeV scales for electrons and ions, respectively).

However, *RHESSI* observations indicate that even greater hard-X-ray (HXR) sensitivity will be necessary to make detailed studies of particle-acceleration sites, which are thought to reside in the tenuous, faint corona (the outermost layer of the solar atmosphere). In comparison with the much denser photosphere (solar surface), coronal bremsstrahlung HXR emission is orders of magnitude fainter. Studying coronal acceleration sites under such circumstances demands an imaging dynamic range (ability to study faint sources in the presence of brighter ones) that is greater than *RHESSI*'s.

Both sensitivity and dynamic range can be tremendously increased by the use of direct-focussing HXR optics, as opposed to the indirect techniques of *RHESSI* and its predecessors. Such direct focussers have been the standard in soft-X-ray astronomy for decades and are now starting to come on-line for the HXR regime. Early experiments included balloon payloads, for example, *HERO* and *HEFT*. The greatest example is the *NuSTAR* observatory, which was successfully launched in 2012 and has ever since performed astrophysical HXR studies with a sensitivity orders of magnitude greater than previous missions. Based on the success of astrophysics HXR missions, it is thus thought that direct HXR focussing could also be useful for solar-flare investigation.

To demonstrate the usefulness of and develop technology toward a dedicated observatory for direct solar HXR measurement, NASA in 2007 awarded a Low Cost Access to Space grant to the *Focusing Optics X-ray Solar Imager* (*FOXSI*) project. The technological goal was to develop relatively inexpensive optics with the fine angular resolution and dynamic range that solar-flare studies require. Scientifically, the mission would attempt to make the most sensitive studies to date of faint HXRs from the 'quiet' part of the Sun, *i.e.*, outside the active regions where essentially all flaring activity is currently observed to occur. Measurement of these HXRs would give credence to ideas that the quiet Sun is full of a sea of small flares or reconnection events that could play a role in supplying the high temperature of the solar corona.

FOXSI's direct HXR focussing capability is achieved by replicated nickel optics produced at NASA's Marshall Space Flight Center. The energy range of the optics is limited by the focal length, and the rocket payload allows only enough length to observe up to ~ 15 keV with a 2-metre focal length. Seven optics modules are included, each containing seven shells nested together for a larger collecting area. Each module is matched with a dedicated silicon-strip detector, providing fine spatial and energy resolutions. These detectors were provided by the *Astro-H* team at the Institute of Space and Astronautical Sciences in Japan. The angular resolution of the optics is ~ 5 arcseconds for on-axis sources, or ~ 9 arcseconds when combined with the detector-strip size.

The *FOXSI* rocket payload was launched for the first time on 2012 November 2 at 17:55 UT, and 6·5 minutes of solar observation were achieved above an altitude of 150 km. Within that time, the payload observed four targets, including a total of three active regions, large expanses of the quiet Sun, and, to everyone's surprise, a small solar flare that occurred just at the time of the flight on the southwestern edge of the Sun. After the successful flight, the instrument returned to the ground *via* parachute and was recovered with essentially no damage, in good shape to fly again.

The occurrence of a small flare during *FOXSI*'s first flight was unexpected and serendipitous, and is being leveraged to maximum extent in the data analysis. The flare was also observed by *RHESSI*; direct comparison of *RHESSI*'s indirect images with unprocessed *FOXSI* images demonstrate the larger dynamic range of *FOXSI*'s direct focussing, as imaging artifacts are drastically reduced. Going further, the point-spread function has been deconvolved from the *FOXSI* images to reveal detailed shape of the flare's thermal loop. Comparison of these images with extreme-ultraviolet images from the *Solar Dynamics Observatory* (*SDO*) results in very similar structure observed by *FOXSI* and evident in the hotter *SDO* filters.

FOXSI's flight data also included two other active regions and a portion of the quiet Sun, but measured count rates were very low from all of those. The lack of measurement of significant flux from one of the active regions has been used to constrain the amount of hot plasma present. Counts observed in the quiet Sun are non-zero and are currently being examined to determine whether they contain any non-instrumental signal.

FOXSI is funded for a second flight, to take place in late 2014. That flight will include upgrades to the optics and detectors to increase the energy to ~ 20 keV. *FOXSI-2* will again examine the quiet Sun for any indication of flare-accelerated electrons. Recently, the *HERO* high-altitude balloon, originally an astrophysics HXR payload, has been revamped for a second life as a solar observer. This upgraded payload, called *HEROES* (*High-Energy Replicated Optics to Explore the Sun*), flew for the first time in

2013 September, performing both solar and astrophysical observations.

Another useful solar HXR tool will be the *NuSTAR* observatory. *NuSTAR*, observing since 2012, was designed to examine faint astrophysical HXR sources, but its capabilities can and will be turned to the Sun. With an effective area over ten times greater than *RHESSI*'s for much of the HXR range, *NuSTAR* will be ideal for searching for small reconnection events in the quiet Sun. The first *NuSTAR* solar observations are expected in the summer of 2014.

In short, several missions now demonstrate that solar hard-X-ray observation *via* direct focusing is feasible and scientifically important. The first *FOXSI* flight demonstrates the viability of the technique and its promising capabilities for solar study. A future spaceborne mission based on this technology could perform detailed study of flare-particle acceleration sites, as well as studying energetic electrons in diverse solar phenomena such as coronal mass ejections, jets, the sources of radio bursts, and small quiet-Sun reconnection events.

The President-Elect. We have a few minutes for questions.

Mr. M. F. Osmaston. It was Robert Lin who pointed out that the isotopic ^{3}He/^{4}He ratio of the solar wind varies by a large amount and in fact on occasion enhanced to 1000 times. This is quite something and nobody else has picked it up subsequently.

Professor D. Lynden-Bell. Can these things be observed in synchrotron radiation by radio astronomy? And if so, isn't that cheaper [laughter]?

Dr. Glesener. Good question. Yes, they can be observed using microwaves instead, particularly the gyrosynchrotron emission. I think that's the other best diagnostic of the electron populations. What is often done, and what we'd like to keep doing, is to study both the hard X-rays and microwaves together. In principle, they could tell us about a continuous electron population but they tell us about different parts of that energy range. The information from those together is quite useful.

Professor J. Brown. The answer to Donald's question is that it is much cheaper but the magnetic field is so uncertain: you don't get a good measurement of the electron flux, which is what we really want, whereas we do know the density of the solar atmosphere quite well.

The President-Elect. Thank you very much to our speaker again. [Applause.] The next speaker is Professor Lisa Kewley, who is going to deliver the Eddington Lecture. Lisa did her PhD at Australian National University and then headed off to Harvard on a research fellowship and followed that up with a very prestigious Hubble Fellowship on the Hawaiian Islands. She was a faculty member there before returning to Australian National University. Over to you, Lisa: 'Galaxy evolution in 3D'.

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

The President-Elect. We have a fair amount of time for questions. One thing I'd like to start with: The *Giant Magellan Telescope* — how is that going in terms of time-scale? We're all interested in *ELT* here.

Professor Kewley. Well, they say 2020, but I think it's going to be more like 2022. The decision to begin building is going to be made in the next couple of months and then they will start building. They want to start building in Chile.

Professor Carole Jordan. If you ignore the strong lines, do you see any evidence of Fe II lines?

Professor Kewley. We haven't looked yet.

Professor Jordan. It's worth looking because some of them are controlled by the ultraviolet stuff. You can get an idea of opacities.

Mr. Osmaston. I'm fascinated that you're seeing extensive evidence of inflows. I think that's what keeps star formation alive in galaxies. If you have a cluster of galaxies, maybe that inflow can't get to the middle of the cluster and that's why they go to ellipticals, where star formation is dead. What is your view on that?

Professor Kewley. We had a project to test that. We had a project to measure shocks and also inflows from metallicity gradients as a function of environment. We are looking at clusters and field galaxies. We are going to compare the metallicity gradients in the clusters with those that we see in the field as a control sample. We'll see where the flat ones are compared to where the steep ones are and we'll know the answer to that question.

Professor R. L. Davies. Your plots and your tests for inside-out disc formation are all against radius, which I think is sensible at the moment, but you're going to have this integral-field data. Do your models give any predictions as to whether there should be different shapes of iso-metallicity contours in merging objects *versus* isolated objects, *etc.*?

Professor Kewley. I don't think they have enough resolution to do it at the same level as we can measure. I think that's a case where the models are going to have to follow the data. There are some people using AREPO at the moment to do zoomed-in simulations where they run the model again but for finer resolution, just for some galaxies. In those cases, it's possible we might have some sort of clue. The other thing is, and I've been saying this for a year or two now, that we're losing lots of information when we compress everything into metallicity *versus* radius because there's a spatial distribution in the metallicity. When we compress this it gets lost in the scatter. Therefore we need new ways of describing the metallically gradient spatially, not just by compressing it all into a single line. That has to happen at the same time as progress in the models.

Professor Lynden-Bell. I have seen some work that shows that barred spirals have a lesser gradient than the normal spirals. Would you like to comment on that?

Professor Kewley. Yes. We've looked at that with a sample that has been observed in Texas. They have a sample of galaxies that are barred. It isn't a large sample — it's about 12 galaxies. They see two gradients. In some cases its flatter in the centre, and at the part where the bar ends it becomes steeper. In other cases there's so much scatter you don't see anything. We did have a look to see in the *CALIFA* data set of 100 galaxies whether there's a correlation between the metallicity gradient overall. They didn't have fine enough resolution spatially to measure if there are two slopes in the gradient. We did look to see if they were flatter in the bars. We didn't find a statistically significant difference between the bars and the regular spiral galaxies. I would say it's inconclusive. It seems that in some bars you do see that, but in others you don't. It probably depends on how much star formation is going on in the bar regions.

The President-Elect. I don't see any more questions, so can we thank Lisa again for a wonderful talk. [Applause.] To conclude, let me remind you that we have a drinks reception in the RAS library. We can frighten everybody in there by turning up 10 minutes early! Finally I will give notice that the next A&G Open Meeting of the Society will be on Friday, 2014 March 14th.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 237: UU Cnc, HD 67788, HD 79888, HD 119915, AND HD 120649

By R. F. Griffin
Cambridge Observatories

Orbits are given for five short-period spectroscopic binaries that have arrived on the Cambridge observing programme in different ways. UU Cnc is an enigmatic variable star that exhibits a β Lyr light-curve and only one spectrum, of type K4 III, even at the primary light-minimum. The photometric and orbital periods have long been known as 96 days; there is a large mass function of nearly half a solar mass. It has been surmised that the massive companion star is hidden within an accretion disc. A fact newly demonstrated here is that UU Cnc is a triple system: the γ-velocity of the one visible star has shown definite variation. The writer's observations of the last 30 years, supplemented by an earlier series published by Imbert, appear to cover a large part of the long-period orbit; a period of about 40 years seems quite probable, but an arbitrarily longer time cannot be ruled out. The 96-day orbit has an apparent eccentricity, surely spurious, of about 0·05, and there is a distinct systematic discrepancy in one range of phase between the mean trend of the observational points and the Keplerian orbital solution that is the adopted approximation to them. Despite the photometric variation of more than half a magnitude, supposedly of largely 'ellipsoidal' origin, there is surprisingly little phase-related variation in the apparent rotational velocity, and no explanation can be offered here for what little there seems to be.

HD 67788 and HD 79888 were discovered to be short-period spectroscopic binaries in a renewed investigation of radial velocities in an extended Area no. 4 of the 'Clube Selected Areas'. Despite their short periods of 7·57 and 8·34 days they have non-circular orbits with eccentricities of about 0·18 and 0·04, and velocity amplitudes of 36 and 23 km s^{-1}, respectively. Very little else is known about them, apart from *V*, *B* photometry transformed from *Tycho* measurements. HD 79888 has the unusually high γ-velocity of –80 km s^{-1}.

HD 119915 and HD 120649 are two stars at the eastern margin of the field of the North Galactic Pole (as defined by the parallel of Galactic latitude +75°). Their binary natures were discovered only in 2010, although they were first observed by the writer in 1971 and 1986, respectively. Both stars have circular orbits.

HD 119915 is a mid-K giant with a period of 101 days and a γ-velocity below –90 km s^{-1}; HD 120649 is probably a late-F star, on or near the main sequence, with an 8·66-day orbit of small amplitude (2·3 km s^{-1}), leading to a very small mass function.

Introduction

Most papers in this series deal with orbits that have periods of years, but recently there has come to light quite a spate of short-period binaries — meaning, in this context, ones with periods of the order of 100 days or less. Here five such objects are treated.

UU Cnc (BD +15° 1733)

UU Cnc is a variable star of about the ninth magnitude, to be found halfway between the 5^m stars 3 and 8 Cnc in the region of the sky, rather barren to the naked eye, to the east of Pollux and Procyon. The star has quite a rich literature (62 papers retrieved by *Simbad*) but seems not to be correspondingly well understood. Its discovery as a photometric variable (then designated '322·1934 Cancri') was published by Hoffmeister[1] in 1934; four years later Lause[2] had determined the nature of its variations as being of the β Lyr type (no interval of constancy, two equal maxima and two unequal minima in each cycle) and given the period as 97 days. More complete and accurate light-curves have since been published by, *e.g.*, Winiarski & Zola[3] and Zola *et al.*[4].

In 1956 Popper[5] gave for UU Cnc the elements of a circular orbit, based on radial velocities from 20 photographic spectrograms that would necessarily have been of low dispersion (Popper gave no information about them, but referred to dispersions of 70 and 110 Å mm^{-1} in connection with other stars of comparable brightness treated in the same paper). He saw only one spectrum, which he classified as K4 III; its source was the star that was in front during the primary minimum, but no other component could be discerned. The Balmer lines, however, were always too strong to correspond to the K4 III type, and appeared to strengthen further at the phase of secondary minimum. Herbig[6], too, found the type of UU Cnc to be K4 III but with enhanced hydrogen lines — he gave the strengths of Hγ and Hβ to be "about as in type G2". Popper gave the mean colour indices of UU Cnc, from four observations made at the Lowell Observatory at random phases, as $(B-V) = 1^m{\cdot}47$, $(U-B) = 1^m{\cdot}46$; he noted that the $(B-V)$ colour agreed with Johnson & Morgan's 'normal colours'[7] ($(B-V) = 1^m{\cdot}48$, $(U-B) = 1^m{\cdot}77$)* for K4 III, but that $(U-B)$ was too blue by $0^m{\cdot}3$, so that quantity represented an ultraviolet excess that he attributed to the presence of a hotter component.

As an aside, we may note that the excess would be much muted if he had used the figures given in the footnote below for the Johnson & Morgan colour indices. Moreover, Eggen[8] later gave the observed colours as $(B-V) = 1^m{\cdot}65$, $(U-B) = 1^m{\cdot}93$, both of which are in extraordinary conflict with Popper's results and considerably *redder* than Johnson & Morgan's supposed norms for the type. Maybe Eggen happened to measure V, but not B and U, near minimum light! — he gives V to only one decimal place and with a colon, as 9·2:,

*Those colour indices cannot be confirmed from the quoted paper, whose Table 14 gives intrinsic colours for K3 III and K5 III but not for K4. Linear interpolation between K3 and K5 would give for K4 indices of $1^m{\cdot}41$ and $1^m{\cdot}64$ for $(B-V)$ and $(U-B)$, respectively.

so one would think that the colour indices deserved colons too. *Simbad* gives the (presumably mean) V magnitude as $8^{m}{\cdot}85$. Such a discrepancy would explain the extraordinary colour indices.

More than 20 years later, Popper (in a paper[9] not retrieved by *Simbad*) took a second bite at the UU Cnc cherry; that time, he actually described and listed his spectrograms as having been taken with prism instruments on the Mount Wilson reflectors at dispersions of 66, 75, and 110 Å mm^{-1} at Hγ, but there are only 19 entries in his list whereas he had previously[5] referred to 20 spectrograms. He referred also to three 'new' spectrograms taken in the 'visual' region of the spectrum in an unsuccessful effort to find evidence of the companion star, but he did not include them in the listing of his spectra, whose dates are all in 1950–55. Confusingly, he also reported anew his four Lowell photometric observations, but the $(U-B)$ colour index had changed from $1^{m}{\cdot}46$ to $1^{m}{\cdot}42$.

The K4 III spectrum of UU Cnc is smeared by rotation at about 25 km s^{-1}, no doubt synchronized to the orbital period of about 96·7 days; those numbers lead to a projected stellar radius, $R \sin i$, of about 48 $R_{\odot}$ or 33 Gm. That is considerably less than the orbital radius, $a_1 \sin i$, shown below to be about 48 Gm. Since the K giant is regarded by most of the close-binary experts who have considered UU Cnc to fill its Roche lobe in the equipotential diagram of the system, it follows that the unseen companion is considerably the more massive component. The reason for its invisibility is supposed[4,10] to be that it is hidden within an optically thick accretion disc. The disc does not contribute, and is not large enough to obscure, much light in the system, whose photometric variations are therefore to be understood as largely arising from the 'ellipsoidal' distortion of the K giant.

An approximation to the radial-velocity orbit of the K giant was given by Popper in his initial paper[5]: in such a close system the orbit could be assumed to be circular, and its period and epoch were already known from photometry, so all that remained was to give a γ-velocity (+50 km s^{-1}) and amplitude (37 km s^{-1}), though Popper also noted the large mass function of 0·5 $M_{\odot}$. Imbert[11] published an orbit based on 60 velocities obtained with the Haute-Provence *Coravel*; in the text of the paper he reports the orbital period as $96{\cdot}667 \pm 0{\cdot}009$ days, but in the table of elements (his Table 2) it is given as 96·967 days; it is the latter that is probably the misprint. The orbit has an apparently very significant eccentricity, $0{\cdot}054 \pm 0{\cdot}007$, which presumably must be spurious, arising from uneven surface brightness and non-sphericity of the star. With $\omega \sim 90°$, the descending side of the orbital graph is steeper than the rising side; moreover, the actual points on the graph for much of the descent form a sequence that is steeper still*. Eaton[12] has shown how the observed orbit of the close-binary system 5 Cet, which with its 96-day period is very analogous to UU Cnc and like all such systems can hardly avoid having a circular orbit, nevertheless has a mathematically very significant eccentricity, with $\omega \sim 90°$. It can apparently be understood in terms in limb-darkening and gravity-darkening† of the inflated

*That is not too obvious in the published plot, which is cut brutally short in phase, with no overlaps at the ends; the descent is split, half-way down, between the two sides of the graph, and visual continuity is lost.

†*Gravity darkening*. Lucy[13] has very helpfully summarized more than fifty pages of dire mathematics put forward by von Zeipel[14] the best part of a century ago as showing that the effective temperature T_e of any part of the surface of a non-spherical star is related to the surface gravity g at that point by the expression $T_e \propto g^{0{\cdot}25}$. Lucy points out that von Zeipel's treatment pertains to stars whose outer layers are in radiative equilibrium; but he then seems to manage to show, in a paper of little more than three pages and with little in the way of overt mathematics, that in the cases of stars with convective sub-photospheric layers, the exponent in von Zeipel's equation would be about 0·08 instead of 0·25, but qualitatively the existence of 'gravity-darkening' in such stars is confirmed.

mass-losing star (in UU Cnc, the only observable one).

The writer's recent pursuit of the literature on this topic leads him to regret having gone to considerable lengths, in the immediately preceding paper[15] (no. 236) in this series, to establish the mathematical validity of the eccentricity formally determined there for HD 45762, which like UU Cnc is regarded as an ellipsoidally distorted star. It, too, has a small and statistically significant orbital eccentricity, with $\omega \sim 90°$, but it now seems likely that that would have been better dismissed — as has been done above for UU Cnc — rather off-handedly as 'presumably spurious' than treated with the care and belief evinced in Paper 236.

UU Cnc was placed on the Cambridge radial-velocity observing programme in 1986 for reasons now beyond recall, and was observed tolerably systematically until 2000. The period and nature of the orbit were obvious enough, but the observations appeared regrettably ragged. The writer, not giving them careful consideration at that time, supposed that the raggedness was due to the great width and corresponding shallowness of the cross-correlation 'dips' in the radial-velocity traces, and was quite possibly exacerbated by some instability (spottedness, *etc.*) in the star itself. Especially after seeing a relatively nice orbit published[11] for the star from elsewhere he rather lost interest in it until quite recently, when a few observations seemed to show a significant negative offset of about 4 km s^{-1} from all the previous ones. Renewed enthusiasm in 2014 demonstrated that the offset was certainly real, and arose from a variation of the γ-velocity that had in fact been going on throughout the time that the star had been under observation. Unfortunately, the observations made in successive periods of time had not been sufficiently distinguished by different symbols on the graph shown to the writer by his computer, until the recent set *was* so distinguished and 'gave the game away'. Trial of an orbit-solving programme that allowed for a linear change in γ-velocity with time demonstrated that, so far from being linear (an approximation to a small part of an orbit of long period), the variation of the γ-velocity was of an orbital nature and that much of a cycle had been completed since the observations began. The minimum period of the orbit is about 12 000 days, of which the writer's measurements cover more than 10 000; unfortunately the phase gap occurs near apastron and could be extended to almost any degree because the velocity curve is almost horizontal there, so no upper limit can safely be set to the period. The data set can be supplemented by the observations underlying the already-published orbit[11], which were nearly all made in a five-year interval preceding any of the writer's measurements. Nothing is said about the zero-point of those observations, in the paper[11] concerned, and it has been necessary to assume that it is the same as for those made with the same instrument (the Haute-Provence *Coravel*) by the present writer, since all measurements made with that instrument are reduced centrally in Geneva. The optimum period (though still very uncertain) for the long-period orbit is about 15 000 days, and is adopted here as a fixed parameter; but it is very sensitive to discrepancies in the zero-points of the different sources of observations, and longer — even much longer — values still cannot be ruled out. The elements of the 96-day orbit, however, are scarcely affected at all by the uncertainty associated with the long-period variation.

The 192 available radial velocities (Imbert's and my own) are set out in Table I. The slight differences between the calendar dates of observations and their MJDs arise because the orbit solution adjusts the MJDs (only) to the barycentre of the outer orbit. The principal contributions to the data set (in addition to Imbert's 60) are 45 of my own measurements made with the same

TABLE I

Radial-velocity observations of UU Cnc

Except as noted, the sources of the observations are as follows:
Up till 1996 — Haute-Provence Coravel (up till 1986: published by Imbert[11]);
1997 onwards — Cambridge Coravel

Date			*MJD*	*Velocity*	*Outer orbit*		*Inner orbit*		*(O – C)*
					Phase	*Velocity*	*Phase*	*Velocity*	
				km s⁻¹		*km s⁻¹*		*km s⁻¹*	*km s⁻¹*
1978	Apr.	2·93	43600·94	+12·0	0·585	+46·3	0·191	−35·7	+1·4
	Nov.	7·14	819·16	38·1	·600	46·3	·447	−8·5	+0·3
		9·17	821·19	42·0	·600	46·3	·468	−4·2	−0·1
		10·17	822·19	43·8	·600	46·3	·479	−2·1	−0·4
1979	Jan.	15·96	43888·98	11·6	0·604	46·4	3·170	−34·3	−0·4
		24·97	897·99	11·8	·605	46·4	·263	−35·4	+0·8
	Feb.	21·93	925·95	59·4	·607	46·4	·552	+12·8	+0·2
		23·03	927·05	61·9	·607	46·4	·563	+15·0	+0·5
		23·95	927·97	62·8	·607	46·4	·573	+16·8	−0·3
	May	8·86	44001·88	15·1	·612	46·4	4·337	−28·1	−3·2
	Nov.	20·15	197·17	19·6	·625	46·5	6·357	−25·1	−1·8
1980	Feb.	24·94	44293·96	21·0	0·631	46·5	7·358	−25·0	−0·5
		26·91	295·93	24·8	·632	46·5	·378	−21·6	−0·1
		28·99	298·01	28·3	·632	46·5	·400	−17·8	−0·4
		29·96	298·98	30·1	·632	46·5	·410	−15·9	−0·5
	Mar.	1·93	299·95	31·3	·632	46·5	·420	−14·0	−1·2
		4·00	302·02	36·6	·632	46·5	·441	−9·8	−0·2
	Apr.	1·85	330·87	81·6	·634	46·5	·740	+36·1	−1·0
		2·90	331·92	82·9	·634	46·5	·751	+36·3	+0·1
		3·93	332·95	83·2	·634	46·5	·761	+36·2	+0·4
		4·89	333·91	82·7	·634	46·5	·771	+36·1	+0·1
		7·89	336·91	81·3	·634	46·5	·802	+34·6	+0·2
	Nov.	10·19	553·21	33·1	·649	46·6	10·039	−12·2	−1·3
		29·06	572·08	11·0	·650	46·6	·235	−36·4	+0·7
1981	Jan.	8·89	44612·91	79·6	0·653	46·7	10·657	+30·0	+3·0
		9·95	613·97	78·4	·653	46·7	·668	+31·2	+0·5
	Mar.	13·87	676·89	17·8	·657	46·7	11·319	−30·5	+1·6
	Oct.	28·19	905·21	81·0	·672	46·8	13·680	+32·5	+1·7
		29·21	906·23	80·0	·672	46·8	·691	+33·5	−0·2
		30·18	907·20	81·7	·672	46·8	·701	+34·2	+0·6
		31·16	908·18	82·7	·672	46·8	·711	+34·9	+0·9
	Nov.	1·09	909·11	81·8	·672	46·8	·720	+35·4	−0·4
		21·13	929·15	63·4	·674	46·8	·928	+15·2	+1·4
		22·13	930·15	61·1	·674	46·8	·938	+12·8	+1·5
		24·12	932·14	57·6	·674	46·8	·958	+7·8	+3·0
		25·14	933·16	51·9	·674	46·8	·969	+5·2	−0·2
		26·11	934·13	52·1	·674	46·8	·979	+2·7	+2·6
		27·13	935·15	47·9	·674	46·8	·990	+0·1	+1·0
		29·08	937·10	39·0	·674	46·8	14·010	−5·0	−2·8
		30·18	938·20	36·0	·674	46·8	·021	−7·8	−3·0
	Dec.	3·16	941·18	29·9	·675	46·8	·052	−15·2	−1·7
		4·17	942·19	27·5	·675	46·8	·062	−17·5	−1·8
1982	Feb.	14·95	45014·97	79·9	0·680	46·9	14·815	+33·6	−0·6
		18·89	018·91	75·5	·680	46·9	·856	+28·8	−0·2
	Mar.	11·81	039·83	26·6	·681	46·9	15·072	−19·6	−0·6
		12·82	040·84	24·7	·681	46·9	·083	−21·8	−0·4
		13·78	041·80	21·5	·681	46·9	·093	−23·7	−1·7
		14·71	042·73	+21·1	·681	+46·9	·102	−25·5	−0·4

