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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2017 January 13 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

J. C. ZARNECKI, *President*
in the Chair

The President. Good afternoon ladies and gentlemen, Fellows, non-Fellows, and visitors — welcome to the first meeting of 2017. It gives me pleasure to announce the list of winners/recipients of the RAS awards for 2017. The formal presentation will be made at the NAM later in the year, so for now we're just announcing the winners. Incidentally, if any of the recipients are here, when I mention your name would you stand up so we can acknowledge you?

Let me start then with the highest awards of the Society, the Gold Medals: in astronomy, Professor Nick Kaiser of the University of Hawaii, and the 'G' Gold Medal to Professor Michelle Dougherty of Imperial College London. [Applause.] The Chapman Medal goes to Dr. Mervyn Freeman of the British Antarctic Survey, and the Eddington Medal to Professor Cathie Clarke, Institute of Astronomy, University of Cambridge. The Herschel Medal is awarded to Professor Simon Lilly of ETH, Zurich, and the Price Medal to Professor Richard Holme, University of Liverpool. The Jackson-Gwilt Medal goes to Dr. Ian Parry, Institute of Astronomy, University of Cambridge; and a new award, for the first time this year, the Agnes Clerke Medal for outstanding personal research into the history of astronomy or geophysics is awarded to Professor Clive Ruggles of the University of Leicester. The Patrick Moore Medal goes to Mr. Tim Browett of Robert Gordon College, Aberdeen. The second new medal, awarded for the first time this year, is the Annie Maunder Medal for outreach, and that goes to Dr. Marek Kukula of the Royal Observatory, Greenwich. The Fowler Awards, one A and one G, respectively, go to Dr. Jonathan Pritchard of Imperial College London, and to Dr. Christopher Chen, also of Imperial College London. The Winton Capital Awards, again 'A' and then 'G': first, Dr. Cosimo Inserra of Queen's University Belfast and Dr. Zhonghua Yao of the Mullard Space Science Laboratory, UCL. The group awards, 'A' and 'G' again: the *Laser Interferometer Gravitational-Wave Observatory* team, probably better known to most of us as *LIGO*, and to *SuperDARN*. The Service Award goes to Mr. Derek Fry of the Grammar School at Leeds, for astronomy, and Professor Richard Harrison of RAL Space for geophysics. Next, Honorary Fellowships; we have three: the first two are in astronomy and the third in geophysics. They are for Professor Boonrucksar Soonthornthum, from the National Astronomical Research Institute of Thailand, Professor Michael Thompson, National Center for Atmospheric Research in the USA, and Professor Maria Zuber of MIT (also in the USA). The George Darwin Lecturer will be Professor Catherine Heymans of the University of Edinburgh. The Harold Jeffreys Lecture will be given by Professor Tim Wright of the University of Leeds, and the final award on the list, the James Dungey Lecture, is awarded to Professor Christopher Owen of the Mullard Space Science Laboratory, University College London. It looks as if all of our winners are very bashful. They all knew about their awards so they probably stayed away, but I suggest we give them all a round of applause. [Applause.] They will formally be given their medals and citations at the NAM, and the various named lectures will be given at various times throughout the year.

Now we turn to the programme, and we start with two talks from the winners of the 2016 Winton Capital Awards, first for astronomy and then for geophysics. I would just like to mention that we have with us tonight, from Winton Capital, Christine Simpson, and I would like her to stand up and say hello. [Applause.] Please do make her feel welcome; she's staying on for a drink or two afterwards and we all very much appreciate the support that we get from Winton Capital in supporting these awards. The first of those two award lectures is given by Ralph Schoenrich from the Physics Department, University of Oxford: 'The structure and history of the Milky Way'.

Dr. R. Schoenrich. When we look up into the sky on a clear, dark night, we can see the band of the Milky Way stretching across the sky. While being surrounded by this disc galaxy, we are just in the process of answering the central questions about its structure, physics, and history. Galactic astronomy is experiencing an unprecedented revolution in the quantity and quality of available data covering the disc(s), halo, and bar/bulge of our Milky Way. Currently, the *Gaia* satellite mission is determining accurate positions and kinematics for about a billion stars, beating its predecessor, *Hipparcos*, by a factor 10 000 in sample size, and a factor 100 in sample extent and accuracy of the determined stellar parallaxes. This effort is complemented by ground-based missions that take millions of high-quality stellar spectra that allow us to determine accurate stellar parameters, such as detailed surface abundances and stellar ages. The Milky Way is the only disc galaxy in which we can obtain such a set of data for representative samples of single stars. However, as it is a rather typical disc galaxy in mass and star-formation history, and does not suffer from recent major interactions which would disturb its secular evolution, it serves as a blueprint to understand disc galaxies in general.

Why is this level of detail so important? In the past decade, Galactic astronomy had to abandon the old paradigm that stars remain roughly near the radius at which they were born. A long-standing puzzle was the diversity of stellar metallicities (their enrichment with elements heavier than helium) in the solar neighbourhood. This tension between theoretical expectations and observations was resolved when we found that the stellar populations in the solar neighbourhood are dominated by immigrants from all over the Galaxy. But this fact gave us more: a way to track the migration of stars in the Milky Way, and hence a key to understanding its physics.

To track redistribution in a system one needs something that is nearly indestructible, that has a unique composition encoding its origin, and whose age can be reliably determined. In geological studies, this role is taken by zircon crystals, *e.g.*, to reconstruct the course of ancient rivers depositing these crystals along their banks. In Galactic astronomy, this role is taken by low-mass stars, like our Sun: while more-massive stars die within tens to hundreds of millions of years, enriching their surroundings with the yields of their nucleosynthesis, like oxygen, magnesium, and to a lesser extent iron, low-mass stars live for time-scales comparable to the age of our Galaxy, or the Universe. Their outer shells preserve the composition of the interstellar medium from which they were born. This composition varies systematically with position in the Galaxy. The inner parts of a disc galaxy like the Milky Way show enrichment of metals, *i.e.*, heavy elements, about a factor ten higher than in their outskirts. The main cause for this is likely to be a slow inflow of gas through the disc towards the central regions, which advects the metals produced by the more-massive stars towards the central regions. In addition, the detailed composition of the interstellar medium changes with time. For example, the enrichment with alpha-elements, which are predominantly produced by very massive stars exploding as core-collapse supernovae, is faster than the enrichment with, *e.g.*, iron, which to a large extent originates from white dwarfs exploding as type-Ia supernovae. Thus the first generations of stars formed in the Galactic disc were enhanced in alpha-elements, while later the composition tended towards solar abundance ratios. This position- and time-dependent diversity in stellar abundances helps us to track the origin of stars; for example, we learn that a star with double the solar abundance in heavy elements must have been born in the inner Galactic disc, and a relatively good determination of this position can be made with sufficient data and a good reconstruction model of the past abundance profiles. With millions of stars at hand, we now have a technique to map from where to where all the stellar populations in the Galactic disc got redistributed, and to examine how those re-distributions depend on other parameters, like the amount of stellar random motions.

How do these migrations work? We can take a simple picture where spiral arms are density waves that rotate with a certain angular speed around the Galaxy. Connected to their over-density is a trough in the gravitational potential which can be compared with waves in the ocean. Just as a surfer has roughly to match the speed of a wave to get picked up and travel on it, stars with angular frequency near the co-rotation with the spiral pattern can be picked up and ride this wave resonantly to change their angular momenta, and hence position in the galaxy, a process called 'churning'. Conservation of the Jacobian integral in this rotating system also implies that stars do not pick up significant additional random motion when migrating around this co-rotation resonance, so the process is distinguishable from disc heating by random perturbers. Interestingly both observations (measuring this migration *via* the metallicity distribution) and our disc simulations already agree on the amount of 'churning' in the disc, but only when we grow a Galactic disc with standard expectations and a standard dark-matter halo, which provides a purely dynamic argument to determine the structure of the dark-matter halo. In other words, already the current data allow us to make inferences about the structure and history of the Milky Way. With *Gaia* we will be able to go further: as mentioned before, the combined datasets will allow us to map ages of stars together with their kinematics and abundances. With this known focus on stellar re-distribution around the co-rotation resonance, we currently expect that *Gaia* will allow us to reconstruct the historical positions of spiral patterns in the Milky Way for the past few Gyrs.

Stellar migration also has implications for our views on the further history of the system. For the past decades, the discovery of a thick disc (a component which extends significantly further away from the Galactic plane, consists predominantly of old stars, and has also strong alpha-enhancement pointing to an early formation in a dense environment) was firmly believed to point to a significant Galactic merging event. Radial migration removed the need for this cosmic catastrophe: the thick-disc stars can be naturally explained as immigrants from the inner disc. It is now established that even thick-disc stars participate in this migration and also puff up, *i.e.*, can expand adiabatically like a gas streaming out of a nozzle when they migrate outwards into regions with lower surface density and hence weaker restoring force. However, what still needs to be explored is how strong the bias of migration for kinematically colder stars is, which might curb the effectiveness of this process. More importantly, we have to ask, if and how much heating by outer perturbations the old inner-disc populations need to acquire enough random motion to form the thick disc. Similarly, we have been able to identify the observed inverse correlation between azimuthal velocities and stellar metallicities in the thick disc, as a clear indication that the thick disc was growing in scale-length during its formation on a time-scale of a couple of Gyrs. The need for merging galaxies to explain the thick disc may still arise with an exact determination of secular heating processes. With *Gaia* data, we will be able to reconstruct the secular/internal heating in the younger populations, and can use this to discriminate between internal and external heating for the older populations finally to shed light on the further history of the Milky Way.

More importantly, these ingredients are providing us with analytical models that can cover the correlations between stellar ages, kinematics, and metallicities. All modern surveys suffer from strong selection biasses, and only a comprehensive model can cover them. This will help us to map out the distribution of dark matter throughout the Galaxy. To take a simplified one-dimensional explanation: we can measure the Galactic gravitational potential away from the disc plane by comparing the motions and densities of stars at lower altitudes to their motions and densities at higher altitudes above the disc plane (*i.e.*, the larger their random velocities, the slower their density declines towards higher altitudes, and the steeper the gravitational well, the faster is this decline). When one has determined the gravitational potential with high precision, subtraction of the known effects of the visible baryonic matter (gas and stars) delivers the dark-matter content or allows us to discriminate against alternative gravity models like MOND. Similar to the advance in modelling dynamics, this will raise the discussion from studying rotation curves to exploring three-dimensional maps with hitherto unknown precision. Beyond the question of existence and amount of dark matter, this will even discriminate against different dark-matter models, and address questions such as whether there is a dark-matter disc component (that could be linked to particle interactions) or just a dark halo. However, the stellar populations we measure in the disc plane (mostly dwarf stars) are not the same populations we measure far from the disc (mostly giants), *i.e.*, we cannot naïvely equate them, but have to use comprehensive models to control the biasses from these selection effects. Otherwise, the wealth of upcoming data turns into a major danger for our field, since increasing precision and sample sizes make systematic biasses the dominant sources of uncertainty.

After all, these are exciting times! While in the past years we have qualitatively found new processes like radial migration, the presence of dark matter, and inference about the physics and history of the Galactic disc, the next years will turn Galactic astronomy into a high-precision science, where our qualitative knowledge will actually be quantified.

The President. We have a very brief time for one or two questions.

Dr. D. Kong. When you do the statistics of the thick scale height of the disc, do you distinguish between the spectral types of the stars, because if you use early types, like giants, then this scale height would be less than 100 pc and you can't see the thick-disc.

Dr. Schoenrich. Yes, of course, which is also what we see in the other plot — all the thick-disc stars are relatively old. What we need to know, though, is the precise age distribution.

Dr. Kong. What data set do you use, what catalogue do you use?

Dr. Schoenrich. This was from the *SDSS* catalogue and the high-quality spectroscopic data were from Bensby *et al.* who analysed them by hand, which ensures better data quality than most automated pipelines.

Dr. S. Jheeta. I just wanted confirmation that I heard you right about the surfer — that he has to have a certain speed. For example, it has to be fast enough to keep up with the wave — is that what you said?

Dr. Schoenrich. He has to have the speed of the wave to couple into the wave. So he has to have approximately the same speed as the wave when he enters, and that's exactly the same as what happens for the stars.

The President. We have to move on. Thank you very much indeed, Ralph. [Applause.]

The second Winton Capital award, now for geophysics, is given by Dali Kong of the University of Exeter, and the title is 'The mysterious interior of Jupiter and NASA's *Juno* mission'.

Dr. Kong. Jupiter is the biggest planet in our Solar System. In terms of diameter, it is more than ten times larger than the Earth. Unlike the Earth, Jupiter is made mainly of hydrogen and helium gases and probably contains an Earth-sized rocky core at its centre. Jupiter is a fast-rotating planet whose 'day' only takes 9·925 hours. Its enormity, gaseous compositions, and fast rotation result in an interior status and observational features that are very different from our familiar Earth's. Scientists are fascinated by Jupiter not only because of the scientific significance of fundamental gaseous planetary physics but also, perhaps more importantly, because Jupiter represents a large variety of planets discovered in extrasolar planetary systems. In all aspects, to study and understand Jupiter, including its structure, atmospheric circulation, internal fluid dynamics, dynamo process, *etc.*, is highly desired.

However, it is not easy to achieve that goal. Hundreds of millions of kilometres away from the Earth, Jupiter hides all the secrets we want to know underneath its thick gaseous envelope. It is neither possible to look directly into its interior nor practical to set up any instrument in/on it to measure directly physical conditions such as pressure, temperature, and composition. People have thought of various ways of seeing deep under Jupiter's cloud level, among which the gravitational effect is extremely promising, because gravity is directly associated with all the interior mass distributions and fluid-dynamical processes. Highly accurate measurement of Jupiter's external gravitational field will be likely to tell us a lot about its interior situations. Based on this principle, NASA's *Juno* spacecraft, which was launched in 2011 and arrived at Jupiter in 2016, is carrying out unprecedentedly precise observations of the gravitational field from polar orbits that are very close to Jupiter.

A gravity measurement yields the total result of the superposition of all interior information. All processes, such as the hydrostatic-equilibrium structure, solid-body rotational distortions, zonal-flow perturbations, and deep-interior convective motions, together produce the overall measured gravity. In an indirect manner, the equation of state of the gases, geometric shape of the planet, abundances of compositions, existence and properties of an inner core, dynamo processes, *etc.*, are also reflected by the gravity. The puzzle therefore is how to extract contributions of gravity signals from the particularly interesting sources, *e.g.*, those arising from Jupiter's zonal winds.

Alternating, fast, cloud-level zonal winds on Jupiter have been measured for several decades, but how deeply they penetrate into the Jovian interior, which is closely associated with the origin of the winds, still remains controversial. The structure of Jovian zonal winds is related to the fundamental dynamics of Jupiter's interior. *Juno*'s measurements are very much expected to help answer this important question.

In the 18th Century, Colin Maclaurin realized for the first time that an isolated, homogeneous, self-gravitating fluid will form a perfect oblate spheroid when a uniform solid-body rotation is present. A spheroidal approximation is generally good for nearly-incompressible terrestrial planets like Mars, Venus, and, of course, Earth. However, in the case of Jupiter-like gas giants, their interiors are highly compressible and inhomogeneous. As a result, to the first order, even without taking into account any disturbances caused by flows, the hydrostatic equilibrium under self-gravity and rotational centrifugal force is generally in an irregular shape, slightly departing from an oblate spheroid. The irregularity causes small-scale gravitational signals that are large enough to be detected by *Juno*. More crucially, without properly modelling such small-scale irregularities, gravity components caused by weak interior flows *cannot* be separated from the total measurement because of their similar strength. We have developed the world's first, fully three-dimensional, non-spheroidal numerical model for the gravitational field of rapidly rotating gaseous planets, when the rotational distortion is too large to be regarded as a small perturbation. Based on this accurate hydrostatic model for Jupiter, we can compute self-consistently the gravity signals resulting from Jupiter's deep zonal winds and determine the penetrating depth of the winds by comparing the model-predicted gravitational moments with *Juno*'s observations.