TABLE I (*continued*)

Date	*MJD*	*Velocity*	*Outer orbit*		*Inner orbit*		*(O–C)*
			Phase	*Velocity*	*Phase*	*Velocity*	
		km s^{-1}		*km s*$^{-1}$		*km s*$^{-1}$	*km s*$^{-1}$
1983 Feb. 17·05	45382·07	+71·5	0·704	+47·1	18·612	+23·6	+0·8
17·91	382·93	72·7	·704	47·1	·621	+25·0	+0·6
18·88	383·90	73·1	·704	47·1	·631	+26·5	−0·5
19·86	384·88	75·6	·704	47·1	·641	+27·9	+0·6
Mar. 5·91	398·93	81·3	·705	47·1	·786	+35·5	−1·4
Nov. 28·06	666·08	59·4	·723	47·3	21·549	+12·3	−0·2
Dec. 1·04	669·06	65·1	·723	47·3	·580	+18·1	−0·3
1986 Feb. 9·94	46470·96	75·0	0·777	48·0	29·874	+25·9	+1·1
Nov. 24·52*	758·54	79·5	·796	48·3	32·848	+29·9	+1·3
1987 Jan. 31·01†	46826·03	60·8:	0·800	48·4	33·546	+11·7	+0·8
Mar. 21·89†	875·91	31·4	·804	48·4	34·062	−17·4	+0·4
Oct. 19·20	47087·22	14·3	·818	48·7	36·247	−36·1	+1·7
Nov. 8·37‡	107·39	42·9	·819	48·7	·456	−6·8	+1·0
Dec. 8·16†	137·18	82·9:	·821	48·7	·764	+36·2	−2·0
1988 Jan. 8·10†	47168·12	26·2	0·823	48·8	37·084	−22·1	−0·5
31·34§	191·36	18·9	·825	48·8	·324	−29·8	−0·2
Mar. 10·94	230·96	84·7	·827	48·9	·734	+36·0	−0·1
16·88	236·90	82·6	·828	48·9	·795	+35·1	−1·3
Nov. 3·23	468·25	16·5	·843	49·2	40·188	−35·5	+2·9
6·19	471·21	13·7	·843	49·2	·219	−36·5	+1·0
1989 Feb. 24·18‡	47581·20	22·8	0·851	49·4	41·356	−25·2	−1·3
Mar. 4·96¶	589·98	39·1	·851	49·4	·447	−8·6	−1·6
5·97¶	590·99	41·3	·851	49·4	·458	−6·5	−1·6
7·83¶	592·85	45·9	·851	49·4	·477	−2·5	−1·0
25·88	610·90	80·6	·853	49·4	·664	+30·8	+0·4
Apr. 30·85	646·87	35·4	·855	49·5	42·036	−11·3	−2·7
Oct. 31·18	830·20	67·4	·867	49·7	43·932	+14·2	+3·4
1990 Jan. 31·02	47922·04	75·5	0·873	49·9	44·881	+24·6	+1·0
Feb. 12·18‡	934·20	44·8	·874	49·9	45·007	−4·4	−0·8
Mar. 15·31§	965·33	20·5	·876	50·0	·329	−29·1	−0·3
1991 Jan. 27·06	48283·08	76·0	0·897	50·5	48·615	+24·2	+1·3
Feb. 4·05	291·07	86·0	·898	50·6	·698	+34·1	+1·4
Apr. 19·83¶	365·85	45·2	·903	50·7	49·472	−3·6	−1·9
Dec. 17·13	607·14	57·9	·919	51·1	51·967	+5·7	+1·1
1992 Jan. 14·08	48635·09	14·9	0·921	51·2	52·256	−35·8	−0·5
18·06	639·07	18·9	·921	51·2	·297	−32·8	+0·5
Feb. 27·33§	679·34	84·3	·924	51·3	·714	+35·1	−2·1
Mar. 3·19§	684·20	85·9	·924	51·3	·764	+36·2	−1·6
Apr. 21·88	733·89	18·7	·927	51·4	53·278	−34·4	+1·8
25·90	737·91	20·0	·928	51·4	·320	−30·3	−1·0
Dec. 18·11	974·12	86·3	·943	51·7	55·763	+36·2	−1·7
1993 Feb. 12·01	49030·02	24·1	0·947	51·8	56·341	−27·6	−0·2
18·02	036·03	34·6	·948	51·8	·403	−17·2	0·0
Mar. 18·94	064·95	84·1	·950	51·9	·702	+34·4	−2·1
24·93	070·94	88·6	·950	51·9	·764	+36·2	+0·5
Nov. 5·35‡	296·35	29·1	·965	52·1	59·095	−24·2	+1·2
Dec. 25·10	346·10	76·5	·968	52·2	·610	+23·3	+1·0
30·11	351·11	+84·1	·969	+52·2	·662	+30·6	+1·4

TABLE I (*continued*)

Date			*MJD*	*Velocity*	*Outer orbit*		*Inner orbit*		*(O – C)*
					Phase	*Velocity*	*Phase*	*Velocity*	
				km s^{-1}		*km s*$^{-1}$		*km s*$^{-1}$	*km s*$^{-1}$
1994	Jan.	5·12	49357·12	+86·7	0·969	+52·2	59·724	+35·6	−1·1
		9·11	361·11	87·0	·969	52·2	·765	+36·2	−1·4
	Feb.	18·00	401·00	17·5	·972	52·2	60·178	−34·9	+0·2
		20·95	403·95	16·2	·972	52·2	·208	−36·3	+0·3
	Apr.	29·86	471·86	72·3	·977	52·3	·911	+18·9	+1·1
	Dec.	10·14	696·14	15·5	·992	52·3	63·230	−36·5	−0·3
		14·14	700·14	17·8	·992	52·3	·271	−34·9	+0·4
		28·14	714·14	36·6	·993	52·3	·416	−14·7	−1·0
1995	Jan.	2·11	49719·11	48·4	0·993	52·3	63·468	−4·4	+0·5
		3·89	720·89	50·6	·993	52·3	·486	−0·6	−1·1
		4·03	721·03	51·6	·993	52·3	·488	−0·3	−0·4
		5·11	722·11	54·7	·993	52·3	·499	+2·0	+0·4
		7·07	724·07	61·7	·993	52·3	·519	+6·2	+3·2
	Dec.	22·13	50073·12	20·8	1·017	52·0	67·129	−29·7	−1·4
		24·11	075·10	19·1	·017	51·9	·150	−32·3	−0·5
		27·02	078·01	16·8	·017	51·9	·180	−35·0	−0·1
1996	Mar.	30·89	50172·88	18·5	1·023	51·8	68·161	−33·5	+0·2
	Dec.	15·18	432·17	81·5	·041	51·3	70·842	+30·6	−0·4
		25·15	442·14	61·4	·041	51·3	·946	+11·0	−0·9
1997	Jan.	26·08	50474·07	17·1	1·043	51·2	71·276	−34·6	+0·5
	Feb.	7·98	486·97	34·0	·044	51·2	·409	−16·1	−1·1
	Mar.	29·90	536·89	68·1	·048	51·1	·926	+15·6	+1·4
	Apr.	9·92	547·91	37·0	·048	51·1	72·039	−12·3	−1·8
		17·89	555·88	23·5	·049	51·0	·122	−28·7	+1·2
	Dec.	21·16‖	803·15	84·7	·065	50·5	74·679	+32·4	+1·8
		25·12‖	807·11	86·1	·066	50·5	·720	+35·4	+0·2
1999	Dec.	20·11	51532·09	13·7	1·114	48·9	82·218	−36·5	+1·3
2000	Jan.	9·08	51552·06	36·2	1·115	48·9	82·425	−13·0	+0·4
	Feb.	11·04	585·02	85·2	·118	48·8	·766	+36·2	+0·2
		20·03	594·01	76·7	·118	48·8	·859	+28·3	−0·4
	Mar.	1·97	604·95	54·9	·119	48·8	·972	+4·5	+1·6
		25·94	628·92	12·0	·120	48·7	83·220	−36·5	−0·2
	Apr.	5·87	639·85	18·6	·121	48·7	·333	−28·6	−1·5
	Nov.	20·18	868·16	80·7	·136	48·3	85·694	+33·8	−1·4
		30·21	878·19	81·6	·137	48·3	·798	+34·9	−1·6
	Dec.	3·19	881·17	79·0	·137	48·3	·829	+32·3	−1·6
		9·15	887·13	70·6	·138	48·3	·890	+22·9	−0·6
		14·16	892·14	62·0	·138	48·3	·942	+11·8	+1·9
		22·11	900·09	37·4	·139	48·3	86·024	−8·6	−2·2
		28·04	906·02	25·5	·139	48·3	·086	−22·4	−0·4
2001	Jan.	14·09	51923·07	13·3	1·140	48·2	86·262	−35·5	+0·5
	Mar.	13·93	981·91	75·5	·144	48·1	·871	+26·5	+0·9
	Nov.	3·20	52216·18	15·5	·160	47·8	89·294	−33·2	+0·8
	Dec.	15·13	258·11	81·8	·162	47·8	·727	+35·7	−1·7
2002	Jan.	25·08	52299·06	15·7	1·165	47·7	90·151	−32·5	+0·5
	Apr.	6·91	370·89	69·5	·170	47·6	·894	+22·3	−0·4
2003	Jan.	10·11	52649·09	80·4	1·188	47·3	93·771	+36·1	−3·0
	Feb.	18·99	688·97	14·4	·191	47·3	94·183	−35·3	+2·4
	Mar.	16·94	714·92	39·8	·193	47·2	·452	−7·7	+0·2
		23·90	721·88	+55·8	·193	+47·2	·524	+7·2	+1·4

TABLE I (*concluded*)

Date	*MJD*	*Velocity* km s⁻¹	*Outer orbit* *Phase*	*Outer orbit* *Velocity* km s⁻¹	*Inner orbit* *Phase*	*Inner orbit* *Velocity* km s⁻¹	*(O – C)* km s⁻¹
2004 Apr. 16·90	53111·88	+61·9	1·219	+46·9	98·557	+13·9	+1·1
19·92	114·90	67·5	·220	46·9	·589	+19·7	+0·9
2005 Nov. 30·15	53704·13	79·5	1·259	46·5	104·683	+32·8	+0·2
2006 Feb. 18·04	53784·02	51·2	1·264	46·5	105·509	+4·2	+0·6
Nov. 19·24	54058·23	20·1	·282	46·3	108·345	–27·0	+0·7
Dec. 17·12	086·11	73·0	·284	46·3	·633	+26·9	–0·2
2007 Feb. 4·04	54135·03	15·0	1·288	46·3	109·139	–31·1	–0·2
2009 Jan. 21·05	54852·04	59·3	1·335	46·1	116·555	+13·4	–0·2
24·10	855·09	65·7	·336	46·1	·586	+19·3	+0·3
Apr. 9·93	930·92	22·6	·341	46·1	117·371	–22·9	–0·5
2013 Apr. 5·88	56387·88	36·0	1·438	45·9	132·439	–10·2	+0·3
Nov. 19·25	615·25	79·3	·453	45·9	134·791	+35·3	–1·9
Dec. 28·10	654·10	12·1	·455	45·9	135·193	–35·8	+2·0
2014 Feb. 5·97	56693·97	69·2	1·458	45·9	135·605	+22·5	+0·8
11·07	699·07	76·7	·458	45·9	·658	+30·1	+0·7
13·96	701·96	79·0	·459	45·9	·688	+33·2	–0·1
16·01	704·01	80·9	·459	45·9	·709	+34·8	+0·2
20·93	708·93	80·7	·459	45·9	·760	+36·2	–1·5
22·91	710·91	81·3	·459	45·9	·780	+35·8	–0·4
25·90	713·90	79·0	·459	45·9	·811	+33·9	–0·9
27·90	715·90	77·3	·460	45·9	·832	+31·9	–0·5
Mar. 1·93	717·93	74·5	·460	45·9	·853	+29·2	–0·6
3·92	719·92	71·5	·460	45·9	·873	+26·0	–0·4
4·92	720·92	71·2	·460	45·9	·884	+24·2	+1·1
5·98	721·98	69·2	·460	45·9	·895	+22·1	+1·2
7·91	723·91	66·7	·460	45·9	·915	+18·0	+2·8
8·91	724·91	63·3	·460	45·9	·925	+15·7	+1·7
11·87	727·87	55·6	·460	45·9	·956	+8·5	+1·2
12·86	728·86	53·2	·460	45·9	·966	+6·0	+1·3
13·86	729·86	50·5	·461	45·9	·976	+3·4	+1·2
15·87	731·87	44·3	·461	45·9	·997	– 1·8	+0·2
16·85	732·85	40·9	·461	45·9	136·007	–4·4	–0·7
18·98	734·98	34·4	·461	45·9	·029	–9·8	–1·7
19·87	735·87	30·7	·461	45·9	·038	–12·0	–3·2
21·84	737·84	27·0	·461	45·9	·059	–16·7	–2·2
25·94	741·94	20·5	·461	45·9	·101	–25·3	–0·1
Apr. 4·92	751·92	10·7	·462	45·9	·204	–36·2	+1·0
7·96	754·96	10·9	·462	45·9	·236	–36·4	+1·4
14·87	761·87	13·7	·463	45·9	·307	–31·8	–0·5
15·90	762·90	14·9	·463	45·9	·318	–30·5	–0·5
16·88	763·88	15·6	·463	45·9	·328	–29·3	–1·0
18·86	765·86	19·3	·463	45·9	·349	–26·4	–0·2
19·87	766·87	20·6	·463	45·9	·359	–24·8	–0·5
26·88	773·88	33·2	·463	45·9	·432	–11·7	–1·0
28·86	775·86	37·9	·464	45·9	·452	–7·6	–0·4
May 2·88	779·88	+48·0	·464	+45·9	·494	+1·0	+1·1

*Observed with Palomar 200-inch telescope.
† Observed withn original spectrometer.
‡ Observed with ESO *Coravel*.
§ Observed with DAO 48-inch telescope.
¶ Observed by Imbert[11] at Haute-Provence.
‖ Observed with Haute-Provence *Coravel*.

instrument as Imbert used (the Haute-Provence *Coravel*), and 74 made with the Cambridge *Coravel* . There are in addition four velocities from each of the original Cambridge spectrometer, the ESO *Coravel*, and the spectrometer at the DAO 48-inch telescope, and one measurement with the Palomar 200-inch. The zero-points of the Haute-Provence and ESO velocities have been adjusted, as is usual in this series of papers, by +0·8 km s^{-1} in an effort to bring them into harmony with the Cambridge zero-point, to which all the remaining data have been reduced. The principal data sets all give mutually comparable mean-square residuals, close to 1·6 (km $s^{-1})^2$; the minor ones are no worse, and if any appear better it could easily be just by a statistical fluke, so all of the data have been given the same weight in the solution of the orbits. The solution has been run with the outer period fixed at 15000 days and the remaining ten elements 'free'; the result is given in the informal table below, and the two orbit diagrams appear as Figs. 1 and 2. The early radial velocities obtained by Popper[5,6] from low-dispersion photographic plates are not sufficiently accurate to assist with the solution of the orbit, but they do clutter up the diagrams, so they have been omitted altogether.

Element	*Outer orbit*	*Inner orbit*	*Imbert*[11]
P (days)	15000 (fixed)	96·6885 ± 0·0012	96·667 ± 0·009
T (MJD)	49822 ± 252	49770·6 ± 1·2	44356·7 ± 1·9
γ (km s^{-1})	+47·91 ± 0·10		+45·90 ± 0·17
K (km s^{-1})	3·19 ± 0·15	36·39 ± 0·13	37·06 ± 0·27
e	0·38 ± 0·04	0·049 ± 0·004	0·054 ± 0·007
ω (degrees)	12 ± 8	94 ± 4	96 ± 8
$a_1 \sin i$ (Gm)	609 ± 30	48·31 ± 0·18	49·2 ± 0·4
$f(m)$ ($M_\odot$)	0·040 ± 0·006	0·482 ± 0·005	0·51 ± 0·01
R.m.s. residual (km s^{-1})	1·26		1·21

For comparison with the new orbit, the elements found by Imbert[11] have been added to the informal table and will be seen to be quite similar to those found here for the 96-day orbit. In particular, the apparent (but surely spurious) eccentricity of about 0·05, with $\omega \sim 90°$, appears reinforced by the much larger data set in the new orbit; although the latter does include the Imbert data it would not reproduce almost exactly the same elements unless the additional data shared the same characteristics. It is further noted that, once again, the observations on the descending side of the velocity curve near phase zero, regardless of their sources, are not well represented by the orbital curve but form a steeper sequence, warning us that the calculation of the orbit as if the star were just a point source in a Keplerian orbit is not an adequate approximation to the true state of affairs. The formal r.m.s. error per observation would obviously be somewhat reduced if the residuals could be computed from the mean trend of the points rather than from the Keplerian approximation to it.

A naïve person might think that UU Cnc, which exhibits a photometric range, largely attributed to 'ellipsoidal' variation, of more than half a magnitude, would exhibit very significant phase-related variations in its apparent rotational velocity. Fig. 3 plots the $v \sin i$ values, determined individually from each observation made with the Cambridge *Coravel*, against phase. There seems to be disappointingly little to see in the diagram; the only feature that the writer sees as significant is an apparent small and surprisingly short-lived decrease around phase ·9, which does not seem to correspond to any particularly significant

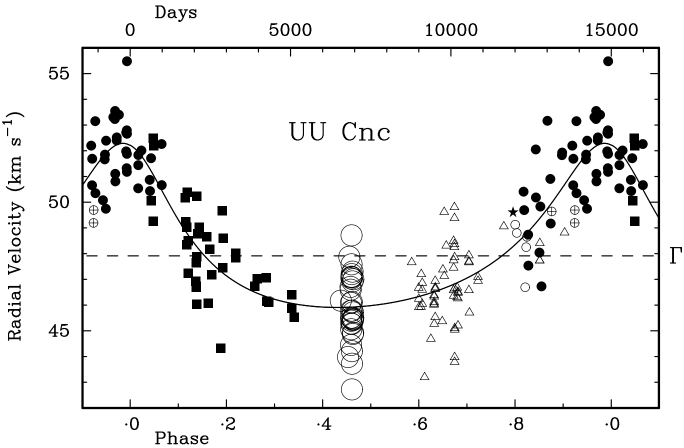

FIG. 1

The well-known 96-day system UU Cancri proves to have a hitherto-overlooked long-period radial-velocity variation that is doubtless the signature of an undetected second companion. This figure plots the variation of the γ-velocity of the 96-day orbit. The observations probably do not cover a complete cycle of the long-period orbit. The earliest observations, represented by open triangles, are those underlying the short-period orbit published by Imbert[11]. The rest of the observations are the writer's own. They start near phase .8. There is one (star symbol) obtained with the 200-inch telescope, four (open circles) with the original Cambridge photoelectric spectrometer, four (one almost hidden; circles with plusses in them) with the spectrometer at the DAO 48-inch telescope, and many obtained with the Haute-Provence (filled circles) and Cambridge (filled squares) *Coravel*s. The large open circles relate to the flurry of recent measurements made with the Cambridge *Coravel* after it was belatedly recognized that the apparent raggedness of the radial velocities was greatly exacerbated by real variation of the γ-velocity.

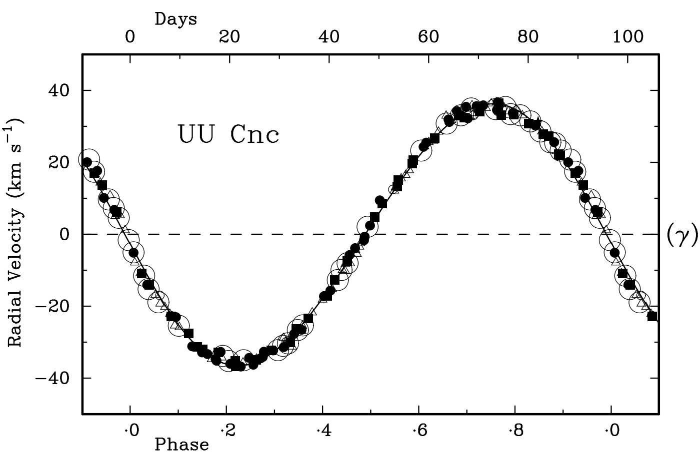

FIG. 2

The 96-day 'inner' orbit of UU Cnc. The symbols are the same as in Fig. 1, but here of course the observations made with the different instruments in somewhat limited intervals of time are not confined to particular ranges of phase (as they are in Fig. 1) but are distributed quasi-randomly around the orbit. It is easily seen that the full line, which represents the Keplerian solution for the orbit, does not fit the points very well: the actual variation of velocity is more rapid (steeper) than the solution admits in the vicinity of the γ-velocity, both on the rising side of the velocity curve and (particularly) the descent.

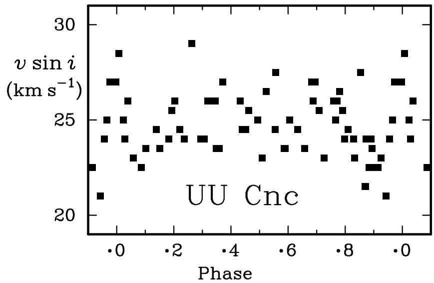

FIG. 3

The apparent projected rotational velocity of UU Cnc, determined from the individual traces made with the Cambridge *Coravel*, plotted as a function of phase in the 96-day orbit. Although the orbit is related to a photometric variation, supposed to arise from the distortion of the only observable star into an ellipsoidal shape, the only seemingly significant variation in the $v \sin i$ appears to be a short-lived decrease near phase .9, not explicable by the writer.

point in the orbit or in the orientation of the ellipsoidal star.

The stellar radius of about 48 $R_\odot$ that follows from the orbital period and $v \sin i$ seems almost unassailable, but it is fully double the radii suggested for stars of type K4 III in tabulations of stellar characteristics. The star was observed by *Hipparcos*, which has given[5] for it a parallax that is almost two standard deviations less than zero! — but it does confirm that the object is a long way away, probably at least a kiloparsec, and therefore has a distance modulus in excess of ten magnitudes and an absolute magnitude brighter than −1.

HD 67788

From time to time, orbits have been presented in this series of papers for stars whose binary natures have been discovered in the course of the 'Clube Selected Areas' survey, which has been on-going at a rather desultory level for getting on for 50 years. The major results for the programme as a whole have appeared in two papers published elsewhere[17,18], but orbits for some of the programme stars have appeared in the present series. It was explained in the prefatory remarks in Paper 216[19] that the richness of the *HD* catalogue in the southern hemisphere (in comparison with the northern) meant that with the publication[18] of the southern Areas the north was left relatively sparsely covered, so observations were being renewed in northern Areas, whose population of the relevant stars (*HD* stars of $m_{pv} \sim 9$ and type K0) had been increased by the expedient of expanding the limits assigned to the various Areas to include more of the sky. HD 67788, and HD 79888 (treated next), are two binary stars discovered in the expanded Area 4. Inasmuch as they are short-period systems that are already well observed, there seems no need to delay publication of their orbits until work on the main programme is completed.