Jupiter possesses the strongest planetary magnetic field in the Solar System, more than ten times greater than that of Earth. It is widely accepted that the Jovian magnetic field is generated by convection-driven motion in the deep metallic-hydrogen region of the planet. However, we know very little about the amplitude and structure of the convective motion, and we do not even know the depth at which the Jovian dynamo operates. Magnetohydrodynamic dynamo processes taking place in the Jovian deep interior are highly complex: thermal buoyancy forces in the metallic region drive convective motion which is strongly controlled by Coriolis forces and which, through magnetic induction, converts the mechanical energy of the fluid motion into the ohmic dissipation of the magnetic field. Though progress has been made in modelling the Jovian convective dynamo, achieving the realistic physical parameters will, in all probability, never be possible and extrapolating the convective dynamo from a numerically accessible model over many orders of magnitude would lead to a large uncertainty. We have proposed that high-precision measurements of the Jovian gravitational field can provide a window into the phenomenon. We calculate the gravitational signature of non-axisymmetric convective motion in the Jovian metallic-hydrogen region and show that with sufficiently accurate measurements it can reveal the nature of the deep convection.

Juno is doing its job in its orbit. With observational results arriving in the coming months, we will apply our models to interpret them and deduce the mysterious interior of Jupiter. In the near future, similar observations for Saturn will be made by the *Cassini* spacecraft in its 'Grand Finale'. Saturn is another important gaseous planet that bears lots of interesting features. We expect that the model for Jupiter will be applied to Saturn very straightforwardly after some minor modifications. In the long term, provided that observations of exoplanets become more abundant and detailed, by virtue of our models that have been tested within our Solar System, we hope to understand more deeply the gaseous planets in our Universe.

The President. Thank you very much indeed. We have time for a few questions.

Professor D. Lynden-Bell. Presumably, if one thinks of Jupiter as a great big spinning thing, it's got normal modes, and presumably there are a whole lot of normal modes, as there are in the Earth, but easier because it's rather solid. Do people work on the normal modes in Jupiter or not?

Dr. Kong. I want to say sorry because I'm not familiar with these relevant researches. I don't quite understand what you mean by normal modes; is that the change of shape?

Professor Lynden-Bell. It's the Kelvin modes: if you kick Jupiter it will vibrate just like a star, or the Earth will vibrate.

Dr. Kong. I see. I don't think that will happen because Jupiter is not like a star and it doesn't have a very energetic interior energy source, so it is not like stars where you have nuclear reactions producing tremendous amounts of energy, and if it has any fluctuations it will be reflected by the global oscillations. At the beginning Jupiter was much larger than the current size and because of the gravitational shrinkage it becomes smaller and smaller, denser and denser, and less compressible. Meanwhile, because of the conservation of angular momentum its rotation goes faster and faster; but all these processes are taking place gradually.

Professor Lynden-Bell. There will nevertheless be normal modes. They may not be excited and what you're saying is they're not excited.

Dr. Kong. I don't think they're excited.

Dr. J. G. Morgan. If you refer to *Monthly Notices*, I think in 1994, my friend Douglas Gough got a paper out just in time before the Shoemaker–Levy impacts would have given the planet a jolly good kick, and I think his conclusion was that nothing would have been detected. I may be wrong.

Dr. Kong. Thank you.

Dr. Schoenrich. If you have those internal convection zones, could you pin down the metal content of Jupiter? It's important for chemical-evolution models.

Dr. Kong. I don't think from the internal convections you can.

Dr. Schoenrich. But if you have a more-precise mass model can you tell how large the nucleus is?

Dr. Kong. Even *Juno* cannot measure the real mass of the core, it's too small. You can incorporate a core into your model of the internal structure but I don't think you can measure the core directly.

Dr. Schoenrich. Exactly — so what measurements would you need to get its composition?

Dr. Kong. You mean the composition of the core of Jupiter? If you want to know the composition of Jupiter, it is mainly like that of a star, hydrogen and helium. It is of similar composition but it contains some compounds like ammonia. It would be reflected in the equation of state. The equation of state will enter the equilibrium model, so if you have higher-accuracy observations it is possible to do the inverse problem.

The President. We must move on, so thank you very much indeed. [Applause.]

We now come to the 2016 James Dungey Lecture which will be given by Betty Lanchester of the University of Southampton. The title is 'Some remaining mysteries in the aurora'.

Professor Betty Lanchester. [It is expected that a summary of this lecture will appear in a future issue of *Astronomy & Geophysics*.]

The President. Thank you very much indeed. We have five minutes for questions or comments.

Professor Kathy Whaler. You mention *MAGSAT*; I wonder if there's any scope for using the current *Swarm* constellation of satellites to investigate this?

Professor Lanchester. Yes, I am actually working with an ISSI group looking at *Swarm* data. I almost decided to use that as an example here, but it's a more complicated event and the resolution was not as good — well, it's different. *MAGSAT* was fantastic at the time, as it was low altitude and quite high resolution. *Swarm* is more complicated for me to understand but I'm looking forward to doing that in the near future, definitely.

Professor Whaler. It'll get lower. [Laughter.]

Professor Lanchester. Yes, it will, and the data will certainly be very valuable for understanding currents in auroral regions. I need to work on that event — my next job.

Professor Whaler. It's interesting because the evolution of the constellation is under discussion and whether we should bring them down during solar minimum. It might be more interesting for you to have them down during solar maximum, although obviously that would curtail the lifetime of the mission.

Professor Lanchester. I'm looking forward to seeing how important such changes may be.

Mr. C. Taylor. I hate to risk making a fool of myself by asking, probably, a very silly question. The standard model of the aurora is externally driven: the energy input is from the solar wind. Is there any possibility that there could be any role for input or driving from within? From the Earth's atmosphere? I'm asking that question for one particular reason, and that's for the comparatively recently discovered sprites at the top of thunderclouds at the moment of a conventional discharge; they're rather auroral-looking things. Is there any possibility of these injecting energy into the ionosphere and into the process?

Professor Lanchester. Well, it's not a silly question at all. I don't know enough about sprites, so I am assuming that their process is different. The aurora would not occur without the ionosphere. Although the solar wind is pulling the magnetic-field lines, the drag of the atmosphere at their feet means that the aurora is definitely generated by the charged atmosphere, but it's a feedback process. Something has to start it, a disturbance in the magnetic field or something has to cause the ionosphere to do its thing. It's got to be hit by something; that means currents have to flow.

Mr. Taylor. Some sort of seed energy, as it were?

Professor Lanchester. Yes, definitely. The atoms and molecules have to be hit by electrons to cause them to be ionized and excited. But the whole process is a feedback loop, with the ionosphere being as important as the initial disturbance, with currents flowing in the circuit, and ionospheric conductance and density variations being crucial for the resulting auroral structures.

Professor P. Cargill. Having seen the simulations at the end, which are very impressive, I think you need to invoke a resistivity, and this is an old story in physics — micro-instabilities. What is the current thinking of Antonius Otto and company about what the process is — what the micro-instability is?

Professor Lanchester. Antonius always says we're not actually working out what it is, we're working out what happens. There are lots of candidates — I don't think we can know. There are other ways of getting a parallel electric field: you can get it from Alfvén waves; shear Alfvén waves cause a different sort of aurora but in the simulation it is just a resistivity which is caused by instabilities driven by electrons drifting too fast with something trying to stop them. That's a hand-wavey answer, I'm sorry!

Professor Cargill. That kind of instability goes on, off, on, off, on, off very quickly. Does that fit in with this picture?

Professor Lanchester. I think it's very difficult: it's just one of the puzzles, the temporal changes that we see.

Professor Cargill. I'm talking about the micro-instability — you said it's at a threshold.

Professor Lanchester. Yes, reconnection occurs only under the right conditions. Indeed, we need more data to feed into the simulations. Well, Antonius is now retired and working on research, so hooray! [Laughter.] I'm looking forward to that. As I said, I chose a new event as more interesting for me to talk about, but now it needs more work.

The President. I think you've satisfied everybody. Betty, thank you very much indeed for the Dungey Lecture. [Applause.]

That concludes today's programme. Could I invite you to a seasonal drinks reception in the RAS library starting now? Finally, I give notice that the next monthly A&G open meeting of the Society will be on Friday 10th of February.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2017 February 10 at 16^{h} 00^{m}
in the Geological Society Lecture Theatre, Burlington House

J. C. ZARNECKI, *President*
in the Chair

The President. Good afternoon ladies and gentlemen, Fellows, guests. Welcome to the monthly Open Meeting for February 2017. We had Council today that apparently took place, according to the agenda, in 2016. [Laughter.] We now move to the programme and we start with the presentation of the Michael Penston Thesis Prize talk. This will be given by Matt Nicholl, now at the Harvard–Smithsonian Center for Astrophysics. The title is 'Unmasking the power source in super-luminous supernovae'.

Dr. M. Nicholl. I'd like to thank the RAS for inviting me to speak today. I'm going to talk about super-luminous supernovae, but it is worth remembering what we know about normal supernovae. Stars more massive than about eight solar masses end their lives when their iron cores collapse to neutron stars. Meanwhile their outer layers are violently ejected in supernova explosions.

The luminosity can reach a billion times that of our Sun, and remains high for weeks or months due to the decay of radioactive ^{56}Ni produced in the explosion. Although supernovae have been detected as far back as 185 AD, and discovered in significant numbers throughout the 20th Century, until about 2005 supernova searches were subject to an unavoidable bias. To maximize the number of supernovae discovered, surveys targeted massive, nearby, star-forming galaxies.

Modern surveys, however, have numerous advantages including CCD cameras with several-square-degree fields of view, robotic telescopes, and sophisticated image-processing software, which together enable us to pick out new supernovae anywhere on the sky. This strategy has led to the surprising discovery that otherwise anonymous dwarf galaxies can play host to explosions that are 100 times brighter than any previously known type of supernova. These new 'super-luminous' supernovae, or SLSNe, were missed for so long not only because of their preference for obscure galaxies, but they are also 10 000 times less common by volume than normal supernovae. Their discovery opens up exciting possibilities to find supernovae in the very distant Universe, perhaps allowing us to see the deaths of the first generation of stars, and to probe cosmological expansion further than ever before. But what actually powers these tremendous explosions?

Could it be that SLSNe are 100 times brighter than normal supernovae due to an overabundant production of ^{56}Ni by a similar factor? A normal core-collapse explosion synthesizes about 0·1 $M_\odot$ of ^{56}Ni, so SLSNe would need to make around 10 $M_\odot$. Interestingly, there is one model where this can happen. Stars with main-sequence masses of 140–260 $M_\odot$ are expected to undergo a 'pair instability' during core oxygen burning where photons are converted to electron–positron pairs, leading to a runaway thermonuclear reaction. This would unbind the entire star and produce a lot of heavy elements, including the required mass of nickel.

In 2011–2012, the *Pan-STARRS* survey discovered two SLSNe very soon after they exploded. We analysed the light-curves and found that they took approximately 50 days after explosion to reach their maximum brightness. The luminosity rise time is governed mainly by the time-scale for photons to diffuse out of the supernova ejecta. In models of pair-instability supernovae, the huge ejecta mass (over 100 $M_\odot$) necessitates a slow rise of about 100 days. The relatively short rise times of SLSNe therefore argue against such massive ejecta. This makes it very difficult to reconcile the observations of SLSNe with any realistic models powered primarily by ^{56}Ni decay. We have continued to build up a sample of SLSNe with well-observed rise times, and in fact it seems that most events have an even shorter time-scale than our early objects from *Pan-STARRS*. Using the light-curve width as a proxy for ejecta mass, it seems that the vast majority of SLSNe eject substantially less than about 30 $M_\odot$ of material.

Some SLSNe show narrow hydrogen emission lines in their spectra, and these are now thought to be powered by efficient thermalization of the explosion kinetic energy in a collision with a dense circumstellar medium (CSM) expelled by the star in the decades before explosion. Much more mysterious are the hydrogen-poor SLSNe. These initially show very blue spectra with absorption from ionized oxygen and doubly-ionized iron, and as they cool show lines of magnesium, calcium, and silicon. In fact, after a few months from explosion these cooler spectra closely resemble normal type-Ic supernovae.

Two main mechanisms have been proposed to explain this latter group of hydrogen-poor SLSNe. One is an interaction with hydrogen-free CSM, while the other is broadly referred to as the 'central engine' model. In this case, the core of the star releases rotational energy into the supernova ejecta, most likely in the form of magnetic-dipole radiation from a strongly magnetized millisecond pulsar, or magnetar. If the time-scale of the magnetar spin-down is comparable to the photon diffusion time-scale, a bright light-curve can result. Model fitting by various authors has shown that both of these models can fit the light-curves of known SLSNe. Therefore we must use other clues to break the degeneracy and determine the power source.

Since SLSNe are so rare, one essential strategy is to conduct detailed studies of the most nearby events. In 2016, the *Gaia* satellite discovered one of the closest SLSNe to date, named Gaia16apd. This object showed the typical blue spectrum and oxygen lines in the optical régime, but amazingly it was more than five times brighter in the ultraviolet than any other SLSN during the first month after explosion, indicating that the ejecta were very hot during this phase. This UV excess was relatively short-lived however, and at later times Gaia16apd looked much like other SLSNe at all wavelengths.

Several UV spectra of Gaia16apd were obtained with the *Hubble Space Telescope*. They showed deep, broad absorption lines, much stronger than those in the optical, which have previously been identified in other SLSNe as blends of carbon, titanium, magnesium, and silicon. Measuring the equivalent widths of those lines showed that, despite the overall higher UV flux in Gaia16apd, the amount of light absorbed by the lines relative to the continuum was very close to that of other SLSNe. This strongly suggests that the energy powering the UV excess in Gaia16apd must come from inside the fastest SN ejecta, as an external source of heating would serve to increase only the continuum and therefore dilute the line strengths compared to other objects. In fact, modelling the light-curve of Gaia16apd using a magnetar central engine revealed a very consistent picture in which a slow spin-down time provides an unusually energetic heating source (compared to similar model fits to other SLSNe) over exactly the duration where we witnessed the UV excess. This supports a picture where all spectroscopically similar SLSNe may be magnetar-powered, but with a diversity of engine time-scales naturally accounting for differences in the temperature evolution.

Another recent SLSN has provided an even more direct clue to the power source. SN 2015bn is a nearby explosion discovered independently by *Pan-STARRS* and the Catalina Sky Survey, and is now the best-observed SLSN in terms of dense photometric coverage, a high-signal-to-noise spectral time series, and deep radio and X-ray limits. A combination of a slowly-fading light-curve with its proximity allowed us to follow the evolution of SN 2015bn for longer than any other SLSN, with observations covering around 500 days from explosion. After such a long time of expanding and cooling, most of the ionized gas in the ejecta has recombined, and the density is low enough for us to see through the ejecta into the heart of the explosion. We obtained a spectrum of SN 2015bn during this late-time nebular phase, and found that the hot continuum component vanished and was replaced by broad emission lines — primarily oxygen, calcium, and magnesium, with some iron. The oxygen-line ratios suggested around 10 solar masses or more of oxygen, implying a massive progenitor star, and the widths of the lines require a kinetic energy greater than most supernova explosions by a factor of a few.