HD 67788 is a 9^m star in Lynx, passing just to the south of the Cambridge zenith; it is to be found about 2° south of the 5^m star 27 Lyn. Its *HD* number has a curious analogy with that of HD 78899, whose orbit was given[20] very recently in Paper 233, and which is in almost exactly the same declination and just an hour of RA (10°) following. *Simbad* retrieves *no* papers relating to HD 67788, so no survey of its literature will detain us here; and the star was not on the *Hipparcos* programme, but its magnitudes have been determined from *Tycho 2* as $V = 9^{m}\!\cdot\!13$, $(B - V) = 0^{m}\!\cdot\!52$. Although the *HD* type is K0 (as

TABLE II

Radial-velocity observations of HD 67788

All the observations were made with the Cambridge Coravel

Date (UT)			MJD	Velocity km s^{-1}	Phase	(O – C) km s^{-1}
2012	Feb.	18·98	55975·98	+30·3	0·612	–0·1
2013	Apr.	19·92	56401·92	–13·8	56·844	+0·2
		20·85	402·85	–31·2	·966	+0·3
		26·94	408·94	+2·9	57·770	+0·1
		27·87	409·87	–23·9	·894	+0·3
		29·86	411·86	+5·6	58·157	–0·1
		30·87	412·87	+33·1	·289	+1·0
	May	1·92	413·92	+40·9	·428	–0·3
		2·89	414·89	+36·2	·556	0·0
		3·86	415·86	+19·7	·684	–0·2
		4·94	416·94	–9·4	·827	+0·6
		5·89	417·89	–31·6	·952	–0·5
		6·87	418·87	–14·5	59·082	0·0
		7·88	419·88	+19·2	·215	–0·3
		8·92	420·92	+39·0	·352	+0·7
		11·94	423·94	+7·5	·750	+0·4
		13·87	425·87	–28·5	60·006	+1·0
		16·89	428·89	+40·3	·404	–0·5
	June	2·90	445·90	+25·6	62·650	+0·3
		5·90	448·90	–21·8	63·046	+1·2
		6·90	449·90	+10·5	·178	–0·6
	Oct.	24·24	589·24	+33·8	81·573	–0·8
		30·24	595·24	+39·4	82·365	+0·2
	Nov.	9·22	605·22	+20·6	83·683	+0·5
		13·21	609·21	+18·3	84·210	–0·1
		19·18	615·18	–30·7	·998	–0·4
	Dec.	20·11	646·11	–14·3	89·081	+0·4
		29·08	655·08	+29·3	90·265	+0·6
2014	Jan.	5·06	56662·06	+13·6	91·187	+0·4
		7·10	664·10	+40·9	·456	–0·2
		10·07	667·07	–15·5	·848	–0·6
		12·09	669·09	–5·3	92·115	+0·3
		13·13	670·13	+26·6	·252	0·0
	Feb.	5·98	693·98	+41·1	95·401	+0·4
		11·06	699·06	–17·1	96·071	+0·1
		12·01	700·01	+14·9	·197	–0·7
		12·95	700·95	+35·2	·321	–0·5
		15·94	703·94	+14·4	·716	+0·3
		22·92	710·92	+27·3	97·637	+0·1
		25·91	713·91	–26·8	98·032	–1·1
		26·91	714·91	+6·5	·164	–1·1
		27·91	715·91	+32·9	·296	0·0
	Mar.	1·90	717·90	+35·5	·558	–0·5
		3·90	719·90	–9·1	·822	0·0
		4·90	720·90	–31·4	·955	–0·2
		5·99	721·99	–10·5	99·098	–0·4
		7·90	723·90	+38·4	·351	+0·2
		8·89	724·89	+40·4	·481	–0·1
		9·94	725·94	+29·7	·620	+0·3
		11·88	727·88	–21·0	·876	–0·2
		12·87	728·87	–29·5	100·007	–0·1
		13·87	729·87	+1·3	·139	+0·4
		15·86	731·86	+40·3	·401	–0·4
		16·86	732·86	+37·9	·533	0·0

TABLE II (*concluded*)

Date (UT)		*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2014 Mar.	18·91	56734·91	−4·6	100·804	+0·2
	19·86	735·86	−29·5	·929	−0·2
	21·85	737·85	+14·4	101·192	−0·1
	23·07	739·07	+38·9	·353	+0·5
	24·03	740·03	+40·6	·480	0·0
	25·97	741·97	+9·5	·736	−0·6
Apr.	4·94	751·94	−21·4	103·052	+0·2
	7·99	754·99	+40·7	·455	−0·4
	14·85	761·85	+39·3	104·361	+0·4
	15·85	762·85	+40·4	·493	+0·3
	16·85	763·85	+29·2	·625	+0·4
	18·88	765·88	−23·7	·893	+0·3
	19·85	766·85	−27·6	105·021	−0·1
	26·94	773·94	−31·6	·957	−0·3
May	2·90	779·90	+7·8	106·744	−0·7

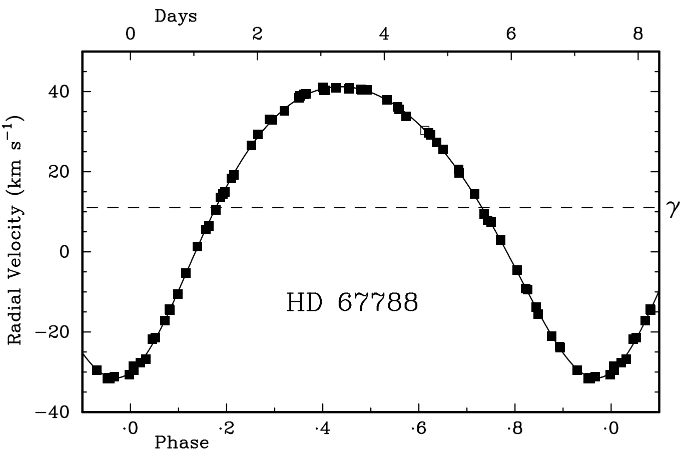

FIG. 4

The observed radial velocities of HD 67788 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All the observations have been made with the Cambridge *Coravel*; the single one made in the first observing season (early in 2012) is identified by an open symbol (partly hidden near phase .6).

for all stars in the Clube Areas programme), the colour index suggests a much earlier type, perhaps near F8. That accords with the notable shallowness of the 'dips' seen in radial-velocity traces, which have little more than half the area of dips exhibited by genuine K0 stars. A main-sequence nature for HD 67788 can hardly be doubted, in view of the short orbital period of about a week.

An initial radial-velocity observation was made in early 2012, and then in the ordinary course of the renewed survey of the northern Areas another was made in 2013. It differed grossly from the earlier one. Another measurement on the very next night showed a further change of nearly 20 km s^{-1}, so the star has since been followed attentively. There are now 69 radial-velocity observations, all made with the Cambridge *Coravel* and set out in Table II. They readily give an orbit whose elements are included in Table VI towards the end of this paper, where also the elements for the three other stars treated below are collected.

The orbit is illustrated in Fig. 4. Despite the relative shortness of the observing campaign, the period is determined with a standard error of only about 12 seconds; and despite the shortness of the period, the orbit is of considerable eccentricity, about 0·18. The minimum mass demanded by the mass function for the secondary star is about 0·47 $M_\odot$, corresponding to that of a main-sequence star of type M0, so it is not surprising that the companion has not been apparent in the radial-velocity traces.

The traces exhibit dips that, though shallow, are significantly broadened, no doubt by axial rotation of the star; the mean value of $v \sin i$ is 7·2 km s^{-1}, with a standard error of the mean of little more than 0·2 km s^{-1}. Usually such values are accompanied by a *caveat* that their determination in such a simple-minded manner means that they should not be regarded as more accurate than ±1 km s^{-1}, but in this case where we are dealing with a solar-type star it is less likely that ignored effects are compromising the result. A $v \sin i$ of 7·2 km s^{-1} would imply an $R_\star \sin i$ of 1·07 $R_\odot$ if the rotation period were supposed to be synchronized to the orbital period. The rotation is, however, more likely to be *pseudo*-synchronized[27], which at the eccentricity of the HD 67788 orbit is about 1·18 times faster than the orbital revolution and so would suggest an $R_\star \sin i$ of about 0·91 $R_\odot$. Since the actual stellar radius, if the spectral type is about F8, is near 1·2 $R_\odot$, the observed rotational velocity could be interpreted as indicating that $\sin i \sim 0{\cdot}76$, making the orbital inclination about 50°. It would, however, be imprudent to claim any great accuracy for that number, especially as it is not even certain that the rotation is related to the orbital period at all.

HD 79888

HD 79888, another object in Clube Area 4, is a 9^{m} star in Ursa Major, halfway between the 3^{m} stars θ and κ UMa, which, together with ι, form the asterism that underlies the Bear's left fore-paw in the conventional pictures of the constellation. It is just 1° south-following the interesting object HD 78899 that is mentioned in the section above but is not itself a Clube star, being too bright and of *HD* type G5 — and again there are curious similarities in the *HD* numbers. Unlike HD 67788, HD 79888 was observed by *Hipparcos*; its parallax was measured at 6·11 ± 1·44 arc-milliseconds, equivalent to a distance modulus of just over six magnitudes with a 1-σ uncertainty of about half a magnitude. In conjunction with the *Tycho-2*-based *V* magnitude of 9^{m}·00, the absolute magnitude is found to be about +3, with the same uncertainty — much too bright for a K0 main-sequence star, although the *Tycho 2* colour index of $(B - V)$ = 0^{m}·81 would be reasonably consonant with such a type (though more so with G8). The star is nearly three magnitudes 'too bright' and must be supposed to be of luminosity class IV; we can only guess at what it may be *doing* there, but its most likely situation in the H–R Diagram appears to be near the minimum of luminosity that occurs for an evolving star shortly after it traverses the Hertzsprung Gap, at the foot of the giant branch. The only paper[22] retrieved for HD 79888 by *Simbad* is one that, if the present writer has correctly understood it, says that in order not to impair the space motion that will putatively be determined by *Gaia*, we need to measure its radial velocity within an uncertainty less than about 75 km s^{-1}. *That* we proceed to do here!

Just like HD 67788, HD 79888 was measured for radial velocity at Cambridge in early 2012 in a first round of observations in the enlarged 'Clube Area 4', and then observed again about a year later — when it gave a result of almost −100 km s^{-1}, more than 40 km s^{-1} away from the first one. Naturally that discrepancy enjoined careful attention to the star, and there are now the 62

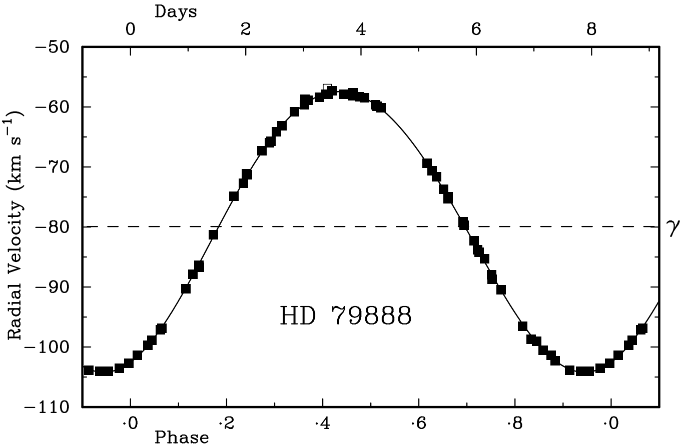

FIG. 5

As Fig. 4, but for HD 79888. In this case (but not in that of HD 67788) the initial observation is rejected.

measurements listed in Table III. They readily produce the orbit that is plotted in Fig. 5 and whose elements are included in Table VI near the end of this paper. All the observations have been given the same weight in the solution, apart from the first one, which was made on a night that was very cloudy and was being used for the survey of 'new' stars rather than for the determination of orbits — it has a uniquely bad residual and has been rejected. The 8-day period is seen to be determined to a precision of about 16 seconds, and the small eccentricity of 0·04 is very definitely non-zero, being nearly 20 times its standard deviation. The unusually high (negative) γ-velocity of –80 km s^{-1}, in conjunction with the accuracy of the orbital period, produces a significant (12σ) difference between the observed period and the 'true' one (measured in the rest-frame).

The small mass function of 0·011 $M_{\odot}$ does not encourage any expectation that the companion star should be visible. If we supposed the primary to have a mass of 2 $M_{\odot}$, the secondary need be no more than 0·4 $M_{\odot}$ (corresponding to about M2 V) to satisfy the mass function; if the primary were less massive, so would be the limit for the secondary. The radial-velocity traces show very appreciable rotational broadening, quantifiable at 6·4 km s^{-1} with a standard error of the mean less than 0·2 km s^{-1} (probably unrealistically small as an external error). Such a rotational velocity is very close to that which would characterize a star of one solar radius rotating in the orbital period. From the fact that HD 79888 is approximately 2·7 magnitudes brighter than a main-sequence star of the same colour index, which would have a spectral type of about G8 and a radius of nearly 0·9 $R_{\odot}$, we might venture an estimate that the HD 79888 radius is about 3 $R_{\odot}$, so it would seem to follow that $\sin i \sim ⅓$ or $i \sim 20°$. But if that were really the case, the mass-function requirement of 0·4 $M_{\odot}$ would become the requirement for $m_2 \sin i$, so the companion mass would need to be at least 1·2 $M_{\odot}$, equivalent to about F8 V and becoming dangerously near to having to be visible in the radial-velocity traces. The arguments leading to that result would also need to be iterated, because a secondary star of such brightness and type would perceptibly alter integrated colour of the system, but in the absence

Table III

Radial-velocity observations of HD 79888

All the observations were made with the Cambridge Coravel

Date (UT)			*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O – C)* $km\ s^{-1}$
2012	Mar.	10·038*	55996·038	−56·9	$\overline{50}$·409	+0·8
2013	Apr.	27·890	56409·890	−99·7	0·036	+0·1
		29·868	411·868	−67·3	·273	+0·2
		30·872	412·872	−58·4	·394	−0·3
	May	1·935	413·935	−60·1	·521	+0·2
		2·896	414·896	−71·6	·636	+0·2
		3·866	415·866	−88·7	·753	−0·7
		4·958	416·958	−102·3	·884	0·0
		5·905	417·905	−102·7	·997	0·0
		6·892	418·892	−90·3	1·116	−0·2
		7·890	419·890	−72·7	·235	−0·3
		8·943	420·943	−59·6	·362	0·0
		11·947	423·947	−83·8	·722	−0·1
		13·885	425·885	−104·0	·954	+0·1
		16·898	428·898	−63·1	2·315	−0·1
	June	3·923	446·923	−58·3	4·477	−0·2
		5·903	448·903	−82·3	·714	+0·3
		6·901	449·901	−98·7	·834	−0·6
		15·905	458·905	−103·9	5·914	−0·2
	Oct.	29·248	594·248	−86·7	22·143	−0·7
	Nov.	9·255	605·255	−58·1	23·463	−0·3
		19·240	615·240	−75·3	24·661	−0·3
	Dec.	29·123	655·123	−57·9	29·443	−0·4
2014	Jan.	5·177	56662·177	−66·0	30·289	−0·3
		10·067	667·067	−101·4	·875	+0·3
		13·134	670·134	−71·3	31·243	0·0
	Feb.	3·053	691·053	−88·0	33·752	−0·1
		14·011	702·011	−96·9	35·066	−0·2
		15·996	703·996	−64·1	·304	+0·1
		18·977	706·977	−75·0	·661	+0·1
		22·991	710·991	−86·4	36·142	−0·2
		26·078	714·078	−59·9	·513	−0·1
		26·947	714·947	−69·4	·617	0·0
		27·949	715·949	−85·3	·737	+0·5
	Mar.	1·950	717·950	−103·5	·977	+0·1
		3·941	719·941	−74·9	37·216	+0·3
		4·989	720·989	−60·8	·341	+0·1
		6·004	722·004	−57·6	·463	+0·2
		7·932	723·932	−79·7	·694	0·0
		8·950	724·950	−96·5	·816	−0·3
		9·951	725·951	−104·0	·936	+0·2
		11·923	727·923	−81·3	38·173	+0·3
		12·920	728·920	−65·7	·292	−0·4
		13·920	729·920	−57·9	·412	−0·3
		15·910	731·910	−73·7	·651	0·0
		16·912	732·912	−90·5	·771	+0·1
		18·940	734·940	−101·4	39·014	+0·2
		19·900	735·900	−87·9	·129	+0·2
		21·896	737·896	−58·9	·369	+0·3
		23·075	739·075	−59·6	·510	0·0
		24·049	740·049	−70·6	·627	0·0
		25·981	741·981	−100·5	·859	−0·1

TABLE III (*concluded*)

Date (UT)		*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2014 Apr.	4·869	56751·869	−98·9	41·044	+0·1
	5·016	752·016	−97·1	·062	0·0
	7·994	754·994	−57·3	·419	+0·2
	14·852	761·852	−71·1	42·241	+0·5
	15·867	762·867	−58·7	·363	+0·8
	16·900	763·900	−58·5	·487	0·0
	18·889	765·889	−84·2	·725	0·0
	19·887	766·887	−99·0	·845	+0·2
	26·947	773·947	−79·1	43·692	+0·3
May	2·910	779·910	−57·9	44·407	−0·2

*Rejected — see text.

of any observational sign of the presence of the secondary, or of any conviction that the rate of rotation of the observed star is of any particular significance *at all*, it seems premature to be concerned about iteration and refinement of the calculation.

HD 119915

This star, and HD 120649 which is treated below, are two stars that featured in the comprehensive survey by Yoss & Griffin[23] of all the late-type *HD* stars in the area within 15° radius of the North Galactic Pole (NGP). The radial velocity of each of them had been measured three times but its variability had not been recognized; it was only in 2010, in a new round of measurements in the NGP field, that their binary natures were discovered.

Both stars are in a region that looks practically empty to the naked eye except at astronomically good sites. HD 119915 is about 1° south-preceding the 5^{m} star HR 5195, which is itself a star that featured in the survey; the former is about 1° preceding HD 120531, whose orbit was published in Paper 190[24] of the present series, and is less than 12′ north-preceding HD 120006, whose orbit appeared in Paper 218[25]. The star has a *Hipparcos* parallax of only 2·21 ± 0·93 milliseconds, which, with its *V* magnitude of 8^{m}·56 given in the NGP survey[23] and 8^{m}·58 by Oja[26], shows the absolute magnitude to be just about zero, with a 1-σ uncertainty of about one magnitude. The (*B* – *V*) colour index was found in both cases to be 1^{m}·38, which agrees well with the type of K4 III deduced in the survey from *DDO*-style narrow-band photometry. The only classification made from actual spectra — in that case objective-prism ones — was one of K3 V, from Abastumani[27]; the main-sequence luminosity is, however, unacceptable in the light of the parallax and the luminosity-sensitive photometric observations.

The first radial-velocity observations of HD 119915 were made with the original spectrometer in Cambridge in 1971 and 1975, and there was another one in 1987 made with the OHP *Coravel*. They were in tolerable agreement with one another, and their (weighted) mean was duly tabulated in the survey paper[23]. One measurement tabulated by Famaey *et al.*[28] in 2005 was also more or less in agreement. An observation in late June of 2010, however, disagreed with the previous ones, and galvanized a programme of frequent observations as the star got more and more ridiculously far west and low down in the evening twilight. (There are, perhaps fortunately, definite limits, when the telescope runs into the floor while still at a zenith distance considerably less than 90°!).

TABLE IV

Radial-velocity observations of HD 119915

Except as noted, the observations were made with the Cambridge Coravel. Those made in 2010 were half-weighted in the solution of the orbit.

Date (UT)			*MJD*	*Velocity* km s^{-1}	*Phase*	*(O – C)* km s^{-1}
1971	Feb.	22·24*	41004·24	−91·4	$\overline{142}$·754	0·0
1975	Mar.	7·13*	42478·13	−93·7	$\overline{127}$·327	+0·4
1987	Mar.	5·22†	46859·22	−94·1	$\overline{84}$·646	+0·8
2010	June	28·98	55375·98	−88·7	0·856	−0·5
	July	6·91	383·91	−86·3	·935	+0·3
		9·96	386·96	−86·1	·965	+0·1
		17·92	394·92	−86·5	1·043	−0·2
		29·90	406·90	−88·9	·162	−0·2
		31·88	408·88	−88·7	·181	+0·6
	Aug.	12·87	420·87	−93·0	·300	+0·2
		15·85	423·85	−94·5	·329	−0·3
		17·87	425·87	−95·2	·349	−0·5
		23·83	431·83	−97·3	·408	−1·2
		27·83	435·83	−96·6	·448	+0·1
		30·84	438·84	−97·5	·478	−0·5
		31·83	439·83	−97·0	·487	0·0
	Sept.	1·84	440·84	−96·6	·497	+0·4
		2·83	441·83	−97·4	·507	−0·4
		11·80	450·80	−96·8	·596	−0·8
		12·80	451·80	−96·1	·606	−0·3
		20·79	459·79	−93·9	·685	−0·2
2011	Apr.	7·13	55658·13	−95·2	3·646	−0·3
	May	10·07	691·07	−86·2	·972	0·0
		15·06	696·06	−86·4	4·021	−0·2
		19·01	700·01	−86·2	·060	+0·3
		25·05	706·05	−87·7	·120	−0·1
	June	2·90	714·90	−90·2	·207	−0·1
		8·00	720·00	−92·3	·258	−0·5
	July	28·89	770·89	−91·6	·761	−0·4
	Aug.	9·86	782·86	−87·8	·879	−0·2
	Sept.	12·80	816·80	−90·1	5·215	+0·3
2012	Jan.	13·27	55939·27	−96·1	6·426	+0·3
	Feb.	2·27	959·27	−95·8	·624	−0·4
		19·22	976·22	−90·4	·791	−0·2
	Apr.	6·09	56023·09	−91·2	7·255	+0·5
		11·07	028·07	−93·8	·304	−0·4
		18·02	035·02	−95·9	·372	−0·6
	May	23·01	070·01	−92·9	·718	−0·3
		25·99	072·99	−91·4	·748	+0·2
	June	19·00	097·00	−86·2	·985	−0·1
	July	15·94	123·94	−91·6	8·252	0·0
	Aug.	14·87	153·87	−97·0	·548	−0·2
		29·83	168·83	−93·3	·696	+0·1
	Sept.	3·83	173·83	−91·6	·745	+0·1
		13·80	183·80	−88·4	·844	+0·1
2013	Mar.	31·12	56382·12	−89·6	10·804	+0·1
	Apr.	2·14	384·14	−89·3	·824	−0·2
		28·04	410·04	−86·9	11·081	−0·1
		30·05	412·05	−87·2	·100	0·0

TABLE IV (*concluded*)

Date (UT)			*MJD*	*Velocity* km s⁻¹	*Phase*	*(O–C)* km s⁻¹
2013	May	5·07	56417·07	−88·5	11·150	−0·1
		9·05	421·05	−89·2	·189	+0·3
		14·04	426·04	−91·0	·239	+0·2
	July	6·97	479·97	−90·2	·772	+0·6
		29·91	502·91	−86·1	·999	0·0
	Sept.	2·82	537·82	−94·5	12·344	+0·1
2014	Jan.	5·31	56662·31	−96·3	13·575	+0·1
		10·27	667·27	−95·1	·624	+0·3
		13·30	670·30	−94·4	·654	+0·3
	Feb.	6·26	694·26	−87·5	·891	−0·2
		21·19	709·19	−86·3	14·038	0·0
		26·21	714·21	−87·3	·088	−0·4
		28·14	716·14	−87·6	·107	−0·3
	Mar.	4·17	720·17	−88·0	·147	+0·3
		5·21	721·21	−88·7	·157	−0·1
		9·11	725·11	−89·5	·196	+0·2
		10·10	726·10	−89·8	·206	+0·3
		12·12	728·12	−90·5	·226	+0·2
		16·12	732·12	−91·5	·265	+0·6
		23·17	739·17	−94·7	·335	−0·4
	Apr.	8·12	755·12	−97·2	·493	−0·2
		15·04	762·04	−96·6	·561	0·0
		16·02	763·02	−96·2	·571	+0·3
		16·98	763·98	−95·4	·580	+0·9
		27·06	774·06	−93·8	·680	+0·1
	May	3·00	780·00	−91·9	·739	+0·1

*Observed with original spectrometer; weight ½.
†Observed with Haute-Provence *Coravel*; weight ½.

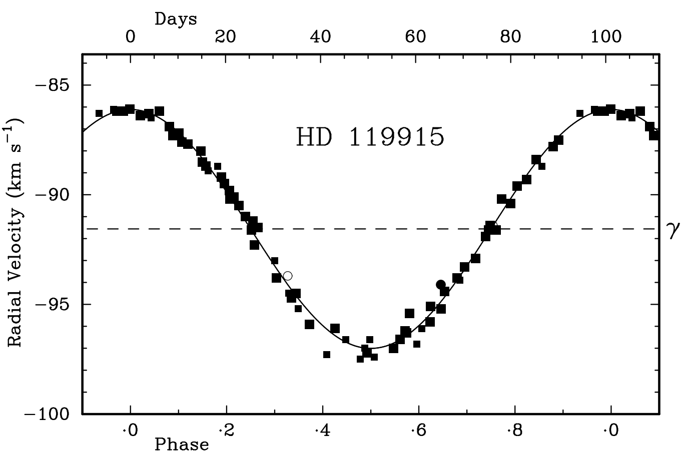

FIG. 6

The observed radial velocities of HD 119915 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All but three (now quite old) observations have been made with the Cambridge *Coravel* in 2010–14. Those obtained in 2010 have been half-weighted in the solution of the orbit, and are plotted with smaller symbols. There are two measurements (open circles; one almost hidden, at the γ-velocity, on the rise) made with the original spectrometer, and one (filled circle, phase .64) made with the Haute-Provence *Coravel*; all three have been half-weighted.

The circular orbit with its period of 101 days was already divined in the light of that summer's observations, but further measurements have naturally offered improvement. Table IV lists the 75 radial velocities now available. In the solution of the orbit, the first main season's observations seem to have larger residuals than subsequent ones, and it has been found appropriate to attribute half-weight to those 18 measures and to the three much earlier ones. The resulting orbit is shown in Fig. 6, and its elements are included in Table VI.

A notable feature of the elements is the γ-velocity of –91·6 km s^{-1}, larger (its sign disregarded) even than that of HD 79888. The mass function is very small and may suggest that the companion is a main-sequence star some way down the M types. The orbit is circular within its uncertainty, as is very often the case for giant stars with periods up to about 120 days. The star gives radial-velocity 'dips' that are considerably broadened by rotation, which in this case probably *can* be expected to be synchronized with the orbital revolution. The mean value of $v \sin i$ is 10·0 km s^{-1}, with a formal standard error of only 0·12 km s^{-1}. In conjunction with the 101-day orbital period it yields a value for $R_\star \sin i$ of 20 $R_\odot$, which is very much the same order of size as would be expected for the stellar radius from the colour index and (none too accurately known) distance.

HD 120649

This star is quite near to the one discussed immediately above, being about 1°·6 north and 1½ minutes of time (about 20′) following HR 5195, the same 5^{m} star as that to which HD 119915 was referred. The very next entry in the *Henry Draper Catalogue*, HD 120650, is another NGP Survey[23] star, 19′ south of HD 120649, and is yet another one discovered to be a binary in 2010, after three previous measurements that rather equally divided the previous 40 years had been in good mutual accord. The only paper retrieved for HD 120649 by *Simbad*, other than the Yoss–Griffin survey paper, is one by Goyal[29] referring to its considerable proper motion. The only *BV* photometry available seems to be that in the survey, V = 9^{m}·12, $(B - V)$ = 0^{m}·54; *DDO*-type photometry indicated a spectral type of F7 III and an absolute magnitude of +1^{m}. A type of G2 III had been given for it at Abastumani[27]. Despite those results, both the proper motion and the short orbital period of about 9 days indicate that HD 120649 is likely to be on or near the main sequence. The colour index is very blue for a star that was supposed in the *Henry Draper Catalogue* to be of type K0, but it is not by any means alone in exhibiting that discrepancy; the index would correspond to that of a main-sequence star with a type of about F8.

The first radial-velocity measurement was made in Cambridge as comparatively late as 1986, with the original spectrometer; HD 120649 must have been one of the last NGP stars to be observed. Further measurements were made at Haute-Provence in 1987 and 1989; the Cambridge one did not agree too well with them, but the discrepancy was not enough to flag up a 'red alert'. It was only in 2010 July that a fresh (Cambridge) observation produced a rather significant discordance; little further progress was made in that season, but relatively intensive observations in 2011 and especially 2012 demonstrated its short-period, low-amplitude circular orbit. The 103 radial velocities are set out in Table V; they were all given the same weight in the solution, which is included in Table VI and illustrated by Fig. 7.

The mass function is only 11 millionths of a solar mass; if the primary star is supposed (despite the published classifications) to have a type of about F8 V, then the secondary has a minimum mass of less than 0·03 $M_\odot$. Of course that does not demonstrate, in the absence of any information on the orbital

Table V

Radial-velocity observations of HD 120649

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

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
1986 May 6·02*	46556·02	−32·1	$\overline{1019}$·397	0·0
1987 Mar. 3·08†	46857·08	−29·1	$\overline{984}$·150	−0·2
1989 Apr. 30·07†	47646·07	−29·6	$\overline{893}$·228	+0·3
2010 July 6·93	55383·93	−32·7	0·452	−0·3
21·93	398·93	−29·6	2·184	−0·3
Aug. 12·88	420·88	−31·0	4·717	−0·3
27·84	435·84	−32·6	6·444	−0·2
Sept. 12·81	451·81	−30·3	8·288	+0·5
2011 Mar. 14·21	55634·21	−32·2	29·343	−0·7
Apr. 7·14	658·14	−28·0	32·106	+0·4
May 10·07	691·07	−28·2	35·907	+0·1
11·06	692·06	−28·3	36·021	−0·4
12·05	693·05	−29·2	·136	−0·5
12·98	693·98	−30·1	·243	0·0
15·00	696·00	−32·2	·476	+0·3
19·02	700·02	−27·9	·940	+0·2
21·01	702·01	−29·2	37·170	−0·1
23·99	704·99	−33·3	·514	−0·8
25·01	706·01	−31·9	·632	−0·1
31·91	712·91	−32·3	38·428	0·0
June 2·90	714·90	−31·3	·658	+0·2
3·97	715·97	−29·6	·781	+0·2
16·98	728·98	−29·8	40·283	+0·9
Sept. 13·81	817·81	−32·5	50·537	0·0
2012 Jan. 6·29	55932·29	−29·2	63·752	+1·0
13·28	939·28	−31·0	64·559	+1·4
Feb. 2·27	959·27	−28·0	66·867	+0·7
19·23	976·23	−28·8	68·825	+0·4
Apr. 11·07	56028·07	−30·1	74·809	−0·7
16·10	033·10	−31·5	75·389	+0·5
18·02	035·02	−31·7	·611	+0·3
30·03	047·03	−27·8	76·997	+0·1
May 15·03	062·03	−30·7	78·729	−0·2
23·02	070·02	−31·6	79·651	0·0
26·03	073·03	−28·2	·999	−0·3
27·06	074·06	−28·5	80·118	0·0
28·01	075·01	−29·5	·227	+0·4
28·96	075·96	−31·1	·337	+0·3
June 13·00	091·00	−28·8	82·073	−0·6
16·00	094·00	−32·4	·419	−0·2
19·00	097·00	−29·6	·766	+0·4
22·99	100·99	−30·4	83·226	−0·5
28·96	106·96	−28·4	·916	−0·2
July 15·94	123·94	−28·8	85·876	−0·2
22·93	130·93	−31·9	86·683	−0·7
23·92	131·92	−29·6	·797	0·0
24·93	132·93	−28·2	·913	+0·1
25·90	133·90	−28·3	87·025	−0·4
26·90	134·90	−28·3	·141	+0·5
27·89	135·89	−31·0	·255	−0·7
28·89	136·89	−31·1	·371	+0·7

TABLE V (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2012 Aug. 1·88	56140·88	–29·0	87·831	+0·1
4·88	143·88	–28·9	88·177	+0·3
8·87	147·87	–31·4	·638	+0·3
10·88	149·88	–28·9	·870	–0·3
14·87	153·87	–31·5	89·331	–0·2
15·86	154·86	–32·1	·445	+0·3
20·85	159·85	–27·2	90·021	+0·7
22·99	161·99	–31·2	·268	–0·7
28·83	167·83	–27·9	·942	+0·2
29·83	168·83	–28·1	91·058	0·0
30·84	169·84	–29·4	·174	–0·2
Sept. 3·84	173·84	–31·7	·636	0·0
5·83	175·83	–29·3	·866	–0·6
7·82	177·82	–27·8	92·095	+0·5
13·81	183·81	–30·4	·787	–0·7
15·81	185·81	–28·0	93·018	–0·1
18·80	188·80	–32·3	·363	–0·6
2013 Mar. 31·12	56382·12	–31·2	115·679	0·0
Apr. 6·10	388·10	–32·1	116·369	–0·3
7·11	389·11	–32·5	·486	0·0
18·11	400·11	–30·1	117·755	0·0
20·10	402·10	–27·9	·985	0·0
May 5·07	417·07	–30·7	119·713	0·0
7·05	419·05	–27·8	·942	+0·3
12·01	424·01	–32·2	120·514	+0·3
June 6·99	449·99	–32·5	123·513	0·0
15·99	458·99	–32·4	124·552	0·0
24·96	467·96	–32·8	125·588	–0·6
July 11·97	484·97	–32·8	127·551	–0·4
19·96	492·96	–32·6	128·474	–0·1
2014 Jan. 10·27	56667·27	–32·1	148·595	0·0
13·30	670·30	–28·3	·945	–0·2
Feb. 2·27	690·27	–29·9	151·250	+0·3
3·20	691·20	–31·5	·358	+0·2
6·25	694·25	–31·2	·710	–0·4
16·19	704·19	–28·2	152·857	+0·6
21·18	709·18	–32·2	153·433	+0·1
26·21	714·21	–28·2	154·014	–0·3
Mar. 4·17	720·17	–31·1	·702	–0·2
5·22	721·22	–29·2	·823	0·0
9·11	725·11	–30·1	155·272	+0·4
10·10	726·10	–32·3	·386	–0·3
12·14	728·14	–31·8	·622	+0·1
16·12	732·12	–28·2	156·081	0·0
23·17	739·17	–28·1	·895	+0·3
24·07	740·07	–27·8	·999	+0·1
Apr. 8·12	755·12	–30·3	158·736	+0·1
15·05	762·05	–32·2	159·536	+0·3
16·02	763·02	–31·8	·648	–0·2
16·99	763·99	–30·1	·760	0·0
27·06	774·06	–28·3	160·923	–0·1
May 3·00	780·00	–31·7	161·608	+0·3

*Observed with original spectrometer; weight ½.
†Observed with Haute-Provence *Coravel*; weight 1.

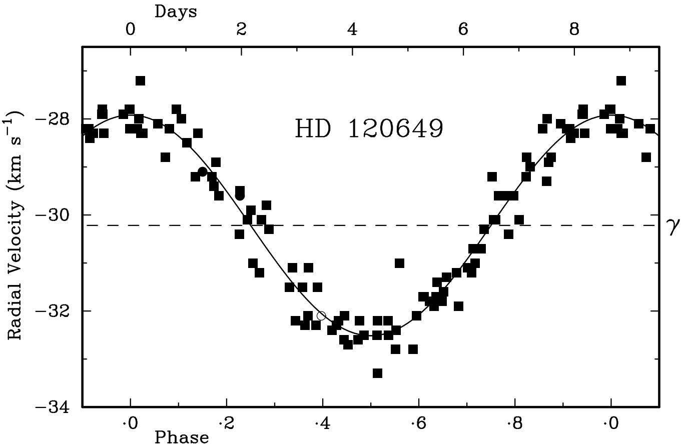

FIG. 7

As Fig. 6, but for HD 120649. Again there are three old observations, but in this case there is one from the original spectrometer, again weighted ½, and two from the Haute-Provence *Coravel* (weight 1). More (100) recent observations have been made of this star, in an effort to reduce the uncertainties arising from the star's relatively early spectral type and small radial-velocity amplitude.

inclination, that it cannot be a normal star. Most of the radial-velocity traces yield non-zero values for $v \sin i$; a formal mean and standard deviation would tend to invest that result with more certainty than is really warranted, and it may be better simply to say that a representative value is 4 km s^{-1}. Such a projected rotational velocity is not out of line with what might be expected for a late-F dwarf, if it is rotating in the orbital period and has a moderate axial inclination.

TABLE VI

Orbital elements for HD 67788, HD 79888, HD 119915 and HD 120649

Element	*HD 67788*	*HD 79888*	*HD 119915*	*HD 120649*
P (days)	7·57479 ± 0·00014	8·33929 ± 0·00018	101·137 ± 0·006	8·66284 ± 0·00018
T (MJD)	56592·473 ± 0·015	56609·73 ± 0·07	55795·07 ± 0·16	55943·098 ± 0·034
γ (km s^{-1})	+11·03 ± 0·06	−79·93 ± 0·04	−91·56 ± 0·04	−30·22 ± 0·04
K_1 (km s^{-1})	36·36 ± 0·08	23·38 ± 0·05	5·45 ± 0·06	2·30 ± 0·06
e	0·1762 ± 0·0022	0·0409 ± 0·0022	0	0
ω (degrees)	196·2 ± 0·8	201·7 ± 3·2	—	—
$a_1 \sin i$ (Gm)	3·728 ± 0·009	2·680 ± 0·006	7·58 ± 0·09	0·274 ± 0·007
$f(m)$ ($M_\odot$)	0·03607 ± 0·00025	0·01104 ± 0·00007	0·00170 ± 0·00006	0·0000109 ± 0·0000008
R.m.s. residual (wt. 1) (km s^{-1})	0·46	0·27	0·31	0·40
P_{true} (days)		8·34151 ± 0·00018	101·167 ± 0·006	8·66371 ± 0·00018
Difference from P (std. dev.'s)		12·3	4·8	4·9

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THE SENSITIVITY OF *ANS* COLOURS OF G DWARFS TO STELLAR ACTIVITY

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One of the earliest systematic photometric surveys of main-sequence stars at mid-ultraviolet wavelengths is that of the *Astronomical Netherlands Satellite* (*ANS*). While the bulk of the science resulting from that survey has centred upon stars of early spectral types, a modest number of late-F and G dwarfs were observed. By combining the *ANS* photometry with soft-X-ray-luminosity measurements from *ROSAT* it is shown that for G dwarfs the 1800 Å band of the *ANS* spectrophotometric system becomes sensitive to stellar activity for stars with X-ray luminosities of $\log(L_x/L_{bol}) > -5{\cdot}5$. Three *ANS* bandpasses redward of 2000 Å are instead dominated by photospheric flux even at the levels of stellar activity encountered among dwarfs of the Hyades cluster.

Introduction

Ultraviolet spectra can provide information about conditions in the chromospheres and transition regions of late-type dwarf stars. Upon progressing to wavelengths shortward of 3000 Å the emission lines originating from those regions of the outer atmosphere become increasingly more prominent against a decreasing flux from the photosphere. Several studies[1,2,3] have shown that the far-ultraviolet (FUV) pass-band of the imaging system of the *GALEX* satellite produces a photometric magnitude that for F, G, and K dwarfs is very sensitive to chromospheric and transition-region (TR) emission and hence to stellar activity. That finding was made possible by combining *GALEX* photometry with large sets of measurements of chromospheric Ca II *H*+*K* emission or coronal soft-X-ray emission.

One of the earliest satellite observatories to obtain ultraviolet photometry of stars at wavelengths shortward of 3000 Å was the *Astronomical Netherlands Satellite*[4] (*ANS*). A discussion of *ANS* photometry of main-sequence stars was given by Wesselius *et al.*[5], with an emphasis on the relationships between ultraviolet colours and photospheric parameters such as effective temperature. By contrast, the aim of this paper is to study whether *ANS* photometry in the case of G dwarfs is sensitive to stellar activity. Admittedly that question stems partly from historical curiosity, but there is some scientific merit to it. The *GALEX* photometric system[6] has two bandpasses[7], NUV (1650–3000 Å) and FUV (1350–1800 Å), both of them fairly broad in wavelength coverage. By contrast, the *ANS* system has five channels over a comparable wavelength range with band-passes of 100–200 Å, thereby allowing better definition of the wavelength domain over which chromospheric and TR emission is significant relative to photospheric flux.

The sample of stars

The *ANS* orbiting observatory carried an ultraviolet experiment package that made measurements of stellar brightness by use of a grating spectrophotometer that transmitted dispersed light to five photomultiplier tubes[4]. The five resulting channels have central wavelengths (and six band-passes) of 1549 (50, 149), 1799 (149), 2200 (200), 2493 (150), and 3294 (101) Å. There is consequently no overlap in wavelength between the band-passes of the five channels, which are denoted herein as *C*15, *C*18, *C*22, *C*25, and *C*33. In the case of the G stars considered in this paper there is much less data for the *C*15 band than for the other *ANS* band-passes, and the measurements have higher uncertainty. Consequently the *C*15 band is not employed in this work.

Wesselius *et al.*[8] published the basic catalogue of *ANS* stellar photometry. Dwarfs of G and K spectral type form a modest fraction of the stars in their compilation, which is dominated by hotter stars of types O, B, and A. Quite a few of the F, G, K dwarfs with *ANS* photometry are included in the catalogue of main-sequence stars for which Hünsch, Schmitt & Voges[9] derived soft-X-ray luminosities L_x from observations made by the *ROSAT* satellite. Using the distances given in Hünsch *et al.*[9], which are based on *Hipparcos* parallaxes[10,11], their values of L_x have been normalized to the bolometric luminosity L_{bol} of each star. Bolometric corrections were based on the stellar $(B - V)$ colour and are on the calibration scale of Flower[12].

An additional source of values of (L_x/L_{bol}) for late-type dwarfs observed by *ANS* is the paper of Piters *et al.*[13]. Their sample of stars overlaps that of Hünsch *et al.*[9], and a least-squares fit to the data for those dwarfs in common between the two papers has the equation:

$$\log(L_x/L_{bol}) = 0{\cdot}034 + 1{\cdot}027\, R_x, \qquad (1)$$

where R_x is the normalized X-ray luminosity from Piters *et al.*[13] and (L_x/L_{bol}) refers to the ratios derived here from the Hünsch *et al.*[9] data. The standard deviation in the derived slope of equation (1) is 0·044. Two stars, HD 142860 and HD 81997, have been excluded from the fit on account of deviating from equation (1) by ~ 0·4 in $\log(L_x/L_{bol})$, whereas the typical dispersion is 0·1 or less for the 11 stars on which equation (1) is based. Since the two sets of *ROSAT* observations were acquired at different times there may be some variability contributing to this dispersion. Equation (1) has been used to transform values of R_x from Piters *et al.*[13] for a number of dwarfs with *ANS* data that are not included in the Hünsch *et al.*[9] catalogue. In practice the effect of equation (1) is not large; for example, a value of $R_x = -6{\cdot}00$ converts to −6·13 and $R_x = -4{\cdot}00$ transforms to −4·07.

A sample of F, G, and K dwarfs having both *ANS* photometry and (L_x/L_{bol}) determinations from *ROSAT* was thereby compiled. Johnson *UBV* photometry was taken from *The General Catalogue of Photometric Data*[14]. The *ANS* magnitudes from Wesselius *et al.*[8] were used to calculate three colours, denoted $C(25\text{–}33)$, $C(22\text{–}33)$, and $C(18\text{–}33)$, for use in this paper. No allowance is made for small amounts of interstellar reddening that might be foreground to the dwarfs in our joint *ANS–ROSAT* sample. Quite a few of the stars are members of the Hyades cluster, and as such their reddening is small[15]. Interstellar reddening ratios as derived from Table I of Wesselius *et al.*[8] are $E(25\text{–}33)/E(B-V) = 2{\cdot}0$, $E(22\text{–}33)/E(B-V) = 4{\cdot}6$, and $E(18\text{–}33)/E(B-V) = 2{\cdot}8$, such that in the case of Hyades cluster stars the likely reddenings are $E(25\text{–}33) \leq 0^{m}{\cdot}02$, $E(22\text{–}33) \leq 0^{m}{\cdot}05$, and $E(18\text{–}33) \leq 0^{m}{\cdot}03$.

Results

Three basic two-colour diagrams for the joint *ANS–ROSAT* sample are shown in Figs. 1 to 3, within which various *ANS*-based ultraviolet colours are plotted against $(B-V)$. In these three plots known members of the Hyades cluster are depicted as filled circles whereas open symbols are used for non-Hyades stars. Among the early-F to mid-F stars the ultraviolet colours correlate with $(B-V)$ quite well whereas increasing scatter is evident towards the G stars. Typical uncertainties in the $C(25\text{–}33)$ and $C(22\text{–}33)$ values are $0^{m}{\cdot}01$ to $0^{m}{\cdot}03$ for the field dwarfs, and $0^{m}{\cdot}03$ to $0^{m}{\cdot}07$ for the Hyades dwarfs, based on the 1σ uncertainties listed in the Wesselius *et al.*[8] catalogue. The question of interest here is whether the scatter in *ANS* colours among the G stars at a fixed $(B-V)$ is driven by differences in photospheric flux (such as would accompany differences in metallicity, for example), or in the strengths of emission lines from the chromosphere and transition region.

In the following discussion attention is restricted to dwarf stars with Johnson colours in the range $0^{m}{\cdot}55 \leq (B-V) \leq 0^{m}{\cdot}67$ from the *ANS–ROSAT* sample. Relevant photometry is listed in Table I. Over this limited $(B-V)$ range we assume that variations in effective temperature cause the *ANS* colours $C(25\text{–}33)$ and $C(22\text{–}33)$, together with $(U-B)$, to vary linearly with $(B-V)$, other parameters such as metallicity and chromospheric activity being fixed. This seems to be a reasonable approximation given the locus of stars in Figs. 1 and 2. Reference lines matching the two-colour sequences for stars in Table I were chosen by eye from inspection of Figs. 1 and 2. They have the equations

TABLE I

ANS colours of dwarfs with $0^m{\cdot}55 \leq (B-V) \leq 0^m{\cdot}67$

HD	$(B-V)$	$(U-B)$	$\log(L_x/L_{bol})$	$C(18-33)$	$C(22-33)$	$C(25-33)$
			Field Dwarfs			
2151	0·618	0·106	−6·34	6·431	2·864	2·766
4614 [a]	0·572	0·015	−6·26	4·512	0·820	0·943
10307	0·616	0·113	−5·51	6·393	3·054	2·885
22484	0·574	0·062	−5·92	5·997	2·494	2·522
72905 [b]	0·618	0·070	−4·46	5·807	2·751	2·689
84737	0·609	0·140	−5·71	—	3·124	2·895
109358	0·585	0·046	−6·22	6·301	2·582	2·625
121370	0·580	0·200	−6·50	5·840	2·916	2·679
133640 [c]	0·650	0·107	−4·13	6·098	2·739	2·712
142373	0·557	0·010	−5·71	5·805	2·150	2·221
146233	0·651	0·174	−5·71	6·487	3·321	3·036
150680	0·644	0·211	−6·56	6·503	3·262	2·937
186408	0·645	0·187	−5·20	—	3·508	3·084
217014	0·665	0·224	−5·51	—	3·676	3·169
			Hyades Dwarfs			
27383	0·561	0·069	−4·78	4·785	2·184	2·282
27406 [b]	0·564	0·067	−4·75	5·178	2·471	2·453
27691	0·568	0·091	−4·58	4·810	2·292	2·364
27836 [b]	0·603	0·120	−4·04	—	2·609	2·562
28237	0·556	0·054	−4·57	—	2·377	2·353
28344 [b]	0·608	0·127	−4·63	—	2·840	2·696
28992 [b]	0·627	0·074	−4·45	—	2·915	2·831
29310 [b]	0·604	0·115	−4·60	—	2·665	2·640
30589	0·575	0·101	−4·99	5·643	2·752	2·685
30676	0·559	0·067	−4·74	4·823	2·219	2·284

[a] RS CVn variable; [b] BY Dra star; [c] W UMa star.

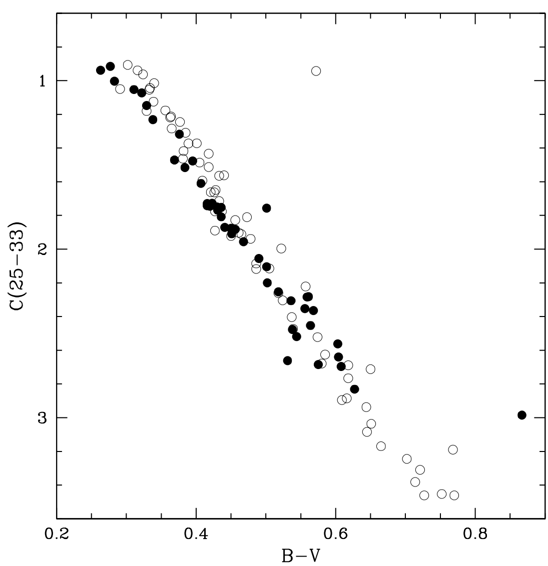

FIG. 1

The $C(25–33)$ colour derived from *ANS* photometry *versus* $(B-V)$ for dwarf stars in the *ANS–ROSAT* sample compiled for this paper. Filled circles: Hyades cluster stars; open circles: non-Hyades dwarfs. Typical uncertainties in $C(25–33)$ are $0^m{\cdot}01$–$0^m{\cdot}03$ for field dwarfs and $0^m{\cdot}03$–$0^m{\cdot}07$ for the plotted Hyades dwarfs.

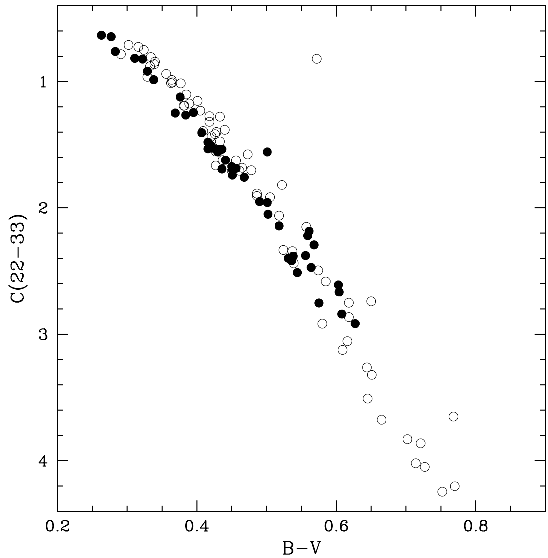

FIG. 2

The *ANS* colour C(22–33) *versus* ($B-V$) for dwarf stars with *ROSAT* observations. Filled circles: Hyades cluster stars; open circles: non-Hyades dwarfs. Typical uncertainties in C(22–33) are $0^m \cdot 01$ to $0^m \cdot 03$ for field dwarfs, and $0^m \cdot 03$ to $0^m \cdot 07$ for Hyades dwarfs.

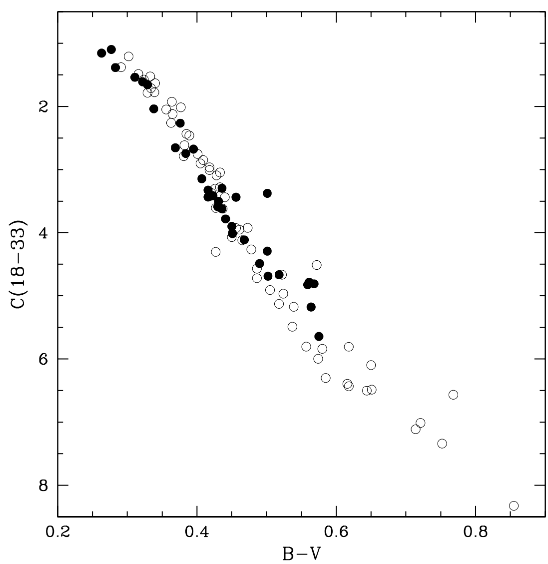

FIG. 3

The *ANS* colour C(18–33) *versus* ($B-V$) for dwarf stars with *ROSAT* observations. Filled circles: Hyades cluster stars; open circles: non-Hyades dwarfs.

$C(25–33)_r = 6·0(B-V) - 0·90$ and $C(22–33)_r = 10·0(B-V) - 3·10$. The dispersion of each star about these reference equations is represented by two parameters $\delta C(25–33) = C(25–33) - C(25–33)_r$ and $\delta C(22–33) = C(22–33) - C(22–33)_r$, where the value of the reference two-colour sequence is calculated at the $(B-V)$ of each star. In addition, the equation $(U-B)_r = (B-V) - 0·47$ gives a reasonable reference against which to define a colour residual $\delta(U-B) = (U-B) - (B-V)_r$ throughout the range $0^m·55 \leq (B-V) \leq 0^m·67$.

In Figs. 4 and 5 the $\delta C(25–33)$ and $\delta C(22–33)$ residuals are plotted *versus* $\delta(U-B)$ for the stars in Table I. Two notably variable dwarfs, the W UMa star HD 133640 and the RS CVn star HD 4614, are not shown in these figures. As in Figs. 1–3, filled and open symbols are used to denote Hyades cluster and field stars, respectively. Boxes refer to the known BY Dra variables in Table I. The $\delta C(22–33)$ residual shows a correlation with $\delta(U-B)$, but much less so the $\delta C(25–33)$ residual.