Two other properties of the spectrum were particularly illuminating. A relatively narrow oxygen recombination line was seen at 7774 Å, which is indicative of a dense inner shell. Even more excitingly, the spectrum bore an uncanny resemblance to the late-time spectra of the hyper-energetic supernovae that accompany long gamma-ray bursts. Long GRBs are caused by powerful engines in young core-collapse supernovae, that drive a relativistic jet through the ejecta. That the innermost structure of SN 2015bn resembled a GRB supernova so closely suggests that it too probably formed an engine, but one that released its energy at later times to heat up the ejecta rather than driving a jet. As all hydrogen-poor SLSNe have occurred in similar dwarf galaxies to GRBs, this observation also confirms a long-held suspicion that SLSNe and GRBs are related.

In summary, multiple lines of evidence, and in particular the spectroscopic properties of SLSNe, strongly indicate a central power source. The outstanding candidate seems to be a millisecond magnetar, as this provides both the requisite energy and time-scale to power their sustained luminosity and high temperatures. However, many questions remain unanswered. In particular, we are yet to understand the differences in stellar evolution in dwarf galaxies that enable SLSNe to form such engines during core-collapse, but metallicity seems to be the key ingredient. The coming years promise to be an exciting time for finding and understanding these most extreme supernovae.

The President. Thank you very much indeed, Matt. We have time for a couple of questions.

Dr. A. Ingram. These are very special supernovae. In the central-engine model, what is so special about the progenitors? Why do some form gamma-ray bursts and some just normal supernovae?

Dr. Nicholl. I think this is the same question of why do they only occur in dwarf galaxies. There's something special about some kinds of stars that allow them to form engines where other stars don't. The simplest kind of thread you can run through this is that all these core-collapse supernovae form neutron stars, and it depends on the spin period and magnetic field of the neutron star whether this is a super-luminous supernova, if it's got an engine with a long time-scale; a gamma-ray burst, if it's got a shorter time-scale; or a normal-luminosity supernova if the time-scale is either extremely long or it doesn't form an engine at all. I think the key ingredient is probably metallicity and how that affects the core rotation, but currently we're quite hazy both on the theory and in observations. We don't have observations of the actual stars in these dwarf galaxies. It's an integrated metallicity, so we don't really know which stars are causing it. People also bring in binary stars and whether they help to spin up the core — I think that's the next question. I think we're now confident that this is roughly what the power source is. Now it's a question of how you actually get there from stellar evolution.

The President. You said early on, if I understood correctly, that there had been a technological change that now makes surveys not just more sensitive but unbiassed — what are you referring to there?

Dr. Nicholl. It's a combination of having robotic telescopes now that can just take snapshots of the whole sky, and the large CCDs that mean you can see the whole sky on a relatively short time-scale. There's also the software side. To detect transients is not an easy task. It takes a long time actually to pick out what's new on the sky, so you really need the computing power to look at the images and see what is new and subtract the images from each other to see if these sources pop out.

Professor P. G. Murdin. The real smoking gun for the central-engine model would be to see the magnetar. Is there any prospect of that?

Dr. Nicholl. Actually, just in the last month or so the first kind of scenario where you might see it has come out. There's been a lot of talk about fast radio bursts lately and there was the first localization of a fast radio burst, in a very similar host galaxy to where we find super-luminous supernovae, in the last month or so. There's actually a quiescent radio source there — if that's connected to the fast radio burst and it's in the same type of galaxy then perhaps the quiescent radio source is actually an old super-luminous supernova and we're seeing radio emission from the central compact object. I'm involved in a project now to chase up all the host galaxies of these things and see if we can detect similar radio sources.

The President. We must move on. Thank you very much indeed, Matt. [Applause.]

Our second speaker today is Richard Parker — he was awarded an RAS Research Fellowship in 2013, which he took to Liverpool John Moores University, but he has now moved on to a Royal Society Dorothy Hodgkin Fellowship at Sheffield. The title of his talk is 'The origin of the Galactic field: where are the suns born?'

Dr. R. Parker. Stars in the disc of the Milky Way galaxy, of which our Sun is an example, do not form in isolation, but rather in groups of between 1 to 10 million other stars. The stellar number density of these groups is observed to exceed the current density in the Sun's local environment by factors of between 10 and 10 million. However, one of the outstanding unanswered questions in star-formation research is that we do not know what the typical, or average, stellar density is for star formation (or even if star formation produces a typical stellar density).

This uncertainty has profound implications for many other astrophysical processes. We observe discs of dust and gas around the youngest stars as they are forming. These protoplanetary discs rapidly disperse within the first 10 million years of a star's life, implying that planets form quickly during a time when the stellar density is much higher than it is around older stars like the Sun.

At these early ages, if a star-forming region is dense enough, the intense ultraviolet radiation from stars much more massive than the Sun can truncate or destroy protoplanetary discs. Once the planets have started forming, dynamical interactions between passing stars can disrupt the planetary orbits, and even remove planets from their host stars. The orbits of extrasolar planets are in many cases very different from those in our own Solar System, and one potential reason is the dynamics of the environment in which they were born.

On larger scales, the relative grouping of stars determines the overall evolution of galaxies. If all stars form in very dense, compact 'star clusters', then the ionizing radiation from the most massive stars — referred to as 'feedback' — acts to limit how efficient the star-formation process is. If star formation generally occurs in low-density regions, then feedback from massive stars cannot be the main regulator of star formation in galaxies.

The question my research attempted to address during my RAS Fellowship was the following: what is the typical density of star formation, and what are the implications for planet formation?

The present-day density of star-forming regions tells us little about their birth density, because dynamical processes can both increase and decrease the initial stellar density. The measured present-day densities in star-forming regions are therefore consistent with both high (>1000 stars/pc^3) and low (<100 stars/pc^3) initial stellar densities.

In order to break this density degeneracy, my collaborators and I have been pioneering techniques to harness the spatial and kinematic information in star-forming regions, and to compare simulations with observations to infer the initial density of star formation. Observations of the very early stages of star formation show that regions are spatially and kinematically sub-structured. In other words, the stars have a hierarchical (often fractal-like) distribution, and their velocity dispersions on local scales are very low (subvirial).

We set up N-body simulations with those initial conditions and followed their evolution over time. The N-body simulations assume that the stars are point-mass particles, and that star formation is instantaneous, but do not model the conversion of gas into stars. However, they have the advantage over hydrodynamical simulations of star formation in that they are computationally inexpensive, and so vast swathes of parameter space can be explored. They were therefore ideal for the large-scale analysis required to determine the initial density of star formation. To this end, we varied the mass, density, and virial ratio of our star-forming regions and followed their evolution over 10 Myr.

Star-forming regions that are set up with small local velocity dispersions rapidly collapse to form a spherical, centrally-concentrated star cluster. We quantified the evolution of the spatial structure in these star-forming regions and their transition to star clusters using the Q-parameter. The Q-parameter uses a graph-theory approach to draw a minimum-spanning tree (MST) between all the stars, which connects all of the stars with a continuous line with no closed loops. The mean edge length of this MST is then divided by the mean separation between all of the stars in the distribution to obtain the Q-parameter. For a hierarchical or sub-structured distribution $Q < 0{\cdot}8$, whereas for a smooth or centrally concentrated distribution $Q > 0{\cdot}8$.

Comparing the Q-parameter from simulations to observations immediately solves the density degeneracy problem. Very dense simulations (>1000 stars/pc^3) undergoing cool-collapse attain much higher Q-parameters than most nearby star-forming regions, with the exception of the Orion Nebula Cluster (ONC). This is an interesting point in light of our earlier considerations of the birth environment of planetary systems, as the ONC contains massive stars that appear to be photo-evaporating the discs of planets in that star cluster.

However, using the Q-parameter alone cannot distinguish between subtly different modes of the evolution of star-forming regions. For example, a collapsing region may have a very similar Q-parameter to an expanding region that has undergone some dynamical evolution prior to its expansion phase.