Among dwarfs with $(B-V) \sim 0^m·6$ the $(U-B)$ colour, often measured with respect to some fiducial such as the Hyades main sequence in a $(U-B, B-V)$ two-colour diagram, is well-documented to correlate with atomic-line blanketing of the photospheric spectrum[16,17], and hence with stellar metallicity[18,19,20]. The correlation between $\delta C(22–33)$ and $\delta(U-B)$ in Fig. 5 for early-G dwarfs therefore implies that the $C22$ passband of the *ANS* photometric system is largely measuring photospheric flux for such stars. Furthermore, it would seem that $\delta C(22–33)$ has the potential for use as a metallicity indicator for dwarf stars, and may be more sensitive to [Fe/H] than is the $(U-B)$ colour (albeit much harder to measure). Given that G dwarfs will have greater photospheric flux in the $C25$ band than in the $C22$ band it seems likely that the $C(25–33)$ colour of these stars is largely photospheric in nature as well. However, considerable scatter is evident in Fig. 4 rather than a clear trend. If stars are binned according to their $\delta(U-B)$ excess then a little more comes to light. Among the 12 stars with $\delta(U-B) < -0^m·01$ the mean value of $\delta C(25–33)$ is $-0^m·07$ with a standard deviation of $0^m·09$. By contrast, for the six stars with $\delta(U-B) > 0^m·0$ the mean and standard deviation in $\delta C(25–33)$ are $0^m·09$ and $0^m·06$, respectively. Thus, in the mean, stars with positive $\delta(U-B)$ have redder $C(25–33)$ colours but there is considerable scatter.

By contrast, the $C(18–33)$ colour seems to exhibit a different behaviour. In Fig. 6 it is plotted directly against $(U-B)$ for the stars in Table I, again excluding the variables HD 4614 and HD 133640, but including the BY Dra stars (boxes). A further subdivision by $(B-V)$ colour has been applied such that open and filled symbols now correspond to stars with $0^m·55 \leq (B-V) < 0^m·60$ and $0^m·60 \leq (B-V) \leq 0^m·67$, respectively, rather than to Hyades membership. There is little correlation between $C(18–33)$ and $(U-B)$ within each $(B-V)$ bin. In Fig. 7 the $C(18–33)$ colour is plotted directly against $\log(L_x/L_{bol})$ for the dwarfs from Table I. A trend is now evident in the sense that stars with the highest X-ray luminosities are attended by relatively blue $C(18–33)$ colours. This trend is most apparent among dwarfs with $(B-V)$ in the restricted range from $0^m·55$ to $0^m·60$, and stars in the two $(B-V)$ bins depicted may actually follow slightly different relationships. In other words, the relationship between $C(18–33)$ and $\log(L_x/L_{bol})$ may depend upon spectral type. The W UMa and RS CVn stars are again excluded from the figure, and in fact are discrepant from these trends. Although not included here, analogous plots of both $C(22–33)$ and $\delta C(22–33)$ *versus* $\log(L_x/L_{bol})$ for the dwarfs in Table I show no correlation. Our conclusion is that Fig. 7 provides evidence that the $C18$ band-pass of the *ANS* spectrophotometer is sensitive to stellar activity for a G dwarf, presumably as a result of including emission lines from the chromosphere and transition region.

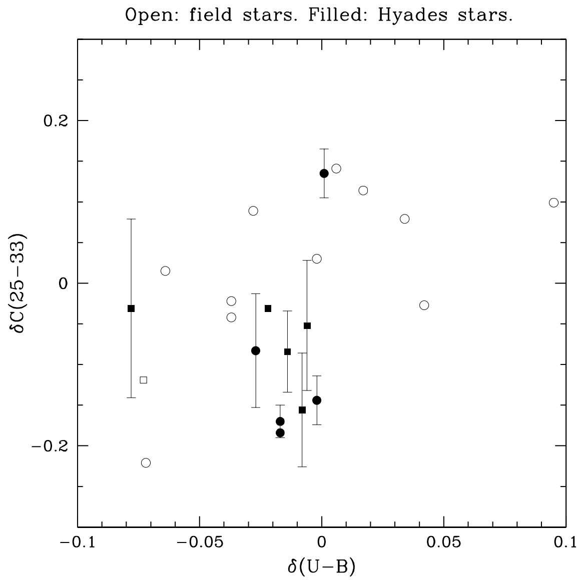

FIG. 4

ANS colour residual $\delta C(25–33)$ *versus* $\delta(U-B)$ for dwarf stars in the *ANS–ROSAT* sample from Table I. Error bars are shown for Hyades stars; for the field stars they are comparable in size to the points or slightly larger. Open symbols: field stars. Filled symbols: dwarfs in the Hyades cluster. Boxes: BY Dra stars. The W UMa star HD 133640 is not shown.

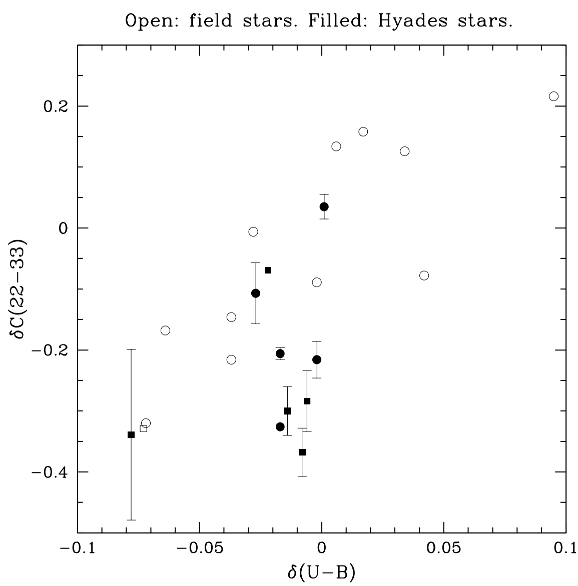

FIG. 5

ANS colour residual $\delta C(22–33)$ *versus* $\delta(U-B)$ for dwarf stars in the *ANS–ROSAT* sample from Table I. Error bars are shown for Hyades stars; for the field stars they are comparable in size to the points or slightly larger. Open symbols: field dwarfs. Filled symbols: Hyades dwarfs. Boxes: BY Dra stars. The W UMa star HD 133640 is not shown.

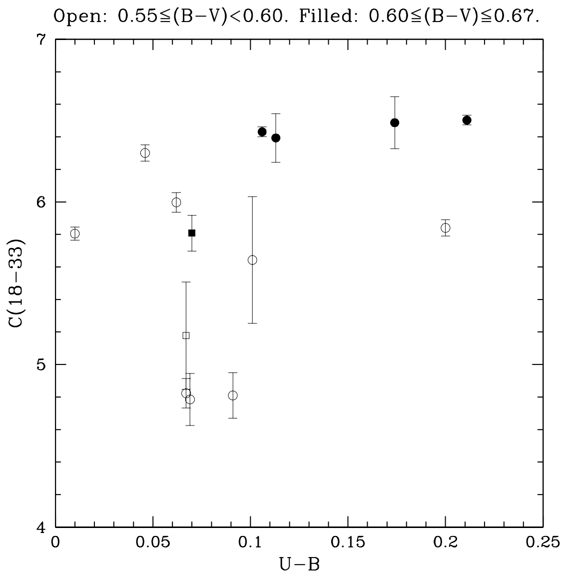

FIG. 6

The *ANS* colour $C(18\text{–}33)$ *versus* $(U - B)$ for dwarfs in the *ANS–ROSAT* sample from Table I. The W UMa star HD 133640 and the RS CVn star HD 4614 are not shown. Open symbols: $0^{\rm m}.55 \le (B - V) < 0^{\rm m}.60$. Filled symbols: $0^{\rm m}.60 \le (B - V) \le 0^{\rm m}.67$. Boxes: BY Dra stars.

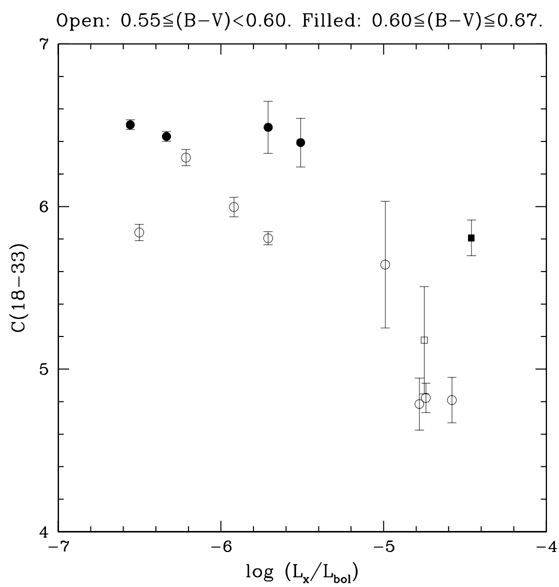

FIG. 7

The $C(18\text{–}33)$ colour *versus* normalized soft-X-ray luminosity for dwarf stars in the *ANS–ROSAT* sample from Table I. The W UMa star HD 133640 and the RS CVn star HD 4614 are not shown. Open symbols: $0^{\rm m}.55 \le (B - V) < 0^{\rm m}.60$. Filled symbols: $0^{\rm m}.60 \le (B - V) \le 0^{\rm m}.67$. Boxes: BY Dra stars.

It is evident from ultraviolet spectra of the Sun[21] and *IUE* spectra of G dwarfs that in the wavelength range 1700–2000 Å chromospheric and TR emission lines are present against the background of a residual photospheric spectrum (see figures in Haisch & Basri[21] and Ayres *et al.*[22], for example). McAllister[23] has studied this photospheric spectrum at high resolution over the wavelength range 1800 to 1970 Å in the case of the Sun. However, based on Figs. 6 and 7 it would appear that photometry centred around 1800 Å is also at least partially sensitive to stellar activity. Redward of 2100 Å the photospheric flux is dominating the *ANS* photometry and producing the correlation seen in Fig. 5. The $C18$ band of the *ANS* photometric system covers the wavelength range 1725–1875 Å, and as such it includes the λλ1808,1817 Si II emission lines which are prominent in the solar spectrum[24]. Spectra of Hyades G1 V dwarfs by Zolcinski *et al.*[25] show that those lines are superposed upon the ultraviolet tail of the photospheric flux, which has dropped to relatively low levels at 1600–1700 Å for dwarfs of G spectral type. At sufficiently high levels of activity among solar-type stars the Si II emission lines may become sufficiently strong to affect measurably the flux in the $C18$ band. In addition, active regions on the Sun have greater continuum emission in the FUV than quiet regions[26], while flare activity on both the Sun and cooler dwarf stars is associated with an enhanced FUV continuum[26–28]. Thus the correlation between the $C(18–33)$ colour and soft-X-ray flux seen in Figs. 6 and 7 for solar-type stars may be driven by several factors contributing to the flux in the $C18$ band.

The $C(18–33)$ colour will be sensitive to the photosphere of a G dwarf not only as a consequence of the low-level tail of the photospheric spectrum in the $C18$ band, but also because photospheric flux will dominate the $C33$ band. Consequently, in Fig. 3 there is a marked trend between $C(18–33)$ and $(B-V)$ among the G and K dwarfs, upon which scatter due to ultraviolet emission lines is superimposed. By limiting the range in $(B-V)$ among the dwarfs in Figs. 6 and 7 an attempt has been made to restrict the photosphere-induced differences in $C(18–33)$. As an additional approach a linear equation has been chosen to serve as a baseline to the data points in Fig. 3 for those dwarfs with $(B-V) \geq 0^{m}\cdot55$. This equation is $C(18–33)_b = 8\cdot00(B-V) + 1\cdot50$. Relative to this baseline a colour residual $\delta C(18–33) = C(18–33) - C(18–33)_b$ has been defined, where $C(18–33)_b$ is evaluated at the $(B-V)$ of a given star. To first order, $\delta C(18–33)$ is an effort to correct for photosphere-induced differences in $C(18–33)$ between early-G dwarfs.

There is no correlation between $\delta C(18–33)$ and $\delta(U-B)$, which are plotted in Fig. 8. In this diagram the points are codified on the basis of membership in the Hyades cluster. Subdividing the stars in Table I according to $\delta(U-B)$ also reveals no trend in the mean value of $\delta C(18–33)$. Among the 12 stars with $\delta(U-B) < -0^{m}\cdot01$ the mean value of $\delta C(18–33)$ is $-0^{m}\cdot44$, with a large scatter that has a standard deviation of $0^{m}\cdot52$. By contrast, for the ten stars with $\delta(U-B) > -0^{m}\cdot01$ the mean and standard deviation in $\delta C(18–33)$ are $-0^{m}\cdot47$ and $0^{m}\cdot44$, respectively. Thus the mean value of $\delta C(18–33)$ shows little, if any, correlation with the traditional $(U-B)$ excess.

A plot of $\delta C(18–33)$ *versus* $\log(L_x/L_{bol})$ for the stars of Table I is shown in Fig. 9. In addition, the small number of dwarfs redder than $(B-V) = 0^{m}\cdot67$ in our *ANS–ROSAT* sample have been added to Fig. 9 (as crosses). Among dwarfs with $\log(L_x/L_{bol}) < -5\cdot4$ there is little evidence of a correlation between $\delta C(18–33)$ and X-ray luminosity. However, at higher values of (L_x/L_{bol}), tracing higher levels of stellar activity, the $\delta C(18–33)$ residual becomes increasingly bluer. In fact, the few later-type stars in Fig. 9 show a similar behaviour to the

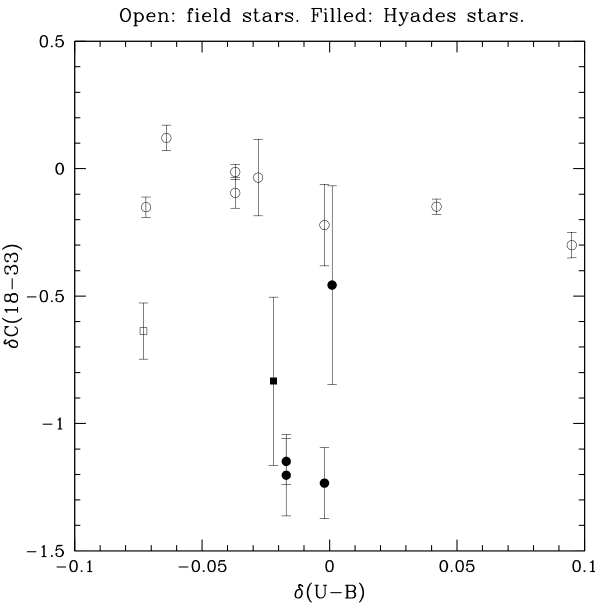

FIG. 8

ANS colour residual δC(18–33) *versus* $\delta(U-B)$ for dwarf stars in the *ANS–ROSAT* sample from Table I. Open symbols: field dwarfs. Filled symbols: Hyades dwarfs. Boxes: BY Dra stars. The W UMa star HD 133640 and the RS CVn star HD 4614 are not shown.

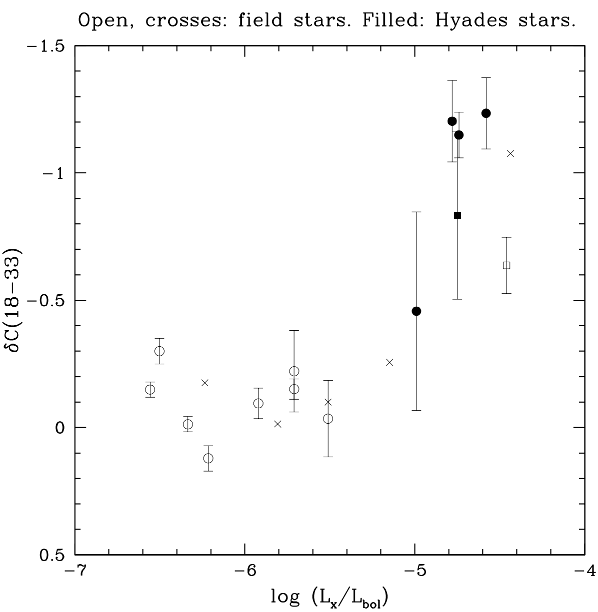

FIG. 9

The δC(18–33) colour excess *versus* soft-X-ray luminosity for dwarf stars in our *ANS–ROSAT* sample. The W UMa star HD 133640 and the RS CVn variable HD 4614 are not shown. Open symbols: field dwarfs. Filled symbols: Hyades cluster dwarfs. Boxes: BY Dra stars. Crosses: dwarfs redder than $(B-V) = 0^{m}\cdot67$.

early-G dwarfs. The *C*18 band would seem to display a correlation with (L_x/L_{bol}) once stellar activity exceeds a certain level, presumably when the emission lines and active-region continuum emission contained within the band-pass become sufficiently strong relative to the photospheric flux. This conclusion seems to be a robust property of our sample of G dwarfs, and independent of the two approaches taken to compensate for photospheric light contributing to the *C*(18–33) colour.

Conclusions

It has been shown in this paper that some of the earliest satellite far-ultraviolet photometry contains within it evidence that stellar activity can be discerned among G dwarfs when it is of a sufficiently high level. Since chromospheric and coronal activity are well documented to decline with the age of such stars, it may eventually be possible to calibrate far-ultraviolet colours like those pioneered by the *ANS* satellite against stellar age. The evidence of this paper is that for greatest sensitivity to chromospheric and TR emission lines a photometric band-pass that extends not much redward of 1800 Å would be optimal. As such, the FUV pass-band of the *GALEX* satellite (with an effective wavelength of 1520 Å and a FWHM bandwidth of 270 Å) would seem to be well suited to such an enterprise. By contrast, the *C*18 band-pass of the *ANS* satellite covers fewer emission lines and encompasses a wavelength region in which there is still photospheric flux. The *C*15 band-pass of the *ANS* observatory is better placed for that purpose than the *C*18 band, but the collecting area of the *ANS* telescope was too small to have made such photometry feasible for large numbers of G and K dwarfs.

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NOTES FROM OBSERVATORIES

THE 'POSSIBLE CEPHEIDS' DO ORI AND VY CMI ARE RR LYRAE VARIABLES

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We took a total of 432 *B*-, *V*-, and I_c-band CCD frames for DO Ori and VY CMi, which are classified as likely classical Cepheids in the *General Catalogue of Variable Stars* and found both DO Ori and VY CMi actually to be RR Lyrae-type variables with periods of $0^{d}{\cdot}41865$ and $0^{d}{\cdot}4634466$, respectively.

Introduction

Hoffmeister[1] found the star DO Ori (named 90·1929 Orionis in the original paper) to be variable and estimated its period to be $P = 6^{d}{\cdot}3435$ based on the then-recorded seven brightest maxima identified from 48 photographic observations, albeit pointing out the poor quality of the light-curve and low accuracy of photometric observations due to the faintness of the variable. The star was classified as a classical Cepheid in the *General Catalogue of Variable Stars* (*GCVS*)[2], most likely based on its period and low Galactic latitude ($b = -3^{\circ}{\cdot}61$). Because of the concerns expressed by Hoffmeister[1], the authors of the *GCVS*[2] did not consider their classification to be certain enough (the type of DO Ori in the catalogue is CEP:).

The variability of the star VY CMi (named 295·1928 Canis Min. in the original paper) was discovered by Hoffmeister[1,3] based on 48 photographic observations. Hoffmeister[1] found the period of its variations to be $P = 0^{d}{\cdot}47583$ based on the nine brightest maxima. However, the large scatter of the times of maxima prompted Hoffmeister to refine the period and find quite a different value of $P = 6^{d}{\cdot}460$, although doubts remained due to the faintness of the star and its position close to the plate boundary. The *GCVS* classifies the star, like DO Ori, as a classical Cepheid with some doubts (the *GCVS* type is CEP:). Berdnikov & Turner[4] performed ten photoelectric observations of the star in the $BV(RI)_c$ bands between 1995 March 27 and April 19 with the 60-cm reflector of the Cerro Tololo Inter-American Observatory equipped with the *ASCAP* pulse-counting photoelectric multiplier. The small number of observations did not allow a period search to be performed, although the *GCVS* period failed to produce a reasonable phased light-curve (see top left plot in Fig. 2 of the above paper). We included these stars in our programme of CCD observations of southern-hemisphere pulsating variables and here we present our results.

Observations

We performed our CCD observations in the period 2011 December to 2013 January (over the JD 2455901 – 2456320 time interval) for VY CMi and in 2013 November – 2014 January (over the JD 2456625 – 2456678 time interval) for DO Ori with the 76-cm telescope of the South African Astronomical

Observatory (SAAO) using an SBIG CCD ST-10XME camera equipped with BVI_c filters of the Kron–Cousins system[5].

We used the same reduction procedure as in our previous paper[6]. We first reduced only the observations made during photometric nights. On each such night we determined atmospheric extinction at two-to-three-hour intervals by observing two pairs of extinction stars (a red and a blue one) in succession: one pair was located near zenith, and another near air-mass ~ 2. We also computed the extra-atmospheric magnitudes of the extinction stars, which we then used to measure extinction based on observations of one of the two star pairs near the centre of the two-to-three-hour interval mentioned above. We used the following standard stars from E Region 5[7] as our extinction stars: E103, E166, E201, E238, E309, E372, E408, E4104, E566, E568, E607, and E673.

We also used the same measurements of the above standards to determine the transformation coefficients ζ and μ from extra-atmospheric magnitudes b, v, and i into magnitudes of the BVI_c system of Kron & Cousins[5]:

$$\begin{aligned} B &= b + \zeta_B\,(B-V) + \mu_B \\ V &= v + \zeta_{BV}\,(B-V) + \mu_{BV} \qquad (1) \\ V &= v + \zeta_{VI}\,(V-I)c + \mu_{VI} \\ I_c &= i\; + \zeta_I\,(V-I)c + \mu_I \qquad (2) \end{aligned}$$

We used the observations made during the best nights to determine the average coefficients $\zeta_B = 0{\cdot}0926 \pm 0{\cdot}0009$, $\zeta_{BV} = -0{\cdot}0485 \pm 0{\cdot}0007$, $\zeta_{VI} = -0{\cdot}0511 \pm 0{\cdot}0007$, and $\zeta_I = 0{\cdot}0050 \pm 0{\cdot}0006$, which we employed to determine the zero points μ for each night by formulae (1).

Transformation of instrumental magnitudes into the standard system requires several iterations. In the process of the first iteration the colour indices $B-V$ and $V-I_c$ are unknown and set equal to zero. After each iteration we compute the colour indices and stop the process once they change by less than $0^{\rm m}{\cdot}001$.

As a result of the reduction of the data for all photometric nights we obtained the catalogue of positions and magnitudes of all objects on the best CCD frames. We identified constant stars from this catalogue and used them as comparison stars for the differential photometry of all stars on all CCD frames including those taken on non-photometric nights, for which we made atmospheric corrections based on the average extinction coefficients: $\alpha_B = 0{\cdot}252 \pm 0{\cdot}021$, $\alpha_V = 0{\cdot}147 \pm 0{\cdot}014$, and $\alpha_I = 0{\cdot}083 \pm 0{\cdot}011$.

Results

We obtained a total of 432 CCD frames. We report our observations in a table (which is available in electronic form at the CDS *via* anonymous ftp to cdarc.u-strasbg.fr (130.79.128.5)). We found both stars to have short periods of $P_{\rm DO\ Ori} = 0^{\rm d}{\cdot}41865 \pm 0^{\rm d}{\cdot}00003$ and $P_{\rm VY\ CMi} = 0^{\rm d}{\cdot}4634478 \pm 0^{\rm d}{\cdot}0000004$. We show our light-curves for these stars in Figs. 1 and 2. Given the characteristic shape of the light-curves and the inferred periods, both stars can be classified as type ab RR Lyrae variables with much confidence. Note that the result for VY CMi is further reinforced by the Catalina Sky Survey[8] data (181 observations spanning the time period from 2005 April 3 to 2013 February 5, or JD 2453464 – 2456329) and observations by Berdnikov & Turner[4] mentioned above (we show the corresponding light curves in Figs. 3 and 4, respectively). The Catalina Sky Survey data allowed us to refine slightly the light elements of VY CMi. Although very small intrinsic scatter of our light-curves for both stars argues against the presence of the Blazhko effect, the more appreciable scatter in the

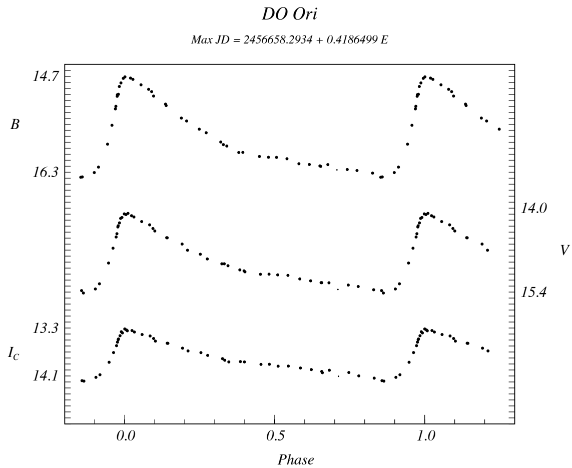

FIG. 1
The BVI_C light-curves of DO Ori.

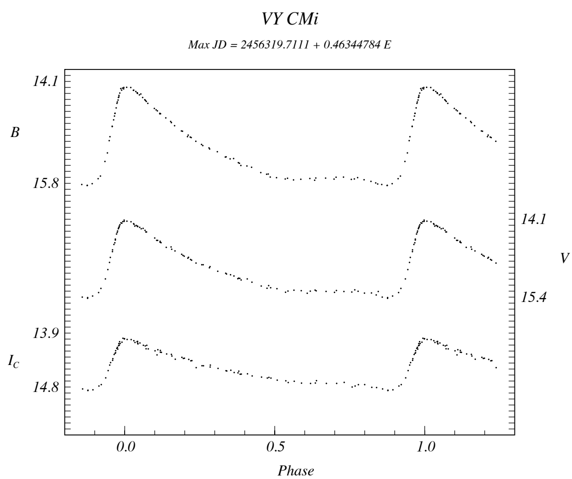

FIG. 2
The BVI_C light-curves of VY CMi.

Catalina Sky Survey light-curve for VY CMi, with the data spanning a much longer time interval (2865 days compared to 419 days for our observations), might actually be due to a weak Blazhko effect. We list the final light elements of the two variables in Table I.

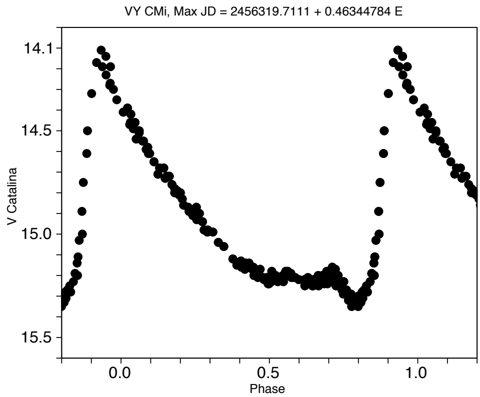

FIG. 3
The Catalina Sky Survey light-curve of VY CMi.

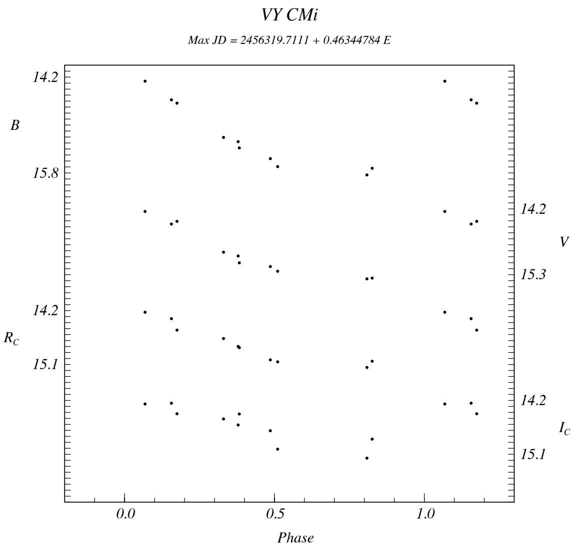

FIG. 4
The Berdnikov & Turner[4] $BV(RI)_C$ light-curves of VY CMi folded with the period of $P = 0^{d}{\cdot}46344784$.

TABLE I
Light elements of the two variables

Star	*Type of variability*	*Reference epoch*	*Period days*
DO Ori	RRab	2456658·2934 ± 0·0003	0·41865 ± 0·00003
VY CMi	RRab	2456329·9134 ± 0·0003	0·4634466 ± 0·0000004

Acknowledgments

This work was supported by the Russian Foundation for Basic Research (grant no. 13-02-00203-a) and the National Research Foundation of South Africa. We are grateful to the administration of SAAO for their hospitality and for allocating much observing time. The CSS survey is funded by the National Aeronautics and Space Administration under Grant No. NNG05GF22G issued through the Science Mission Directorate Near-Earth Objects Observations Program. The CRTS survey is supported by the U.S. National Science Foundation under grants AST-0909182 and AST-1313422.

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CORRESPONDENCE

To the Editors of 'The Observatory'

Revisiting the Colour of Saturn as Perceived in Antiquity

Intrigued by the discovery of the enormous Phoebe dust-ring around Saturn in 2009, we published a letter in *The Observatory* wondering whether this might throw light on two longstanding questions of ancient astronomy concerning the planet[1].One is the mystery of why the ancient Babylonians and Assyrians, followed by the Hindus and Greeks, called the planet Saturn 'black' in their lists of standard planetary colours[2]. As *all* the other colours in those lists are naturalistic (*e.g.*, red for Mars, white for Jupiter), a similar explanation is to be expected for Saturn. We wondered whether the Phoebe Ring may have been visible from the Earth at some time in antiquity. If so, that would have meant that Saturn was perceived as a large black space delineated by the Ring. That might also help resolve the second problem surrounding the ancient descriptions of the planet. Babylonian astrologers, again echoed in the Graeco-Roman and Hindu worlds, routinely compared it to, or even identified it with, the Sun — as in the Babylonian description of the planet as 'the Sun of Night'. The Phoebe Ring, *if* visible, would have appeared larger than the Moon, making Saturn a plausible nocturnal counterpart to the Sun.

Our hope was that an interested astrophysicist might be able to verify or refute through calculation whether the amount of dust in the Phoebe ring could feasibly have been much greater in antiquity (through cometary or other activity) — to the degree that it would once have been visible to the naked eye. Unfortunately we received little feedback here, but we were delighted with an important lead provided by the late Richard Stothers (Goddard Institute for Space Studies) in correspondence and then in a letter published in these pages[3]. While not rejecting the Phoebe Ring possibility, Stothers suggested that the perceived 'blackness' of Saturn may rather have arisen from its appearance in heliacal positions: "A rather faint object like Saturn (two magnitudes fainter than the brightest star Sirius) appears dim gray when seen through the thick layers of the atmosphere near the horizon. This is because the human eye cannot distinguish colours at low light levels."

Stothers was correct in stressing the importance to the Babylonians of how astronomical bodies appeared at their heliacal risings. Pursuing his suggestion further, we approached the problem of Saturn's 'black' colour from a lexical angle. It transpires that in the two principal languages of ancient Mesopotamia — Sumerian and Akkadian — there was no word for the colour grey. (As an amusing sidelight to show that 'ivory tower academics' are not an extinct species, we received a response from a cuneiform correspondent — who will remain anonymous — stating that the Sumerians needed no word for grey, as there is nothing grey in nature. What, then, of rocks, pigeons, the British summer sky, *etc.*?) It is a reasonable inference that in some cases at least the ancient Mesopotamians would have filled that semantic gap by using the closest available term, 'black', which is also acknowledged to cover the meaning 'dark'. We supported this by collecting instances where other planets and phenomena such as haloes are described as 'black'. This can only conceivably mean 'grey' or 'dark', otherwise such features would have been invisible. We have now published the evidence in an extensive article in a journal of Ancient Near-Eastern studies[4], which reviews all the other possible explanations for Saturn's 'blackness': our conclusion is that its heliacal appearance as grey is the only likely one.

Surprisingly, the expected characterization of Saturn as 'yellow' does not appear to go back any earlier than Plato (4th Century BC). Babylonian testimony for Saturn's colour seems to be restricted to 'black' (= grey/dark) and, on one occasion, 'red or white' — but no text refers to it as yellow. Stothers' suggestion of heliacal colours inspires an explanation which also accounts for the Babylonian description of Venus as blue–green instead of white: higher dust levels in the Earth's atmosphere in antiquity (from volcanic activity and cometary dusting) may have meant that the planets exhibited such 'heliacal' colours more frequently, even at higher altitudes. Palaeoclimatologists may be able to determine whether this suspicion is feasible or not.

Our paper also tackles the related question of the paradoxical association of the obscure and 'black' planet Saturn with the Sun. Following an exhaustive review of previously suggested explanations, the only one that seemed really plausible was that Saturn impressed the ancients with its steady course, more stable and regular than that observed for the other planets. Steadiness and reliability, of course, were characteristics of the Sun-god, who shared the soubriquet *Kayamānu* ("the steady one") with the planet Saturn. This is reinforced by an overlooked datum: the synodic period of Saturn is 378·1 days, which is the closest of all the planets to the length of the solar year. The Babylonians measured synodic periods and fairly approximated Saturn's as 380 days. Before the advent of Greek astronomy, with its introduction of circular orbits, the synodic periods of planets were considered to be of great importance and were duly observed and noted: indeed, ancient Babylonian (and almost certainly Egyptian) knowledge of planetary synodic periods was essential for the

Greek scientists of the 4th Century BC — such as Eudoxus — who were trying to determine the planets' orbital periods.

The conclusions regarding Saturn lead to some conjectures on earlier developments in pre-mathematical astronomy. The identification of Saturn as a nocturnal Sun seems to be a relatively early one, posed as an answer to the primitive question of where the Sun goes when it disappears from the sky at night. One answer, evident from sources such as the *Epic of Gilgameš*, seems to have been that the Sun travelled through a tunnel or the Netherworld before it rose again[5]. An alternative idea seems to have been that the Sun continued to travel in the night sky, but as Saturn. That is consistent with a hymn in which the Sun-god Šamaš is said to "remain sleepless, you who come by day and return by night". (How the Babylonians envisaged the Sun-god returning to the east to rise again remains unclear.) Such a concept must clearly have arisen after 'midnight' planets were distinguished from the stars, a development that seems not in evidence before the 2nd Millennium BC. It certainly also predates *c.* 1000 BC, by when the Babylonians had developed the concept of seven 'planets' (Jupiter, Saturn, Mars, Venus, Mercury, Moon, and Sun) as a set of bodies that moved counter to the fixed stars along the same 'path', the ecliptic. In that grouping, the Sun is physically distinct from Saturn.

Once the latter step had been made, it would seem that the idea of Saturn's solar identity was gradually removed from the realm of practical observational astronomy. The archaic linkage of Saturn and Sun was then necessarily relegated to astrology *per se*. It survived in classical and Hindu astrology, a vestigial, yet important and ancient artefact of a rudimentary stage in the history of planetary astronomy.

Our paper[4] *Saturn as the 'Sun of Night' in Ancient Near Eastern Tradition* is dedicated to the memory of Richard Stothers (1939–2011), a true interdisciplinarian, whose contributions to puzzles in the history of astronomy have been invaluable.

Yours faithfully,

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REVIEWS

Faraday, Maxwell, and the Electromagnetic Field: How Two Men Revolutionized Physics, by N. Forbes & B. Mahon (Prometheus, Amherst), 2014. Pp. 300, 21 × 14 cm. Price $25·95 (about £16) (hardbound; ISBN 978 1 61614 942 0).

Faraday and Maxwell are two of the most attractive personalities in the history of science and their life stories are inspirational for any budding scientist. They also happened both to be geniuses. This delightful book by two authors who have in-depth knowledge of their chosen subject can safely be put into the hands of anyone who wants to understand what those giants actually did and why it was so important, without the necessity of having a technical background in physics and mathematics.

Faraday and Maxwell could not have come from more different backgrounds: Faraday from a simple English working-class background, Maxwell from the Scottish landed gentry. Neither was expected to become pre-eminent in the sciences and yet both of them had the insatiable curiosity which is a prerequisite for success in research in the sciences. In both cases, their interests spanned the whole of the sciences. Where they came together was in their complementary activities in the understanding of the phenomena of electromagnetism.

Faraday's extraordinary experimental skills, uninformed by any mathematics at all, resulted in the discovery of electromagnetic induction and placed the subject on a secure experimental basis. In addition, he invented its visualization in terms of magnetic lines of force, which was vital for Maxwell's mathematization of the laws of electromagnetism. Faraday was meticulous as an experimenter with remarkable powers of observation. In his laboratory at the Royal Institution he had about him all the materials to undertake investigations very quickly and this enabled him to carry out a huge numbers of speculative experiments, in the process discovering new phenomena. He was exactly the right person in the right place at the right time. His *Experimental Researches in Electricity* recorded faithfully and in detail all the electrical experiments he carried out in the Laboratory, interpreted in terms of lines of force.

Maxwell recalled in the preface to his great *Treatise on Electricity and Magnetism* of 1873, "... before I began the study of electricity, I resolved to read no mathematics on the subject till I had first read through Faraday's *Experimental Researches in Electricity*." Maxwell had the mathematical equipment with which to convert the concept of lines of force into the theory of electric and magnetic fields. The discovery of the displacement current came out of the visualization provided by a purely mechanical model of electromagnetic forces, which the present authors explain in some detail. There is no doubt that the introduction of the concept of fields was a key insight for the whole of physics. It infused not only electricity and magnetism but also the interactions between particles in the kinetic theory of gases. Following the results of his viscosity experiments, he demonstrated that, in order to account for the temperature dependence of the viscosity, particles could be abolished and replaced by centres of fields of force. And yet, Maxwell's thinking was rooted in Newtonian mechanics and he constantly sought mechanical illustrations to guide the thinking of non-experts. Two lovely examples are his gear and governor mechanism to illustrate the process of electromagnetic induction and his mechanical model to illustrate the motions of the particulate bodies which he showed must make up Saturn's rings.

This story of electromagnetism, its origins and consequences are very nicely described by Forbes & Mahon without any mathematical apparatus. One or two additional points could be made about Faraday's and Maxwell's achievements. First of all, both were experts across the whole of natural philosophy, what we now call physics. Faraday was primarily a chemist and his works in these areas were influential and of practical benefit. Maxwell carried out simultaneously researches in thermodynamics, statistical mechanics, the theory of colour vision, the mathematics of knots, the strength of structures, and so on. The second lesson, particularly for young people, is that both Faraday and Maxwell were totally absorbed in what they were doing. Without that total absorption, dedication, and serious hard work, it is not possible to take any research discipline to a new level. Third, we can recognize now that Maxwell got electromagnetism right, but at the time his was only one of a number of possible theories. In the same way, his work on the kinetic theory, although correct for monatomic gases, could not explain the ratios of specific-heat capacities for the more common gases such as oxygen and nitrogen. His distinguished colleagues were right to be cautious until the correctness of his insights into electromagnetism were confirmed by the experiments of Hertz eight years after Maxwell's death. Similarly, the effects of quantization had to be taken into account in estimating the specific-heat capacities of molecular gases — but this was only understood first by Einstein in 1905–6.

So, an excellent book for the non-specialist and an ideal gift for young people wanting to understand the excitement of scientific discovery. — MALCOLM LONGAIR.

The Perfect Theory: A Century of Geniuses and the Battle over General Relativity, by Pedro G. Ferreira (Houghton Mifflin Harcourt, Boston), 2014. Pp. 304, 22·5 × 15 cm. Price \$22·40 (about £13) (hardbound; ISBN 978 0 547 55489 1).

The author, a professor of astrophysics at the University of Oxford, calls his book "the biography of general relativity", which is an apt description. While the various chapters of this biography, the applications and further development of GR, have of course been told elsewhere, the emphasis on GR from its formulation by Einstein up to present-day research makes for a coherent read, as opposed to collecting the information from various sources (*e.g.*, books on cosmology, neutron stars, quantum gravity, *etc.*) written at different levels and for different readerships. The book manages to cover all the essential ground, both before and after the death of Einstein, without being too long; this is possible because essentially only GR is discussed — neither, beyond what is absolutely necessary, special relativity (let alone other work by Einstein) nor the contexts of the various applications and developments of GR. (This does mean that Mach's Principle isn't mentioned except for a note saying that it won't be mentioned; this might seem strange at first but a superficial discussion wouldn't have added enough to be useful and a detailed discussion of this and similar tangential matters would have made the book too long and parts of it too detailed and too difficult compared with the rest of it.)

After a personal prologue, fourteen chapters describe various aspects and applications of GR. The chapters concentrate almost exclusively on a clearly defined topic but at the same time the main narrative is essentially chronological, a reflection of the fact that one area at a time tended to dominate research in GR, especially up until about 1970. It is worth mentioning the main themes of each chapter explicitly: Einstein's work before his move to Prague; the formulation of GR, the 1919 eclipse expeditions; the expanding Universe; collapsing and compact stars; the period when work on GR took a back seat to other developments, the influence of politics on science, Einstein's later years; the demise of the steady-state theory; renewed interest in GR both observational (QSOs, pulsars, CMB) and theoretical (the first phase of quantum-gravity research); singularities; unified-field theories, Hawking radiation; gravitational waves; observational cosmology; black-hole information paradox, string theory, loop quantum gravity; modified gravity; the Milky Way's central black hole, new and planned observational programmes. The last chapter also provides a personal note, linking back to the prologue.

Although I was already familiar with most of the story, it was still enjoyable to read it again as a coherent narrative. Many anecdotes I had encountered before, but the end-notes give sources for almost all of them, occasionally providing names for often anonymous characters such as Ludwik Silberstein. The major players in the field are fleshed out with interesting biographical details: Einstein, de Sitter, Friedmann, Lemaître, Eddington, Oppenheimer, Wheeler, DeWitt, Penrose, Hawking, Bekenstein, *et al.* Where necessary, more information is given. For example, although the story of Hoyle's BBC broadcasts and pejorative use of his coined term "big bang" are well known, more detail is provided about the background: Hoyle's use of that platform deliberately to present to the public the steady-state theory as conventional and GR-based models as radical alternatives.

There are few typographical errors and no serious ones. Experts might trip over a couple of passages which read as something other than the author intended, certainly small goofs in what otherwise appears to have been good editing, but they are few and far between. The common mistake of describing Lemaître as a Jesuit, even though he wasn't[1], is repeated (see ref. 2 for a description of another recent occurrence of this error in an otherwise very good book), though another common mistake is avoided: Wheeler is correctly described as having popularized, not coined, the term "black hole".

There are no illustrations, but neither are any necessary. Although I generally like footnotes, I wasn't bothered by the fact that this book has none. At the end of the book the author mentions web sites which will allow the reader to access many of the references in the book; most readers are probably not at an academic institution which would allow direct access to the officially published papers and most are probably not aware of arXiv, ADS, Spires, Google Scholar, *etc.* This is followed by detailed notes for each chapter: after briefly discussing some books and web pages which provide more detail on the chapter in question, sources are provided for direct quotations and some other information, introduced by a short quote or description as there are no end-note numbers in the text. Some of the sources are interviews with the protagonists. I think the end-notes (more than 18 pages of small and very small print) are a good choice for this book: none of the end-note material is essential for following the main text, but it is all there for the reader who wants more details. The list of references takes up 12 pages of very small print and includes both technical and popular works; this is an enormous amount of detail for a book such as this and an excellent resource. It is divided into a list of books and a list of articles. The former includes many more than those discussed in the end-notes and I will certainly read at least some of those which I haven't yet read. Any list of books which follows DeWitt-Morette with Dickens and Peebles with Proust has to be worth investigating further. Although a list of just books is handy for making a shopping list, if I wasn't familiar with a reference I often had to look in both lists in order to find it. Eighteen pages of very small print for the index are also much more than one would expect and improves an already excellent book.

It would be hard to find someone even remotely interested in General Relativity, astrophysics, cosmology, or the recent history of science who would not enjoy reading this book. Even though much might be familiar to some, the story of GR is well told, the whole is more than the sum of the parts, and many will learn something new. — PHILLIP HELBIG.

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How Einstein Created Relativity out of Physics and Astronomy, by D. R. Topper (Springer, Heidelberg), 2014. Pp. 254, 24 × 16 cm. Price £90/$129/€106·95 (hardbound; ISBN 978 1 4614 4781 8).

Does this book add something to our knowledge of Einstein and the theory of relativity that has not already been said in the plethora of books on the same subject? Well, Einstein and relativity are such fascinating subjects that one should keep an open mind.

I did not start my reading on page one, but went straight to the subject I thought to be of greatest interest to astronomers: Part IV, 'Cosmology'. It begins with a very conventional historic overview, starting with Aristoteles, but containing no new information, nor original angles of view. On the other hand I was astonished about several remarkable omissions; thus, in his history of the discovery of nebulae Topper talks of Galileo, but mentions neither Simon Marius nor even Kant or Laplace who introduced the concept later known as island universes. Einstein's paper of 1917 is introduced in the same conventional vein.

The author then continues with 'Three challenges to Einstein's cosmic model'. The first of these challenges came from de Sitter. Topper writes about de Sitter's alternative to Einstein's universe: "Since so much of the universe is empty space, with matter scattered throughout, he applied Einstein's cosmological equation, without the λ, to a matter-free universe and found that it was stable". Topper does not give a citation to de Sitter's paper, which he most probably never read, otherwise he could not have written such a preposterous statement. De Sitter's paper was published in the *Monthly Notices*, **78**, 3, 1917, and it included the cosmological constant, λ, which is related to R, the constant radius of de Sitter's universe, by the relationship $\lambda = 3/R$. Let us proceed to the second challenge. It comes from Friedmann, who gets only marginally better treatment: "His results, however, did show that by eliminating the cosmological constant the equation revealed a logically possible model, albeit still unstable". That statement gives the impression that Friedmann had eliminated λ in order to obtain a "logically possible model". However, just as de Sitter in 1917, Friedman in 1922 had kept λ in his considerations. He discussed several solutions for various values of λ, among them also one for $\lambda = 0$.

After de Sitter and Friedmann, Topper hits an absolute low with Lemaître. Lemaître and Eddington were those lonely figures who valiantly defended the cosmological constant even after Einstein and de Sitter had renounced it in 1931 and 1932. About this Lemaître, Topper writes: "In 1927 the Belgian physicist and Jesuit priest Georges Lemaître, unaware of Friedmann's work, also eliminated Einstein's constant and showed that the resulting model implied a continually expanding universe, an expansion that began from Einstein's initial static model". Quite apart from the fact that Lemaître was not a Jesuit, Topper evidently has never looked into Lemaître's paper of 1927. Indeed, Topper affixes to the above statement a reference to Kragh & Smith (2003); needless to say, their text does not contain such gross misrepresentations.

The book then jumps to the period after Hubble's publication of the observationally determined linear velocity–distance relation $v = \mathrm{H}\cdot r$. In 1932 January and February Einstein visited Pasadena. Topper claims: "On the cosmological deduction of the theory, the key person was Hubble along with Humason, …", and "Two months with Hubble were enough to pry him loose from his attachment to the cosmological constant". To the uninitiated this conveys a completely distorted picture. The interviews of Einstein with *The New York Times* and the *Los Angeles Times* during those two months clearly show that on his arrival in Pasadena Einstein already knew that his static universe had become untenable. It was Eddington who, in the 1930 May *Monthly Notices*, had delivered the proof and which he certainly discussed with Einstein when the latter visited Eddington in 1930 June. Thus, it was a theoretical argument that shook Einstein's belief in his static universe. It was certainly helpful for Eddington that he could point to Hubble's publication of 1929 which made it clear that the Universe was dynamic and not static. Topper mentions Hubble as the key person for Einstein to talk to about theoretical cosmology. Where is the evidence for such a claim? For Einstein the cosmological key person in Pasadena was Tolman; Einstein's diary and letters provide the evidence, whereas Hubble is not even mentioned in Einstein's diary of those two months.

The rest of the chapter on cosmology is written in the same vein as the introduction: recounting events about which we have already read a dozen times in other publications without adding new colours.

After so many basic blunders I lost all appetite to read the other chapters of the book; I then simply scanned diagonally through the book. It is striking, how often the author falls back on secondary information and does not bother to study the primary sources. This leaves me with the impression that the author mainly consulted secondary sources, and that some of them he seriously misquoted. I cannot see any readership that could benefit from this book. — HARRY NUSSBAUMER.

In Search of the True Universe: The Tools, Shaping, and Cost of Cosmological Thought, by M. Harwit (Cambridge University Press), 2014. Pp. 393, 25·5 × 18 cm. Price £35/$50 (hardbound; ISBN 978 1 107 04406 7).

After a short introductory chapter on the state of physics at the end of the 19th Century, the rest of the book is divided into three parts, with titles which are longer and more precise versions of 'tools', 'shaping', and 'cost'. The first two contain chapters which are more or less straightforward accounts of events in cosmology or astrophysics; one of them, the development of cosmological models between about 1915 and 1935, has featured in other recent reviews in this *Magazine*. These essentially self-contained historical chapters serve as examples discussed in the remaining chapters in the book, which are mostly concerned with the sociology and politics of astrophysics in the 20th and early 21st Centuries. The book as a whole is thus somewhat difficult to summarize, though the Epilogue is essentially a one-page summary of the sociological and political aspects. The title of the book is somewhat misleading, since the scope is broader than just cosmology, encompassing much of astrophysics and astronomy as well (or else "cosmological" is used in a very broad sense; in the text, "astrophysics" is usually used to denote the subject of the book).

The focus is mainly on the United States, though of course Europeans such as Einstein, Eddington, and Hoyle feature prominently in the historical sections. As someone who has had a distinguished career as an astronomer, served on more and higher-level committees than most of his colleagues, and been the director of the Smithsonian Institution's National Air and Space Museum, Harwit is well qualified to write a book such as this which discusses not only the history of science in some detail, but also the surrounding sociological and political framework. Many events are described from his personal, behind-the-scenes perspective.

An important theme which occurs in several chapters is, in general, the influence of the military on astronomy and, in particular, the radical change in the way astronomy has been organized and funded since World War II (to a large extent as outlined in Vannevar Bush's *Science — The Endless Frontier*); not only did astronomy make use of military technologies but also it became much more influenced by and dependent on the state. Although this fact is nothing new, the number of examples underlines just how big this change was. An example often used is the Great Observatories programme (the *Compton Gamma Ray Observatory*, the *Advanced X-ray Astrophysics Facility* (later renamed the *Chandra X-ray Observatory*), the *Hubble Space Telescope*, and the *Space Infrared Telescope Facility* (later renamed the *Spitzer Space Telescope*)). In recent times, however, owing to the end of the Cold War, at least a perceived lack of funds, and the fact that many of the main topics in current cosmology (such as dark energy, dark matter, and the early Universe) seem impractical even to far-sighted (or, alternatively, naïve) military strategists, the pendulum is swinging back somewhat, with benefactors such as the Keck foundation and Microsoft co-founder Paul Allen playing roles similar to that of Hooker in the first half of the 20th Century. (Even an obviously practical enterprise such as monitoring potentially dangerous near-Earth asteroids is in the hands of the private Sentinel project, despite Congress passing the Near-Earth Object Survey Act which instructed NASA to do so.)