To overcome this problem, we also incorporate information on the relative densities of massive stars with respect to the lower-mass stars. The local surface density is calculated for each star, and then the median for the entire region is compared to the median surface density of a chosen subset (in this case the ten most massive stars). The ratio of these median values is the 'local surface-density ratio', $\Sigma_{\rm LDR}$.

When a region is undergoing core-collapse, the massive stars tend to sink to the central locations faster than lower-mass stars (a process called 'dynamical mass segregation'). This causes the most massive stars to have higher-than-average surface densities. However, when a dense region expands from birth, the most massive stars also attain higher-than-average surface densities because they dominate their local potential, and sweep up retinues of lower-mass stars.

By comparing simulation data of the evolution of structure (quantified by the Q-parameter), and the local surface density, $\Sigma_{\rm LDR}$, we have shown that most nearby star-forming regions have relatively low initial densities (~100 stars/pc^3). These densities mean that perhaps 5–10% of planetary systems would be affected by their birth environment. Furthermore, using the $Q - \Sigma_{\rm LDR}$ relation, we have been able to rule out super-virial (expanding) motion in star clusters, which was postulated as a smoking gun for the rapid removal of gas left over from star formation.

The next stage of this research, which we have only just started, is to incorporate information on the velocities of stars. The most common approach is to measure the line-of-sight radial-velocity dispersion and to determine whether a star-forming region is in virial equilibrium or if it is super-virial. Our initial results are quite worrying, because the velocity dispersion often suggests a region is expanding, whereas the true virial ratio is in equilibrium (and this is corroborated by the spatial information).

Given that most star-forming regions appear to be relatively low density, we can start to ask the question of where our Solar System fits in the context of extrasolar planetary systems. The presence of short-lived radioisotopes in Solar System meteorites was thought to constrain highly the Sun's birth environment, but recent work by two of my students has shown that radio-isotope-enrichment levels in the Solar System may be the expected average from star formation.

In summary, while we have established that most star-forming regions have relatively low initial stellar densities, they are not so low that they can be completely ignored in the context of planet formation. Furthermore, new and upcoming facilities (*e.g.*, *ALMA*, *Gaia*) will provide so much more information on the stellar velocities that a clearer picture of the initial conditions of star formation will be possible in the next decade. Finally, I would like to thank the RAS for sponsoring this research.

The President. Time for a few comments and questions.

Professor I. Crawford. The thing that's interesting is that the Sun's planets are in much more circular orbits than some of the other systems, so is that consistent with your argument that the cluster in which the Solar System formed may not have been very massive?

Dr. Parker. Yes, I think the density in which the Sun, and most stars in the local neighbourhood, formed could disrupt maybe 5% of planetary systems; 95% are obviously unscathed, so I think the Solar System is not inconsistent with that.

The President. It sounds like everybody is completely clear. Richard, thank you very much indeed. [Applause.]

Our third talk today celebrates the RAS Group Achievement award in Geophysics which went to the *EISCAT* consortium, and they're represented today by Ian McCrea of the Rutherford Appleton Laboratory, and he will talk on '*EISCAT_3D*: the future of incoherent-scatter radars'.

Dr. I. McCrea. I would like to start by thanking the RAS for giving us the Award. I want to talk about what *EISCAT* is going to do in the near future, as we have a new facility to develop. The *EISCAT* Scientific Association is based in Sweden and was founded in 1975. The headquarters are based in Kiruna whilst our other facilities are in Norway (which includes Svalbard), Sweden, and Finland. There are six member countries: Norway, Sweden, Finland, the UK, Japan, and China; we also operate an affiliate class of membership which allows radar observing time to be bought as and when required. The current affiliates include Russia, France, Ukraine, and South Korea, and we are hoping to add new members to this class, including the USA and South Africa.

The current radar dishes are Cassegrain-fed instruments, with the exception of Tromsø, which is a VHF radar array covering 120 × 40 metres. We need to be sensitive to different frequencies in order to optimize our data from different layers in the upper atmosphere, ranging from 70 to 1000 km. The Earth's magnetic environment is complicated, so *EISCAT* is simultaneously operating facilities in the auroral zone (Tromsø) and under the polar cap (Svalbard), since the Earth's magnetic topology is different in those places.

We broadcast a powerful radar pulse, which is monochromatic in frequency, and receive in return a very weak signal, spread in frequency, which is scattered back by each consecutive layer of atmosphere. The spread of spectral frequencies provides a distinctive shape of the power spectrum, which tells us about the temperature, density, and composition of the upper atmosphere, and the collision frequency between the ionized particles of the ionosphere and the neutral particles of the upper atmosphere. Combining data from the three main sites also gives us 3D vector information about atmospheric movement.

This is not the only radar of its type in the world. The US operates a chain of such radars, stretching from Greenland down to Arecibo and Peru, close to the Earth's equator. There the magnetic-field lines are almost parallel to the Earth's surface, whilst at high latitude, where *EISCAT* is located, the field lines are highly inclined to the Earth. The Russians have an old defence radar now converted to incoherent scatter use, whilst the Ukrainians have one at Kharkov. Japan has a couple and the Chinese are developing new facilities, as are the Indians, although designed for slightly different kinds of science. The *EISCAT* location is special because it is located beneath the auroral oval and is also at the edge of, and occasionally underneath, the polar vortex, a characteristic circulation feature of the middle atmosphere, which is responsible for the ozone holes and which forms in winter but which breaks down in spring.

EISCAT's main job is to probe the structure and dynamics of the upper atmosphere. The ionosphere is difficult to predict, as it is affected from above by the Earth's magnetic field and geospace environment, and by winds and waves, for instance, from below. *EISCAT* has looked at the auroral energy spectrum and studied the very energetic particles coming into the Earth's environment from space. We have studied naturally-occurring plasma physics, but we can also drive our own plasma physics because we can transmit a powerful HF energy beam, which couples energy into the atmosphere, to carry out controlled experiments. The coldness of the middle atmosphere makes the presence of meteoritic dust easy to detect, through the accretion of charged ice, forming characteristic narrow layers. The polar region is convecting dynamically and transports and dissipates solar-wind energy, giving rise to small-scale irregularities which can affect communications, so this is one of the practical aspects of *EISCAT*'s work. We can also look at the solar wind *via* the scintillation of radio stars, as well as determining both the number and size of meteors. We can study indirectly the temperature and density of the neutral upper atmosphere, showing that, while the lower atmosphere is warming, the upper atmosphere is actually cooling.

In its first 35 years of operation, *EISCAT* has produced more than 2000 papers and 60 PhD theses, including mine. Plans for the future include trying to resolve smaller details inside our transmitted beam, which at present expands by 1 km for every 100 km. We would also like to expand our coverage area, either with very-rapidly-moving single beams or multiple simultaneous beams and to be able to operate continuously. We would like more sensitivity and the ability to probe further out into near-Earth space, but also to work at lower altitudes to look further down into Earth's middle and lower atmosphere.

These improvements were first considered in 2002, and in 2004 *EISCAT* applied to the European Union for funding. In 2005 we started a four-year design study and have since engaged in a lot of outreach and dialogue to gather the requirements of the scientific community. The resulting design looks a lot like the most recent designs for new low-frequency radio-telescope technology, which is not accidental, as a great deal of discussion has taken place with that community. The proposed new radar, called *EISCAT_3D*, has been added to the ESFRI European road map of scientific infrastructures, which is part of the European Union's future planning, and has opened the way to EU funding under FP7 and now H2020, supporting more development, field tests, and prototypes.

During the period of these studies, Dr. Anita Aikio (from the University of Oulu, in Finland) and I have been travelling around Europe for discussions with scientific partners asking them what they want to see in a new *EISCAT* radar. These inputs were then fed back to the engineers in order to try and come to a compromise between our scientific aspirations and what was possible technologically. The *EISCAT_3D* scientific case was published last year in *Progress in Earth and Planetary Sciences*. Many of *EISCAT*'s long-standing scientific targets will be achievable for the first time with the new facility, and in addition we are now discussing with our new partners in ESA to see how data from a continuously-operating radar can feed into the modelling and situational awareness of the upper atmosphere, to warn of changing space-weather conditions in response to such things as changes in the solar wind and the particle flux from outer space.