Another recurring theme is network theory, illustrated with examples from various committees (down to the time of day of various memos), again often using the Great Observatories as an example, and from the astrophysical community as a whole. A third theme is the question as to what extent our view of the Universe is determined by external constraints such as available technology, political goals, *etc.*

Obviously, these are very great influences, but fortunately Harwit doesn't make the mistake of concluding that our theories of the Universe are nothing more than social constructs. A book such as this can hardly avoid mentioning Thomas Kuhn and his idea that change in science is primarily due to paradigm shifts originating more with scientists than with that which they study, but Harwit is appropriately critical, noting that cascades (in the sense of sudden large changes in networks) can have a variety of causes, not all of which qualify as revolutions in the sense of Kuhn (who sees essentially all major changes — even those caused by obviously external events such as the discoveries of X-rays and radioactivity — as human-driven paradigm shifts having little to do with objective reality). Although he doesn't call it that, Harwit's view is essentially what I like to call a no-hair theorem for science: even though the order, details, influence, and perceived importance of events in the history of science obviously depend on the contingent history of humans, as a theory matures it eventually attains a state which is essentially independent of how it came to be. A fourth theme, especially towards the end of the book, is the fact that short-term frugality carries the danger that the huge amount of observational data might not be usable in just a few decades. With time-scales ranging from the length of a student's thesis through decadal reviews to at most the working life of an astronomer, often not enough thought is given to the preservation of data for posterity, due not just to tight funding but also to the fact the this problem is often overlooked.

One area not explored in the book, but which obviously influences the way astrophysics is done, is the funding structure for non-permanent (or not-yet-permanent) scientists who do much of the work but are even more influenced by sociological and, especially, political events than tenured astronomers. Similarly, although Harwit discusses relatively modern institutions such as arXiv and even Wikipedia, he doesn't mention the recent heated discussion about the cost of traditional journals, though this is quite relevant to his themes of funding, sociology, politics, and networks.

The book contains a few photographs (all of people) and diagrams; all are black and white but this is sufficient. (About half of the diagrams are related to the discussion of networks.) Overall, the layout and appearance are superb. References, denoted by numbers, are given at the end of each chapter; explanatory footnotes, denoted by letters, are at the bottom of the page. This is the way it should be done! The frequency of typographical errors is about average. Most are harmless, though anyone needing to look up the photon wavelength corresponding to 1 GeV (in a table in the appendix) or the definition of redshift (in the glossary) will be confused by the incorrect definitions. The twelve-page glossary will be useful for some readers, though of course opinions will always vary concerning which terms should be included. The glossary is not always up to the high level of the rest of the book (where I spotted no severe factual errors, though a few concepts, perhaps because of too-quick editing, are presented at least confusingly); for example, the definition of 'planet' applies just to our Solar System, though extrasolar planets are discussed in the text. Terms which appear in the glossary are italicized at their first appearance in the main text, though since italics are used for other purposes as well, some other indication would have been better. In some cases, it is not clear if Harwit is emphasizing a word which I wouldn't, or whether the term was meant to be included in the glossary but was left out. There is a nine-page index; a few times I expected to find something in the index but found that the page in question was not referenced or that the topic wasn't there at all. (Also, I occasionally expected to find a reference for something quite specific mentioned in the text but didn't.) Again, what to include is to some extent a matter of taste, but I think the index could have been somewhat more comprehensive. Though I have lost no pages, the glue holding the pages to the binding in my well-treated copy hasn't prevented the back cover from becoming partially detached; hopefully this is an isolated problem and doesn't affect a significant fraction of the printing.

My few complaints are minor and involve mostly technical matters of production. The book is well written, presents some familiar themes in a new light as well as some ideas which will be new to many readers, and allows the reader a glimpse behind the scenes which only Harwit could provide. Though the emphasis is on the sociology and politics of science, it is obvious from the 'example' chapters that the discussion of science itself stems from a scientist who is familiar with the details of the material. I recommend the book to all interested in the sociology and politics of science or the last hundred years of astrophysics. — PHILLIP HELBIG.

Relativity for Everyone: How Space-Time Bends, by K. Fischer (Springer, Heidelberg), 2013. Pp. 129, 23·5 × 15·5 cm. Price £16·95/$29·99/€32·09 (paperback; ISBN 978 3 319 00586 7).

The book market for relativity is rather crowded, with everything from simple illustrations of the ideas to those with a formal development of the subject, with various levels of mathematical skill assumed. This book is at the simpler end of the spectrum, but aims to explain the concepts, and indeed some of the equations, with words, thought experiments, and plausible arguments. There are some nice touches ("light is pure energy, without resting mass, rest-less, always moving at speed *c*") and some of the arguments work well, but I am not convinced by all of them. Sometimes there is no alternative to a rigorous treatment. The role of pressure in the Einstein field equations is one place where I think the simplified treatment falls short. There are equations in the book; it's just that they are written mostly in words, rather than mathematical symbols, and some of them are quite involved. Bizarrely, the γ symbol is defined as the inverse of the Lorentz factor, which will confuse readers who have come to this book after reading more conventional treatments. — ALAN HEAVENS.

The Universe: An Illustrated History of Astronomy, by Tom Jackson (Shelter Harbor Press, New York), 2012. Pp. 144, plus 12-page timeline and 12-pages of sky maps, 27 × 22·5 cm. Price $24·95 (about £15) (hardbound; ISBN 978 0 9853230 5 9).

Both a fascinating book and very good value for money! Jackson provides 100 entities and events, spanning the history of astronomy from Stonehenge to the *Kepler* spacecraft. Number 50 is 'Space travel' and features Tsiolkovsky. Additional items include an 8-page primer called Astronomy 101, eight imponderables (suggesting that the author is not a supporter of inflation), capsule biographies of 39 astronomers from Aristarchus to Zwicky, monthly sky maps for both north and south (each focussing on one constellation and with coverage optimized for Sydney and Nebraska), and time lines from 3761 BC to 2012 AD of astronomy, science and invention, world events, and culture.

Is it perfect? Of course not! Our Japanese colleagues would surely be horrified to hear that their neutrino detector is filled with radioactive heavy water, and even Sudbury, which does use heavy water, would worry about the 'radioactive' part. The discovery of what has become known as dark matter is credited to Jan Oort in 1933 as part of a search for solar motion. Yes, he did a better job than Jeans and Kapteyn in 1922 (one of whom used the phrase dark matter), but they were looking at the motions of other stars perpendicular to the Galactic plane and didn't find much.

I always suppose that an author has done a better job on the subjects I don't know much about than on the ones I do, so my 'take-aways' from the book include things like *Mariner 2* reaching Venus, the patenting of the silicon chip, the Cuban missile crisis, and the death of Marilyn Monroe all happening the same year (1962 to keep you from having to look it up). Yes, these were current events for me, not history.

Even brief passages of time can render items out of date. Joe Kittinger's 1969 parachute jump is probably no longer a world record, and, looking ahead, I hope that India will rethink its decision to call its humans in space "gaganauts". My first two thoughts on seeing the word in the index were (*i*) Russian alternative to cosmonauts (honouring Gagarin) and (*ii*) what people being tested for space fitness do in the 'vomit comet'.

So, on that inspiring thought, I would like to send you out to buy this book (mine was a 'freebee' from 'Another Journal' that decided not to have it reviewed) and to read it, without choking or gagging on the modest price. The images and photographs alone are less than 12 cents each. — VIRGINIA TRIMBLE.

A Guide to Wider Horizons, by K. Krisciunas (Kendall Hunt, Dubuque), 2014. Pp. 127, 23 × 18 cm. Price $25 (about £15) (paperback; ISBN 978 1 4652 3894 8).

A semi-mythical professor supposedly once told a class that the next exam would cover all of human knowledge through Chapter 11. It is not quite the case that Kevin Krisciunas has covered all of human knowledge up to 2013, but he has made a brave attempt at quite a lot of it. Written language, from single words and eponyms to whole books (lost, moral, fictional, and informative) fills the largest number of chapters. Astronomy comes next, but the author is particularly badly served by the images in "Improvements of Astronomical Imaging." They are positives rather than the negatives astronomers usually look at (for good reasons) and so smeary that progressing from drawings to photographs to digital imaging hardly seems worth the effort involved. The longest single piece is mathematical, and written at just the right level for a chelonian of very little brain who had her last formal math class a bit more than 50 years ago. That chapter, however, contains a self-inconsistency. Krisciunas says of Ramanujan "but maybe it [work he might have done past age 33] would not have been proportionately more original work. Most mathematicians do their best work by the time they are 30-something". But the third hero is Gauss (1777–1855), some of whose notable contributions came around his 60th birthday. Euler comes in between, both in the book and in longevity.

How long do astronomers live? The median has been 72, but some of the people date from long before modern medicine. An interesting comparison might be, "how long do black Oscar winners live?" Three of the first seven died before 50. But seven of the total 14 (including 2014) are still alive, many at considerable ages, which will push the median well above 80. The author's list of murdered and suicidal astronomers and physicists is an interesting one, omitting Majorana, who in my parallel universe is still sipping chianti in some Italian monastery at the age of 108 (by the time you read this). This is not impossible. The last survivor of Theresienstadt was 110.

The volume bursts with connections and suggestions. There are 88 constellations, and 88 keys on a standard piano; also (not mentioned) 88 symbols on a standard typewriter keyboard. Recommended books include *Freakonomics*, *Tipping Point*, and *Guns, Germs, and Steel* (and others by the same authors), though not *Black Swan*, which has some of the same flavour. A short chapter on marvellous first sentences ("It was the best of times; it was the worst of times") and such omits my favourite: "It was a dark and stormy night on the west coast of Scotland. But this need not concern us, as our story does not take place on the west coast of Scotland. As a matter of fact, the weather was just as bad on the east coast of Ireland." Kevin's favourite phrase from a how-to-speak-Zulu book for tourists — "my hovercraft is full of eels" — is a worthy successor to "one of our postilions has been wounded" from a much earlier compilation "des autres phrases utiles". But no more favourites, since I want you to buy and read the whole book!

Conflict of interest? A mild one; I don't make the index, but the list of eponyms includes the officially obscure Merton–Trimble–Krisciunas conjecture, which, in turn, explains why Jeffreys tends to get left off the WKB–J (Wentzel–Kramers–Brilloin–Jeffreys) method. But the most useful thing I am carrying away is why the late scientometrician and physicist Jan Vlachy (former editor of the *Czech Journal of Physics*) called papers with very long, very high citation histories "genial". Not friendly, but the German (and perhaps Czech) word for genius! The author's other languages include Spanish and Lithuanian, and a few examples creep in.

Is living well the best revenge? Perhaps, and Krisciunas recommends a good many moral, educational, and well-written books that could help you do this. But I am inclined to prefer "dropping raccoons full of diphtheria virus down her chimney". — VIRGINIA TRIMBLE.

Exploring Science through Science Fiction, by B. B. Luokkala (Springer, New York), 2014. Pp. 241, 23·5 × 15·5 cm. Price £19·99/$29·99/€32·09 (paperback; ISBN 978 1 4614 7890 4).

This book is intended to make science accessible to non-scientists through the medium of science fiction. It seems to be geared mainly towards American-college literature students. 'Science fiction' is here heavily weighted towards TV and movie screens: the reader will search in vain for names like Arthur C. Clarke or Larry Niven, but will find over twenty mentions of Spock. The pages are thick with references to *Star Trek* and *Star Wars*, but *Dr. Who*, in spite of his 50-year run on British television, gets only a nod in passing. Special relativity gets a couple of mentions, not quite up there with *Men in Black* (mentioned thrice) or *I, Robot* (eight times).

One problem with this approach is the instantly forgettable nature of much pop culture: presumably not everyone is an *aficionado* of old science-fiction movies, *Star Trek* re-runs, and the like, and this reviewer was unfamiliar with many of the scenes and movies described. Another is the sheer scope, so that inevitably the text flits from topic to topic, omitting much. It would have been good, for example, to see discussion of Kardashev civilization types or Von Neumann probes, with the myriad implications of their existence or non-existence: these topics have appeared in *Star Trek*. Given this breadth of material, it's hard to avoid lack of depth; for example, we are told that $E = mc^2$ but not why, nor what it signifies beyond making exotic space drives or big bombs. In spite of these difficulties there are some serious and thought-provoking questions asked of students in various exercises; and there are fun calculations throughout. We find the power required for James Bond's wristwatch laser to cut through the floor of a railroad car, the time taken for air to leak through a hole in a spacecraft, and so on. It's an entertaining way to introduce a few basic scientific concepts to students who might otherwise never come across them. — BILL NAPIER.

Publishing and the Advancement of Science, by M. Rodgers (Imperial College Press, London), 2014. Pp. 200, 23 × 15·5 cm. Price £50 (hardbound; ISBN 978 1 78326 370 7), £25 (paperback; ISBN 978 1 78326 371 4).

Michael Rodgers had a lively and distinguished career as a scientific commissioning editor with Oxford University Press (twice), W. H. Freeman (twice), Longman, and Spektrum (Heidelberg). In the UK publishing industry he is noted for an imaginative approach to the crafting of popular scientific books and college-science textbooks. This book is a personal (just occasionally it is too personal …) memoir in which he recalls significant events in his career.

In this review I focus on this volume as an invaluable "insider's account" of scientific publishing in the period 1968–2003, which fully overlaps my own shorter career as a scientific editor and publisher for Cambridge University Press. A back story in this book — how science editors work with academic authors, and how writers should relate to their editor — is a great introduction for anyone contemplating writing a popular scientific account or an undergraduate textbook.

Rodgers uses a series of case studies to illustrate the significant stages in getting a book published. In brief these include: getting the synopsis right, the importance of providing well-written sample material directed at the target market, the need for a flowing narrative style that sweeps the reader along, and how to choose a title and a jacket that will sell the book.

The first case study is Stephen Hawking's *A Brief History of Time*, published in the US in 1988. This publishing phenomenon has sold ten million copies, despite the claims of many readers that they gave up after 20–30 pages. Rodgers identifies three unique selling features for this book. First, "it had a brilliant title." Second, it promised to deliver a lot: an account of the Universe, from its origin to its ultimate fate, in less than 200 pages, and just one equation. Third, "it was written by an insider of considerable stature."

Rodgers had no personal involvement in *A Brief History of Time*, but his analysis above informed his own publishing strategy, which is set out in considerable detail in his memoir. Among the books from his list that gave him the most fulfillment he lists Richard Dawkins' *The Selfish Gene* and *The Blind Watchmaker*, as well as Peter Atkins' *Physical Chemistry* and *Galileo's Finger*.

If you have the ambition to write a scientific book that will make a big impact, you will find this book will whet your appetite. And you will learn of the enormous amount of effort that is required by the author, the commissioning editor, and the publisher in order to create a best-selling book on an academic subject. In short, this book is a helpful guide for academic authors who are poised to send a proposal to a publisher. — SIMON MITTON.

Science Sifting — Tools for Innovation in Science and Technology, by R. R. & J. Dietert (World Scientific, Singapore), 2013. Pp. 288, 22·6 × 15·1 cm. Price £56·00 (hardbound; ISBN 978 981 4407 21 2), £25·00 (paperback; ISBN 978 981 4407 22 9).

Science Sifting is designed as a textbook, exercise book, and toolkit for science students, and aims to help beginning scientists broaden their views and their research capacities. The book is written in an easy and plain style, with numerous citations by scientists and philosophers, and is extremely well documented with hundreds of references to books, papers, and web sites. Every chapter concludes with a one-paragraph summary of the matter dealt with.

The book, from the first chapter to the eighteenth, focusses on flexibility, creativity, and innovation as necessary assets for reaching a fulfilling long-term research career, and deals with techniques on how to remove road blocks in doing research, in hypothesis formulation, and in the writing up of research results. In particular, the application of concept maps, the use of meditation in managing work and in coping with pressure, the need for play as a necessary complement to labour, the function of sleep, and the necessity of 'out-of-the-box thinking', are issues that in general are not covered in the more classical text books. The book contains numerous references to stories about famous philosophers, artists, researchers and scientists, *viz.*, Fleming, Koestler, Franklin, Mandelbrot, Sagan, Bethe, Maxwell, Kelvin, Curie, Feynman, Einstein, Medawar, Churchill, Edison, and so on.

The intended readership of this book is scientists, PhD students in the natural sciences, and young postdoctoral researchers, and although I could not embrace every concept proposed or each method explained, I found the book quite useful. Unfortunately the production suffers from some defects that surpass accidental mistakes. For example, the index not only gives incorrect page numbers from time to time, but its alphabetical order is quite unusual: names of persons are arranged in order of first name instead of surname, and several names are given by surname only (Dali, da Vinci, Goethe, ...). Very disturbing are the countless typographical errors, for example "Lyndon B. Johnson's panamas" (for 'pyjamas'), "Madelbrot" for 'Mandelbrot', "Jacque Onasis" for 'Jackie Onassis', "herzt" for 'hertz', "Vincento Galilei" for 'Vincenzo Galilei', as well as sentences like "the Da Vinci Museum of Leonardo Da Vinci". It is obvious that the manuscript of this book has not been properly proofread before it went to print. — CHRISTIAAN STERKEN.

Astronomy Photographer of the Year 2013, collated at the Royal Observatory, Greenwich (Collins, Glasgow), 2013. Pp. 192, 27 × 27 cm. Price £25 (hardbound; ISBN 978 0 00 752579 9).

In an earlier issue of this journal (**133**, 236, 2013) I reviewed the previous version of this work. (This is now available as a paperback: ISBN 978 0 00 752354 2.) Despite enjoying the excellent photographs, I was rather critical of the design and, in particular, of the technical descriptions and comments accompanying each photograph. I am pleased to say that this year's book is undoubtedly better in most respects. There are still a number of images displayed across (and thus broken by) the gutter, but the instances seem slightly less objectionable than in the earlier work.

The photographs are judged in seven categories, including one for images obtained by robotic telescopes, but processed by the competitor. In the note describing how the category for 'Best Newcomer' has been renamed 'Sir Patrick Moore Prize for Best Newcomer', the editors unfortunately perpetuate the myth that Patrick's lunar drawings and charts were used in preparation for the Apollo landings.

I remain somewhat irritated by the fact that the orientation of the images is not consistent — examples being the Orion Nebula and the Eta Carina Nebula. Perhaps the most surprising, to my eye, was the image of the Pleiades on p. 106, which is not only left-right reversed — taken with the use of a diagonal, perhaps — but is reproduced with east at the top.

In general, the information provided by the photographers about their individual images and the 'background' information given by the editors is far superior to the earlier edition. A few of the photographers' descriptions are incomplete. That for the image of the Milky Way on p. 32, for example, implies that it was a single exposure, but this is corrected in the technical details which state that it was a 12-image panoramic composite. This is shown, in any case, by the strong curvature of the Milky Way — as in the overall winner by Mark Gee. In a single image, such as several others that are included and the one by Stephen Banks (p. 146) used for the book's jacket, the Milky Way will, naturally, always appear straight. The technical details for the 'sunset/Moonrise' panorama on pp. 173 imply it was a single 1⁄125-second exposure, whereas the photographer states that he combined several images. The one image (p. 36) of star trails correctly records that it was obtained by combining 160 individual 20-second exposures.

The technical descriptions of the images in the 'Deep Space' category show a great improvement in the information about total exposure times (up to 120 hours for the Centaurus-A image on p. 94) and in the number of frames used to create the composites.

I am puzzled by the photographer's description of the 'Highly Commended' image on pp. 14–15 as showing four lunar-halo arcs. Even examining the on-line image (uninterrupted by the gutter), I am able to distinguish just the 22° and 46° lunar haloes and no other arcs. The background information provided by the editors for the 8-image panorama on pp. 22–23 taken from Glacier Point in Yosemite National Park (again with a curved Milky Way) is slightly misleading and potentially confusing in that they draw attention to the peak known as Liberty Cap, rather than the more prominent (and more famous) granite Half Dome, also in the image.

Full-size images are included of all the winning photographs over the period 2009–2012, but given the wide range of techniques employed, it was probably a sensible decision to omit the section on astrophotography for beginners that appeared previously. Any beginner is likely to be disconcerted and discouraged by any comparison between their own results and the highly advanced techniques used in many of these magnificent photographs. — STORM DUNLOP.

The Constellation Observing Atlas, by G. Privett & K. Jones (Springer, Heidelberg), 2013. Pp. 221, 25·5 × 17·5 cm. Price £26·99/$29·99/€32·09 (paperback; ISBN 978 1 4614 7647 4).

Patrick Moore's name is perpetuated by Springer in their on-going 'Practical Astronomy Series'. Any new constellation guide necessarily invites close comparison with similar products, and so I looked at many on my shelves from Admiral Smyth and George Chambers to the present day. Of the dozen or so books I have looked through, I always particularly liked Klepesta & Rükl's *Constellations* (Hamlyn), and Rükl's decades-later and larger *Constellation Guidebook*.

First of all, the book's format is rather small for an atlas. Looking at good old *Norton*'s, the page format there is considerably larger, but its crystal-clear charts go down only to naked-eye limiting magnitude or so, whereas Privett & Jones contains colour maps of each constellation down to magnitude 8·5. Star spectral types are shown in colour. The various objects are also colour-coded. But the map key appears once only, on page 6, and perhaps the charts look a bit crowded. The facing pages of text give some details of mythology, location, and describe the more interesting objects (provided there are any). I think that the maps are the better part of the book, though a slightly higher print resolution might have been used, and we shall note omissions later.

There is a good general introduction, and then we have a page of descriptive text and a map page for each constellation, all alphabetically ordered. Patrick Moore in his *Observer's Book of Astronomy* divided the constellations first into the circumpolar ones, then the ones visible from the UK season by season, and then added the southern ones last. I liked that much more. Would it be a better plan for a beginner? It is assumed by the authors that the observer is going to be able to locate each constellation, so the reader must already possess another star atlas or planisphere or computer programme, or subscribe to a popular magazine. With Collins Gem *Stars* by Ian Ridpath, for instance, there are maps for finding constellations, and Rükl's *Guidebook* gives a location map for each one.

The jacket states that the *Atlas* is "designed for anyone who wishes to learn the constellations". So we must assume beginners are to be included. A beginner will probably start by visual observation, so I would have expected to see at least a few representative eyepiece drawings (or even some wide-field pictures) to show what deep-sky objects really look like at low magnification. But no, we just find the usual sort of electronic images, close-ups and mostly in colour. They are all the work of skilled observers, including Grant Privett himself, but the beginner is constantly warned that many nebulae will be at the limit of a small aperture. Are we talking dark sites or suburban skies? If the latter, you wouldn't realistically spot the Owl Nebula with a 15-cm aperture. From a suburban site I never found the Whirlpool galaxy 'granular' even with a 30-cm, though the two nuclei were resolved and there were indications of the spiral arms. On the other hand, from a really dark site I have seen the Veil Nebula and the members of Stefan's Quintet well with 25 cm. To be fair, no two opinions will be the same when it comes to the visibility of faint objects. To finish with the illustrations, there is nothing to show what double or multiple stars look like in the eyepiece, and here I recall Leslie Ball's lovely drawings of coloured doubles for the *Observer's Book of Astronomy*, or those in the 1960s *Larousse Encyclopaedia* (or even old Chambers).

It's clear that the *Atlas* has been written by a practical observer, whose knowledge nicely comes through in the text, and his tips and comments will certainly be helpful to all. I liked the various anecdotes and puns, but there is not much detail about any particular object. The text seems accurate, though I spotted that Nathaniel Pigott (page 18) morphed into Edward Pigott later (page 70). There is a certain amount of wasted space with the small constellations, and elsewhere one wishes a limit of one page had not been imposed. In some other books the text simply runs on.

Is anything left out? Well, yes it is. Taking the Cygnus pages as a single example, the Cocoon Nebula is plotted and even shown in a separate CCD image, but it is neither described nor assigned its IC catalogue number. And on the same page the North America Nebula (NGC 7000) is described without naming it! Then there is 61 Cygni, described in the text, and shown *but not labelled* on the chart. Maybe the text needs to be better cross-referenced to the charts? In fact the text gives less information on some constellations than the smaller-format *Constellation Guidebook* by Rükl, or the much smaller Collins Gem *Stars* by Ridpath. The jacket claims "unmatched thoroughness".

The index is very poor, and is surely the weakest point of the *Atlas*, though it does at least relate Messier and NGC numbers to pages. Just 15 named objects are indexed, but it is essential to have many more: what about the Cocoon, Dumbbell, Lagoon, and Owl? They all feature in the text and maps! Moreover, the short list of featured IC objects omits the Cocoon (IC 5146) again. In the 'Additional Information' section, why are some outdated books on planets cited? Under 'Web Based Support', the BAA is said to produce a Newsletter; that's no longer true, but it does publish a bimonthly *Journal* and has an extensive website.

Would I recommend this guidebook? Not really. To the beginner the maps are too complex, though the text may be useful. The serious observer will find the descriptions limited, but may like the maps. — RICHARD MCKIM.

Comets! Visitors from Deep Space, by David J. Eicher (Cambridge University Press), 2013. Pp. 208, 25 × 18 cm. Price £17·99/$24·99 (paperback; ISBN 978 1 107 62277 7).

Comets are fascinating on so many different levels. You might happen to be the first person to glimpse one. And then you are immortalized, the comet being named after you forever. There is also their inherent unpredictability. (Maybe that is why the word deserves an exclamation mark in the title of this book!) You have no idea when the next bright long-period comet will hove into view. And when they are discovered, often out in the asteroid belt on their way in towards the Sun, you have little chance of accurately predicting their future behaviour. Older readers can well remember the disappointment with Comet Kohoutek (C/1973 E1), inappropriately named the "comet of the century". That was a damp squib if ever there was one. And more recently, just think of all the anticipation heaped on Comet ISON (C/2012 S1). Unlike the Great Comet of 1680, which speeded through the solar corona relatively unscathed, ISON evaporated into a puff of gas and dust at perihelion. And finally we have the enigmatic cometary nucleus. What is the mass? What is the physical form of the interior? How strong is it? We just do not know. Fingers crossed, ESA's *Rosetta* spacecraft will solve some of these mysteries later this year.

Comets! is a non-technical exposition of the history of cometary observations enhanced by many handy hints and encouragements for potential modern-day comet observers. Much is made of our progress in understanding the physics and chemistry of these mysterious bodies. Special emphasis is given to the impacts of comets with planetary surfaces, the enigmatic Oort Cloud, humanity's assessment of cometary significance, and the possibility that comets carry with them biotic material and the seeds of life. There was, however, one minor thing missing in this book. I did not seem to pick up the absolute joy of the comet community when it came to the revelation of the first image of a cometary nucleus. The instantaneous transformation of a theoretical prediction into a pictured reality was an unforgettable key stage in cometary science. Back in the 1950s there was uncertainty, and a big debate about the form of the central regions of comets. Was it a single kilometric-sized dirty snowball? Or was it a disparate bee swarm of rocky meteoroids? We weren't certain. Some even predicted that ESA's *Giotto* would see nothing, and that sending a spacecraft to a cometary interior was nugatory. Science is not just a steady progress. There are step-changes, and *Giotto*'s proof of Fred Whipple's snowball model was one of them.

David J. Eicher (editor-in-chief of *Astronomy* magazine) has a way with words. Clarity, joy, inquisitiveness, and knowledge grace every page. It is clear that he is a great comet fan and we are very fortunate that he has taken the time to share his enthusiasm with us. — DAVID W. HUGHES.

An Astronaut's Guide to Life on Earth, by Chris Hadfield (Pan Macmillan, London), 2013. Pp. 296, 24 × 16 cm. Price £18·99 (hardbound; ISBN 978 1 4472 5710 3).

This is the story of a modern hero who became a social-media phenomenon and briefly brought human spaceflight back into the limelight after decades of public disinterest. Against all the odds, Chris Hadfield became one of a handful of Canadian citizens to experience the wonders of spaceflight, eventually becoming the first astronaut from his country to command an expedition on the *International Space Station* (*ISS*).

More than 500 people have now circled our planet since Yuri Gagarin's momentous voyage in 1961. During the first two decades of the Space Age, many of the space pioneers became household names. However, times have changed. Today, a crewed mission to the *ISS* barely merits a mention in the media, and most people would struggle to recall the names of any current astronauts. Hadfield is one of the few exceptions — and this biography goes a long way to explaining why he stands out from the crowd.

A substantial part of the book is inevitably devoted to events associated with his three space missions — two fleeting flights on a Shuttle and a grand finale on the *ISS*. During a career that spanned two decades, he became one of the few westerners to visit the Russian *Mir* space station, then installed a Canadian robotic arm on the *ISS* before joining a multinational crew that spent five months on the *ISS*. He also became the first Canadian to walk in space, eventually participating in two EVAs.

A glimpse at his CV suggests that Hadfield fits the usual macho profile of an astronaut. Inspired at the age of 9 by Neil Armstrong's "giant leap for mankind", he dreamed of following in his hero's footsteps. Obsessed with flying, he became a leading fighter pilot, then became the top graduate at the US Air Force test-pilot school in 1988, before being selected as one of four new Canadian astronauts from a field of 5330 applicants.

Yet this volume makes clear that he is more than a typical stereotype of a daredevil flyer filled with "the right stuff". The clue is in the book's title. Every chapter reveals Hadfield's philosophy of life, how he believes we should approach the vicissitudes of life and make the most of the cards that fate has dealt.

His approach to living can be summarized by this quote: "If you start thinking that only your biggest and shiniest moments count, you're setting yourself up to feel like a failure most of the time. Personally, I'd rather feel good most of the time, so to me everything counts: the small moments, the medium ones, the successes that make the papers and also the ones that no one knows about but me. The challenge is avoiding being derailed by the big, shiny moments that turn other people's heads. You have to figure out for yourself how to enjoy and celebrate them and then move on." — PETER BOND.

Astrophysics from Antarctica (IAU Symposium 288), edited by M. G. Burton, X. Cui & N. F. H. Tothill (Cambridge University Press), 2013. Pp. 337, 25 × 18 cm. Price £76/$125 (hardbound: ISBN 978 1 107 03377 1).

Human beings are a remarkable species. Analysis of our mitochondrial DNA indicates that it is only about 60 000 years since our ancestors left Africa, walked around the world and, presumably, interbred with all the pre-existing forms of hominid. In that brief time the peripatetic life style has taken us to every continent on our planet, no matter how inhospitable, and even to the Moon. This publication reports an IAU conference held in 2012 August, discussing the attempts to place astronomical instrumentation at one of the most inhospitable place on Earth, the Antarctic, and despite the title, the Arctic. The thing which is inspiring is that none of this is being done for financial or economic gain. No one is trying to force their world views or ethics onto other people. Instead it is being done in the search for pure knowledge, to find out something about the nature of the Universe and our place in it.

Many of the papers are aspirational in that they describe potential instruments or site testing which will enable others to place their instruments in the most advantageous places. However, such is the pace of change that already results are coming in from at least one of the experiments described here, the polarization measurements of the cosmic microwave background. Many of the instruments, either actual or proposed, stretch what is understood to be a 'telescope'. When this reviewer was a child a telescope could be looked through, have photographs taken through it, or perhaps have the light fed to a spectrograph. New-fangled 'radio telescopes' had been invented but were not commonly available. We now have instruments which cover the whole of the electromagnetic spectrum from the gamma rays to the longest radio waves but who would have predicted that a 'telescope' could consist of a cubic kilometre of ice and a few thousand photomultiplier tubes? Alternatively, how about balloon-borne experiments which can last for tens of days because of the continuous solar heating during the southern summer and the direction of the winds which circle the continent of Antarctica. Almost every aspect of astronomy is contained within this publication. There are papers on neutrinos, on the interstellar medium, the free-electron count in the Antarctic atmosphere, gamma-ray bursts, long-term photometry of variable stars, gravitational lensing, and micro-meteorites. From the farthest distances we know of to the local, all distances and scales are contained within this publication and it would be invidious to pick out any one as being of more interest than the others. No matter what field of astronomy one works in there will almost certainly be a paper contained in this book which will have some relevance to you. It is inspirational in that it shows what we, as a species, can achieve when we are allowed to, so even if you have no intention of ever becoming a 'Pole-Cap' observer there will probably be something in here to stimulate you. — E. NORMAN WALKER.

Observational Molecular Astronomy, by D. A. Williams & S. Viti (Cambridge University Press), 2014. Pp. 174, 23·5 × 15·5 cm. Price £35/$55 (hardbound; ISBN 978 1 107 01816 7).

This is the tenth in a CUP series of *Observing Handbooks for Research Astronomers*. According to the Preface it is not a textbook. The users of this series are supposed to be established professional astronomers who presumably have the 'textbook' background, but who can make use of some guidance as to what research is likely to be fruitful and how to go about doing it. I believe this book will serve that aim admirably, but it could also be used a textbook if need be, or, even, as in my case, it can be read simply for enjoyment. Most of all, I believe it will be of great help to a graduate student (and his or her supervisor) or postdoctoral fellow who is looking for a suitable research field.

The two authors are at University College London, and I note that one of them is Emeritus Perren Professor of Astronomy. As a former Perren Student I was immediately nervous about reviewing the book, wondering how I was going to write anything negative about it. Fortunately and to my relief I genuinely could not find anything negative to write about.

First I should perhaps make clear what ground the book does not cover. It has a subtitle: *Observing the Universe Using Molecular Line Emissions*, and that tells us, correctly, that it is mainly concerned with the wider Universe — our Galaxy and the Universe of external galaxies. Thus the reader will not find material on the extensive molecular physics of comets and planetary atmospheres. And it deals mainly with line *emissions*, which are typically observed with radio or submillimetre telescopes, rather than with the absorption lines seen in stellar spectra but originating in the space between us and the stars.

The authors provide us with far, far more than merely a list of the molecules found so far, although they do provide a list of the 172 (not including the many isotopomers) known to the authors at press time, together with an indication of the type of object or environment where they may be found. They also provide Web sites (I tried them and they worked) where lists of molecules and necessary spectroscopic data are maintained.

Two concepts than run through the book are those of *drivers* and *tracers*. A collection of molecules out in space is not going to do very much if it is just left to itself. For interesting physics and chemistry, it needs some stimulus ('driver') to start the ball rolling. Examples of drivers are ultraviolet light, X-rays, cosmic rays, dust (many reactions, particularly those involving hydrogen, take place on the surfaces of dust grains), shock fronts, and so on. Different sorts of molecules are useful for different purposes. They are 'tracers'. Thus a molecule such as methanol has a rich rotational spectrum with many lines, and is consequently a useful tracer for determining rotational temperature. Methyl cyanide has a high dipole moment and is a good tracer for kinematical structure. The authors give many examples, including specific sources, indicating what chemistry can be initiated in what environments, and what molecules are suitable for what studies. Of course H_2 ought to be the number one tracer of Galactic structure, but, because it has no permanent dipole moment, it also has no pure rotational spectrum. Therefore one uses instead CO. There are at least two problems here. One is to know the ratio H_2/CO in the Galaxy. The other is that the low-J lines of CO may be optically thick. How does one tackle such problems? Well, the first thing to do is to read this book!

Just one small word of caution. Chapter 8 offers some 'recipes' for interpreting the observations by way of supplying various equations for calculating interesting results from the measurements made. Some of the equations given appear not to balance dimensionally and should be used with caution. This is because they are designed for use only by using a rather strange system of units, namely a system in which the vacuum permittivity has a numerical value of $1/(4\pi)$. It would be disastrous, for example, (and wrong by many orders of magnitude) to use the formulae given and expect to calculate a molecular dipole moment in C m, or indeed in any other familiar unit. I would suggest that the reader should check the dimensions of each equation. He or she will then discover that some equations appear to be dimensionally wrong by the dimensions of permittivity, which are $M^{-1}L^{-3}T^2Q^2$. This will tell you where a $4\pi\varepsilon_0$ has been omitted from an equation. You can then insert the missing $4\pi\varepsilon_0$ and can then use any coherent unit system you like.

Among the many examples of molecular physics cited, one that interested me particularly was the way in which molecules may become favourably deuterated. Thus the ratio of XD to XH in some sources is by no means equal to the ratio of D to H. For example, towards the direction of one source, the abundance of deuterated methanol CH_2DOH is almost as much as that of ordinary methanol CH_3OH, in spite of the general ratio of about $D/H = 1{\cdot}4 \times 10^{-5}$. Of course the authors explain the fascinating molecular physics that causes this fractionation. I am now worried. Some years ago my student Wayne Jaworski measured the ratio ^{13}CN to ^{12}CN in Comet Halley, and we found that it was the same as the ^{13}C to ^{12}C ratio in the Sun. This, we reasoned, showed that Comet Halley, in spite of its unusual orbit, is an original Solar System object. Perhaps we should have concluded that, because of favourable isotopomer fractionation, the ^{13}C to ^{12}C ratio in the comet is not the same as in the Sun, and Comet Halley is *not* an original Solar System object.

Well, there are all sorts of molecular problems of that nature, and I would recommend that anyone embarking on a career in radio, microwave, or submillimetre astronomy and wondering what to do, why to do it, and how to do it, should own this book. It is worth mentioning that it also appears to be well and strongly bound. This is important, for it is a book that will not languish untouched on a bookshelf, but will be eagerly and often returned to and will become well thumbed. — JEREMY B. TATUM.

The Physics and Evolution of Active Galactic Nuclei, by Hagai Netzer (Cambridge University Press), 2013. Pp. 353, 26 × 18 cm. Price £40/$65 (hardbound; ISBN 978 1 107 02151 8).

Hagai Netzer has written a rather splendid advanced textbook on active galactic nuclei (AGN). It is authoritative and complete. There are a number of other textbooks on AGN — why might you get this one? I think that depends on why you want it, but the bottom line is that if you do research on AGN, you probably want to make sure your graduate student has this book. It is pretty good as a didactic work, but it is *very* good as a source book.

The book starts with an overview of the observational properties of AGN. It then moves on to a series of chapters covering the underlying physics — radiation processes, black holes, and spectroscopy. As you would expect with Netzer, the material on atomic properties and spectroscopy is particularly definitive. The next big chunk covers what could be called AGN botany — types of AGN and the mixture of components found. Following that, Netzer puts AGN in their astrophysical and cosmological context, covering host galaxies, formation, and evolution. A final chapter looks at a series of outstanding questions.

The coverage then is extremely broad, but also very complete — no major issues are missing — but still the book is only 350 pages long. You can deduce from this that it is written in a rather condensed style, with very little room for didactic explanation of any one topic, but it is very reliable and complete. My graduate student loves it, and keeps it on his desk, but keeps coming to ask me to unpack cryptic statements. So if you want something that undergraduates can understand and use for senior-year projects *etc.*, this isn't it — Brad Peterson's book *An Introduction to Active Galactic Nuclei* is probably what you want. If you want an explanation of the physics, Julian Krolik's book *Active Galactic Nuclei* is probably the best. To cover specific areas you will want other review papers or books; for example, the splendid Frank, King & Raine on *Accretion Power in Astrophysics*. But if you want a single book that covers all the bases at graduate level, and gives you a jumping off point, this is the one. — ANDY LAWRENCE.

An Introduction to Thermodynamics and Statistical Mechanics, 2nd Edition, by K. Stowe (Cambridge University Press), 2013. Pp. 556, 25 × 19 cm. Price £35/$60 (paperback; ISBN 978 1 107 69492 7).

The first question that came to my mind when I was reading this book was "when will the author first mention 'heat'?". It takes him a while, all the way to Chapter 5. If you ask me, the title of this book should have been different. The author starts with a thorough description of the statistics of small and large systems, explains the First and Second Laws from a statistical point of view, and only starts to talk about heat engines somewhere in the final part of the book. I understand his choice although I personally would have taken a different approach.

The book is aimed at undergraduate students with no previous knowledge of statistics and quantum physics. The author starts with a short introduction to quantum physics, but I have to say that this is a little too short. Students with no previous knowledge of quantum physics might feel a bit lost after reading it. Aside from that, I think the book is at the right level. The author clearly explains what the consequences are for the laws of physics that he is describing. There are a lot of worked examples in every chapter and the author clarifies concepts by giving applications in a physical context. This is especially helpful in the first part of the book, where it is easy for students to lose track of the physical context. Near the end of the book there are some very nice applications in the field of semiconductor physics, cooling techniques, and astrophysics. Every chapter has short summaries and contains many problems for students to work on. Answers to odd-numbered problems are given in the back of the book. I would have preferred to have the answers to the other problems as well.

All in all I think this is a very good text for undergraduate students. It covers a wide range of subjects, has many problems, and is very readable. It might be a little bit heavy on the statistical part and I would not have been surprised if this book had not had 'thermodynamics' in the title. — J. W. MASSOLT.

Astrophysical Techniques, 6th Edition, by C. R. Kitchin (CRC Press, Boca Raton), 2014. Pp. 536, 26 × 18·5 cm. Price £38·99 (hardbound; ISBN 978 1 4665 1115 6).

Astrophysical Techniques is well established as a standard reference covering the principles and practice of instrumentation and detectors at what might be called advanced introductory level. On receiving this latest version, I dug out my copy of the first edition, published in 1984, for comparison. After three decades, the basic structure of the book remains essentially unchanged, with the same overarching chapter headings of 'Detectors', 'Imaging', 'Photometry', 'Spectroscopy', and 'Other techniques', but the passing of the years is marked by the introduction of short new sections on 'Dark matter and dark energy detection' (under 'Detectors'), 'The inverse problem' and 'Electronic images' ('Imaging'), and 'Computers and the internet' ('Other techniques'). Nor does one have to look hard to find shifts in emphasis; the coverage of 'photography' has more or less halved, while the discussion of 'photometry' embraces area detectors as well as traditional photometers. Frequent references to current instruments add a flavour of topicality.

The aim is evidently to strive for breadth rather than depth, which might be taken as a strength or a weakness, depending on your needs. The lack of significant detail in many areas, and the absence of pointers to the primary literature, mean that the book is unlikely to be useful to the practising instrumentation scientist, but the modest mathematical content and the provision of exercises make it suitable as the basis for a first-year-undergraduate course, or as a comprehensive reference for the advanced amateur. My paperback copy of the first edition cost £15; the new, nicely-produced hardback version, with around 20% more pages (and a couple of colour plates), is good value, and it's a sign of the times that it can also be bought as a kindle e-book from Amazon, for a few pounds less. The book's longevity testifies to how well it fills what would otherwise be a conspicuously large hole in the market, and it can continue to be warmly recommended as a comprehensive introduction to the wide diversity of astronomical instrumentation. — IAN D. HOWARTH.

New Trends in Radio Astronomy in the ALMA Era: The 30th Anniversary of Nobeyama Radio Observatory (ASP Conference Series, Vol. 476), edited by R. Kawabe, N. Kuno & S. Yamamoto (Astronomical Society of the Pacific, San Francisco), 2013. Pp. 431, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 836 7).

My favourite surprise from this conference volume is the report of gaseous spiral-arms in the host galaxy of Centaurus A. Ellipticals did not do this in the days before *SMA* (*SubMillimeter Array*) and *ALMA* (*Atacama Large Millimeter Array*). A close second comes as part of a plan to expand VLBI (Very Long Baseline Interferometry) centred on *ALMA* to the ends of the Earth. The authors propose to retrofit the *ALMA-NA* prototype antenna for low temperatures and redeploy it at Summit Camp, Greenland. The longest baseline should just about resolve the horizons of the black holes in Sgr A* and M 87 with observations at 230 and 345 GHz. The site has less than 2 mm of precipitable water vapour most of the year and so is, I suppose, drier even than Southern California has been this year.

Others of the 119 items (provided by 169 participants from 16 countries) contain broader ideas; for instance, that *ALMA* will connect the single-dish scale of 10″ with the interferometer scale of 1″ and so reveal detailed mass distributions at a resolution of 1000 AU in star-formation regions. Meanwhile, *Herschel* data imply that the proper initial condition for star formation is a web of gaseous filaments that later break into pre-stellar ('starless') cores; rather like the lead-up to galaxy formation!

The book is, however, an exceedingly frustrating one, even without the absence of pp. 47–58 in my copy. Also absent are any indices of topics or astronomical objects (or even authors), a table to decode acronyms, and a glossary. About 20 facilities besides *ALMA* have contributed to the science, and a table of those, decoded, would also have been helpful. Would an on-line-only memoire of the event have been better? Not exactly, since those 'extra value' indices, tables, *etc.*, are generally also not found in purely electronic conference records.

The longest paper, and one of the most interesting, comes from the after-dinner talk by Norio Kaifu (director of Nobayama Observatory, whose 30th anniversary was being celebrated, and current president of the International Astronomical Union). He began by saying, "It is well known that Minoru Nakagami and Kenichi Miya reported a significant burst of radio signal at 14·63 MHz [surely Mc/s when they did it]s from sky with elevation angle very close to the sun in 1938, during observations of Dellinger phenomenon." Now, if you will also go look up 'Dellinger phenomenon' it will be well known to both of us, and we can join in waving farewell to the participants in the conference photo, which is reproduced on a scale such that not even the few front-and-centre folk can be identified with a magnifying glass, except as "blond woman, probably not from host country, wearing a jade cardigan" and "scant-haired gentleman, probably from host country [as were more than 100 of the participants], wearing a dark red sweater". They are sitting, standing, and kneeling near a dock that extends into a very attractive lake, presumably near Hakone, where the meeting took place. But the mountain behind the lake and its surrounding hills is fully snow-covered, explaining the cardigans, sweaters, and so forth. — VIRGINIA TRIMBLE.

Progress in Physics of the Sun and Stars: A New Era in Helio- and Asteroseismology (ASP Conference Series, Vol. 479), edited by H. Shibahashi & A. E. Lynas-Gray (Astronomical Society of the Pacific, San Francisco), 2013. Pp. 581, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 842 8).

Whatever may be said about the internet (and who doesn't?), the concept of a printed hard-copy of conference Proceedings seems unwilling to die. Is it the need to see one's work in print, refereed or not, to gild a CV or justify a travel grant? What we have here appears to be the conference Proceedings of what was clearly a very energetic meeting held in Japan in late 2012, attended by pulsation and seismic-mode analysts from across the globe. The book is well produced, beautifully combed for spelling and style (even though many authors were non-native English speakers), and attractively interspersed with colour photos, mainly of speakers, that are near the relevant papers. And yet the book does not actually reflect the conference since the order of papers is quite different from that given in the on-line programme. Whereas the conference itself was graced with introductory talks that reviewed the state of play and set the scene, in the printed version those talks are relegated to the back, long after new developments have been described. There is no introduction; one is plunged without preliminaries into theoretical papers about modelling the Sun, and is left somewhat bewildered to divine the relationships, apart from their titles, between the different papers that may once have formed a coherent set of conference talks. There is no explanation for the re-ordering; if there was a cogent reason, the reader is not made privy to it.

There is a lot of very-high-flying science here, many ideas and plans for future work, and many new results from *CoRoT* and *Kepler*; all 67 participants presented either a paper or a poster, and much was still 'work in progress'. One senses strongly that the field of astroseismology is in excellent health, which augurs well for its future. But this book has too much repetition, stemming largely from the fact that each 'write-up' has felt obliged to produce a stand-alone paper regardless of what was actually said at the conference. Many reiterate the importance and relevance of solar and stellar seismology to astrophysics, and with many also including a *Conclusion* which largely repeats the *Abstract*, the reader may weary a little of so many restatements. As always, though, Gough is worth reading for his succinct yet adequately explanatory descriptions, concise yet complete; Jeffery, Balona, and other giants in this field also write in exemplary style by distilling the essence of the science without going overboard with too many details and speculations, and also manage to present information without citing huge lists of references that leave the reader somewhat helpless unless logged-in to the ADS.

But what an opportunity has been missed! There's ample material here for a thorough discourse on the physics of the Sun and stars, if only time and energy had been devoted to extracting the actual research results from each paper and combining them suitably into topics or observational régimes. Such a book would have served the astronomy community far better than will this rather dislocated set of write-ups, would have given the conference participants much better value for their registration fees, and would not have needed to be 580 pages long. — ELIZABETH GRIFFIN.

Supernova Environmental Impacts (IAU Symposium No. 296), edited by A. Ray & R. A. McCray (Cambridge University Press), 2014. Pp. 401, 25 × 18 cm. Price £76/$125 (hardbound; ISBN 978 1 107 04477 7).

It sounded like a great idea! Supernovae are generally said (*i*) to heat interstellar material so that it did not all collapse and form stars long ago, and (*ii*) to collide with, and compress, existing gas clouds and so trigger star formation. Let us, therefore, plan a conference that will bring together lots of folk working on those two sets of processes and try to see if it all hangs together. This does not quite seem to be what happened. Many of the two-page (poster) to 8–10-page (review talks) items in the proceedings consider only a specific SN or SNR and not their impacts on anything. The four presentations closest, I think, to the topic were (*i*) B. B. Nath on supernova-driven galactic outflows (radiation pressure and cosmic rays compete); (*ii*) G. Hensler on the supernova–ISM/star-formation interplay (a subset of existing simulations, not yet including cosmic rays and magnetic fields); (*iii*) Q. D. Wang on supernovae and the galactic ecosystem (saying that most SNe go off in superbubbles, produce no long-lasting, bright remnants, and do not either stir or compress in the advertized fashion); and (*iv*) E. Ntormousi *et al.* on formation of cold filaments from colliding superbubbles (perhaps a partial answer to item (*iii*), and the output does look somewhat like filaments in ISM clouds as seen by *Herschel*).

A subset of the discussions after the talks is included, not perhaps quite as the speakers intended:

"Podsiadlowski: What was the assumed SN Ia note in your MB1 simulation? I guess for a X-ray efficiency of ~1% you need about 1 SN every 10^3 yr?"

"Wang: The standard SN Ia rate as a fraction of stellar mass is used."

As has become depressingly common with IAU Symposium proceedings, there is no index of topics or astronomical objects and no list of participants with institutions. And although the meeting was organized into sessions the book is not. — VIRGINIA TRIMBLE.

PAPERBACK RELEASE

The Exoplanet Handbook, by M. Perryman (Cambridge University Press), 2014. Pp. 410, 24·5 × 19 cm. Price £30/$45 (ISBN 978 1 107 66856 0). Reviewed in **132**, 202, 2012.

OTHER BOOKS RECEIVED

Turbulence and Self-Organization: Modeling Astrophysical Objects, by M. Ya. Marov & A. V. Kolesnichenko (Springer, Heidelberg), 2014. Pp. 657, 24 × 16 cm. Price £153/$229/€181·85 (hardbound; ISBN 978 1 4614 5154 9).

This substantial volume provides a comprehensive account of the impact of natural turbulence in the formation of a wide range of celestial bodies. Stochastic modelling is used to highlight self-organization processes, with particular relevance for disc structure and evolution. It is aimed at graduate students and researchers in a wide range of space sciences.

Here and There

SOMEWHAT POINTLESS

Red giant stars are proving to be an incredible source of information for testing models of stellar evolution. — *ApJ*, **767**, 82, 2013.

GOOD VALUE FOR MONEY

… superbly crafted 24 inch Sproul refractor, erected at Worthmore College in Pennsylvania, in 1911. — *Astronomy Now*, 2014 February, p. 86.

A WHALE-SIZED ERROR

Arp 147, a galaxy pair in the constellation of Cetus, more than 400 light years away from Earth, is named after him. — *Daily Telegraph*, 2014 January 27, Obituary of Halton Arp.