In addition to backscatter from the upper atmosphere, there will be a lot of returns from hard targets such as satellites and space debris, and some scientific communities are very interested in those. The enhanced capabilities of phased-array radar have in turn exposed certain security issues involving tracking space-based objects, which *EISCAT* has had to confront for the first time

Each sub-panel in the *EISCAT_3D* array will be made up of 91 antennae and the area of one *EISCAT_3D* site will cover approximately 400 square metres, which will be inherently scalable, simply by adding additional panels. The main transmit/receive array will be located near Skibotn in Norway, which is a good location considering the availability of roads, power, and general infrastructure, and will also enable the facility to provide supporting data for rocket flights from nearby launch sites in Sweden and Norway. The first two *EISCAT_3D* receiver sites to be constructed will be at Bergfors in Sweden and Karesuvanto in Finland. The power output of the present *EISCAT* radars is around 2 MW, but with the new facility we hope to reach 5 MW in the first instance, and ultimately expand to 10 MW power. Such an increase in power, combined with a larger receiving aperture, will widen our coverage and provide greater sensitivity. If sufficient funds become available, two further receiving sites will be added in due course, at Andøya in Norway and further south in Sweden.

At Skibotn, the large array will be supplemented with some smaller outlying imaging arrays. We'll use radio-telescope-type imaging algorithms to construct high-resolution images from this modular facility, in a similar way to distributed radio-astronomy facilities such as *LOFAR* and *SKA*. *EISCAT* is now in a phase known as "preparation for production" during which a test array, with one 91-antennae sub-panel, will be constructed and tested at Tromsø later this year. The initial construction of one full transmit/receive array and two receiving arrays, called "Phase 1", needs around £60 million of capital investment. So far, *EISCAT* has commitments for 75% of this amount, mostly from the Nordic countries. We have applied for UK capital money from the Autumn Statement but have not yet heard the outcome, as the science capital bids have not yet been decided. We hope that Japan and China will also be able to contribute. We would like to attract capital investment totalling around £75 million within a year or so, at which level there is a realistic possibility of getting Phase 1 constructed, together with some of Phase 2, in which the transmitter power will be increased to the full 10 MW.

The President. Ian, you mentioned that there were a couple of *EISCAT* people in the audience — why not introduce them?

Dr. McCrea. Let's see who is here. Anasuya Aruliah, from University College, has worked extensively with *EISCAT* over the years. Matthew Wild (my colleague at RAL) runs our database, and is sitting next to Anasuya. Also here is Mike Lockwood, from the University of Reading, who is one of the prime exploiters of *EISCAT*; I don't know how many tens of papers Mike has contributed to *EISCAT*'s publication list, but it is very many. There were several others who were at the geophysics discussion meeting over at the RAS earlier on today, so thanks to all of those.

Professor D. Lynden-Bell. What's the best discovery you can imagine?

Dr. McCrea. Well, I'm often asked the question "What is the Higgs Boson of *EISCAT*?" and I always say that's the wrong question. There is no single Higgs Boson discovery that would transform our community. I think the achievement that would make the whole community the happiest, and would be a collective achievement of the whole community, involves multiple facilities, together with our modelling capabilities: it would be to go as far down the road as we can toward the modelling and prediction of the very dynamic environment of the upper atmosphere and near-Earth space. I told you that the upper atmosphere is driven by energy from both below and above. There is a lot of energy dissipation and dynamics associated with this region, so it's highly structured and constantly changing. Does that mean we can never model it? Clearly not, because we have models that work to some degree already. What we're trying to do, not just because it improves our scientific understanding but it improves the practical use we make of the ionosphere, is to go as far as we can toward predicting where the aurora will be, where the convection will be, where the strong gradients will be, what the effects will be on communications and global positioning, and how atmospheric drag affects satellites. That's what people want to know and that's the jigsaw that we're helping to build, I think.

A Fellow. What will happen to the existing sites once *EISCAT_3D* is up and running?

Dr. McCrea. Do you want one, Colin? [Laughter.] No, the answer is that *EISCAT* does currently plan to decommission the Tromsø, Kiruna, and Sodankyla sites. We will keep the Svalbard radar running, because Svalbard is at higher latitude, on open field lines, it's newer (only twenty years old compared to our thirty-year-old radars further south), and does essentially different science. *EISCAT* has been approached by various groups who might be interested in using the radars for other purposes, including meteorological applications, and potentially making them into test beds for new radio techniques. In fact, it was originally thought it was going to be a very expensive exercise to decommission those radars, but it's not. It turns out that there's so much metal in them that the scrap value alone makes it quite cheap to decommission them.

Professor M. Lockwood. Ian, I should remind you that at the opening of the original *EISCAT* the King of Sweden said that he would buy the VHF because he thought it was beautiful. [Laughter.]

Dr. McCrea. Well, there you go! Is he still alive?

Professor Lockwood. It might be time to remind him of that. [Laughter.]

Dr. McCrea. That's interesting, I didn't know that.

The President. You alluded to the fact that you detect what presumably may be military satellites — but do you throw the data away or do you lock them up?

Dr. McCrea. This has actually become quite a sensitive issue to the extent that I have to be a little bit careful as to what I say about it. If you think about it, it's obvious that a very powerful scattering radar, intercepting a relatively large solid object, is going to get a very large echo from it. In principle, this means that *EISCAT* can see everything that drifts over it, above a few centimetres in size. When people realized that that was the case, it started to make them a little nervous. As a result, what *EISCAT* has decided is basically to clip out all those strong echoes and discard them before the data are distributed to the scientific community. However, there is the possibility, for researchers interested in using such data, to apply to *EISCAT* for permission to look at the high-power returns that would normally be thrown away. This is unlikely to be an issue for known objects and there are good reasons to track such objects, of course, if we want to understand what the heating and cooling of the upper atmosphere does to their orbits, for example. There is work going on with the European Space Agency now to detect space-debris fragments and to track some larger objects with *EISCAT*, for exactly this kind of scientific purpose.

The President. One last question there.

Dr. P. Wheat. A quick one: does that open up any possibilities of funding from the airline industry and space-debris people in terms of selling on your data?

Dr. McCrea. Not at the moment, but in the longer term it might. I already talked about the Space Surveillance and Tracking (SST) programme being done with the European Space Agency. The ESA space-debris people have been interested in *EISCAT* for a number of years, and if you look at their website you'll see pictures of *EISCAT* all over it. There is certainly the possibility to attract further ESA funding into *EISCAT* for that kind of work. The European Union is also running a similar SST study at the moment, though of course we don't know quite how we're going forward in any European Union programmes at the moment.

The President. On that happy note of not knowing where we're going [laughter], we need to move on. Ian, thank you very much indeed. [Applause.]

Our final presentation today is from the Astronomer Royal, Martin Rees, from the University of Cambridge, and the title of his presentation is 'Prospects for SETI and the Breakthrough Listen project'.

Professor Lord Rees. Speculations on 'the plurality of inhabited worlds' go back for centuries. From the 17th to the 19th Century, it was widely suspected that the other planets of our Solar System were inhabited. The arguments were often more theological than scientific — that life must pervade the cosmos, because otherwise such vast domains of space would seem a waste of the Creator's efforts. The Scottish physicist David Brewster (remembered for the 'Brewster angle' in optics) conjectured on such grounds that even the Moon must be inhabited. He argued that had the Moon "been destined to be merely a lamp to light our Earth, there was no occasion to variegate its surface with lofty mountains and extinct volcanoes, and ….. give its surface the appearance of continents and seas. It would have been a better lamp had it been a smooth piece of lime or of chalk".

The space age brought sobering news. Even Mars, the most Earth-like planet in the Solar System, was a frigid desert with a very thin atmosphere. But what has transformed and energized the whole field of exobiology is the realization that there are probably around a billion planets in the Milky Way that are 'Earth-like'. And there's even such a planet around the nearest star, Proxima Centauri. Those planets would be 'habitable'. But of course that doesn't mean that they are inhabited. Life's origin might involve a fluke. On the other hand, this crucial transition might have been almost inevitable given the 'right' environment. But serious biochemists are now addressing that question. Clues as to whether the nearest exo-planets harbour life will come, in the next decade or two, from high-resolution spectra using the *JWST* and the next generation of 30+-metre ground-based telescopes.

But even if primitive life were common, the emergence of 'advanced' life may not be. But that's the most fascinating question. That's why we should welcome 'Breakthrough Listen' — a major ten-year commitment by Yuri Milner to deepen the searches. The programme is initially utilizing time that's been bought on three major telescopes: an optical telescope at the Lick Observatory — looking for suspiciously narrow-band optical emission. The second and third are the Green Bank and Parkes radio dishes. Other telescopes, for instance *MeerKat* in South Africa, and ESO's optical telescopes, will soon be deployed. A new project spearheaded by Paul Horowitz of Harvard will search the sky for nanosecond flashes.

Conjectures about advanced or intelligent life are of course far more shaky than those about simple life. But I would venture two conjectures about the entities that SETI searches could reveal: (*a*) they will not be 'organic', and (*b*) they will not remain on the planet where their biological precursors lived. I base these guesses on extrapolating the far future of Earth-based life and technology.

The history of human technological civilization is measured in millennia (at most) — and it may be only one or two more centuries before humans are overtaken or transcended by inorganic intelligence, which will then persist for millions of years.

Suppose that there are other other planets where life began, and Darwinian evolution followed a similar track to what's happened here. Even then, it's unlikely that the key stages would be synchronized. If the emergence of intelligence on a planet lags significantly behind what has happened on Earth, then it reveals no evidence of ET. But life on a planet around a star older than the Sun could have had a head-start of a billion years or more, and have evolved well into the 'electronic' stage.

So we'd be most unlikely to 'catch' alien intelligence in the brief sliver of time when it was still in organic form. If we detected something manifestly artificial it would more likely represent a by-product (or even a malfunction) of some super-complex interstellar technology that could trace its lineage back to alien organic beings which might long ago have died out. Indeed, the habit of referring to 'alien civilizations' may be too restrictive. A 'civilization' connotes a society of individuals: in contrast, ET might be a single integrated intelligence.

But of course, in our state of ignorance about what might be out there, we should clearly encourage searches in all wavebands; we should also be alert for artifacts and other evidence of non-natural phenomena — for instance, Dyson spheres, artificially created molecules (or a mega-*EISCAT*!).

SETI searches are surely worthwhile, despite the heavy odds against success, because the stakes are so high that it seems worth a gamble — we'd surely all like to see searches begun in our lifetime. They interest a far wider segment of society than 'straight' astronomy.

Finally, there are two familiar maxims that pertain to this quest. First, 'extraordinary claims will require extraordinary evidence'. But, second, 'absence of evidence isn't evidence of absence'.

The President. Thank you very much, Martin, for taking us to such realms of imagination.

Mr. H. Regnart. Two comments, the first on contingency. It's worth remembering that the theropod dinosaurs didn't become extinct, and if the weather was a little better one would probably be singing in Berkeley Square. [Laughter.] There is a species of South American parakeet, apparently, which has approximately the same intelligence as the bonobo, our nearest mammalian intellectual rivals – approximately equal, apparently, to a bright four-and-a-half-year-old human, and this suggests that, like flight, intelligence has the potential to develop such as to be encouraged to occur whenever there's an opportunity, perhaps more than once. Second, when it comes to the extraterrestrial search for higher intelligence, an additional reason for funding shown by recent political events [laughter] is that life on Earth has proved a disastrous failure. [Laughter.]

Professor Rees. Some people would say we haven't detected things because that's true of these others as well, of course. And if we're going to detect something it's got to have a technology in advance of ours but be psychologically like us in that it wants technology. It's no good if they're living a contemplative life under some ocean — we won't detect them.

Dr. S. Jheeta. Thank you very much for the excellent presentation. My question is really simple. How far in terms of light years will we be able to detect, do you think, using the forthcoming telescopes like *ELT*?

Professor Rees. It absolutely depends on what the source is; we don't know. The Earth's artificial radars could be detected at a nearby star by a facility like Arecibo. At the other extreme, the sort of huge laser which Yuri Milner is trying to promote to send a small probe to our nearest star would be powerful enough to be detected at an extra-galactic distance, and you can imagine Kardashev's type-III civilizations, *etc*. It simply depends on what the power is, and since we don't know what the chances of these powerful things are, we should look for everything, and I think it's important to spend some fraction of the time not looking just at nearby stars anyway but scanning distant galaxies.

The President. Martin, if I remember correctly, you had some years ago cautioned against us broadcasting.

Professor Rees. No, Martin Ryle and Stephen Hawking have both said that [laughter]. Actually, I find it hard to take that idea seriously because I think if there really were intelligent aliens, they would know all about us already. They'd still want to know some things about us — I mean they'd know all our science but what they'd like to know if they did come here is about our biosphere. They'd know about evolution but they couldn't predict all the creepy-crawlies and all the life in the oceans and on the land. That's what they'd want to know if they came, but I don't worry about letting them know we're here. They probably know already if they are there.

The President. Sorry I accused you of that!

Reverend G. Barber. Having followed this search for about half a century now with great interest, I rather have to ask the question — how long do we go on searching before we decide we've drawn a blank, in what Paul Davies, in a recent book, called *The Eerie Silence*?

Professor Rees. I would say that obviously it depends on how many people want to try. I mean, do you want to go on trying even if the chance is small? What I would say, as we have more and more powerful telescopes, and more powerful techniques, is that it would be good to use a bit of the time on those instruments to deepen the search, because just as the Breakthrough Project is going to deepen the search compared to twenty years ago, we know that we'll have even deeper searches in twenty years' time. I think we should keep on going because however much we do, it'll be a mere tiny, tiny fraction of parameter space that we're exploring.

The President. This must be the final question.

Dr. Wheat. There seems to be a trend in communications these days to go encrypted and spread spectrum, which is going to be a lot harder to pick up, so it seems to me that what we've really got to catch is that transient phase when somebody is going through what we went through maybe twenty or thirty years ago. Have you any thoughts about how we're going to catch that?

Professor Rees. I think I should have said clearly that I think even if we detect something that is manifestly artificial, the likelihood that it's a message of any kind, still less a message we can decode, is very small. I think it's more likely to be some lasers or some malfunctioning machine or something like that. Of course, your point is an important one. If it was a message then we wouldn't know how to decode it, just as radio engineers who had never heard about FM would be flummoxed by present-day techniques and, of course, the optimum signal compression is to make something as like noise as possible, and so for all those reasons, obviously, it's hard. I think you've got to be an ultra-optimist to think that we'll detect a message that's aimed at us and intended for us to understand — there's a very low chance of that. But what I do think is worth looking for is some evidence of something that is artificial: a very-narrow-band signal, some kind of pulses, or even, of course, we should look for more exotic things, an artefact. For example, there was a star found by *Kepler* which was in fact natural but looked peculiar, and we might find some asteroid that is especially shiny and spherical or something like that. [Laughter.] I have no idea, but we should keep a look out for things of that kind.

The President. Well, thank you very much, Martin. Clearly you've stimulated us all, so can we thank Martin and, in fact, all of our speakers? [Applause.] I will just finish by reminding you that the next monthly Open Meeting of the Society will be on Friday 10th of March and, of course, I invite you to come to the drinks reception which is now in the RAS library.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 255: HD 143688, HD 153302, HD 153722, AND HD 155026

By R. F. Griffin
Cambridge Observatories

The stars discussed here came to attention when they were observed as part of the 'Clube Selected Areas' programme[1] of radial-velocity measurements. They are all in Area 1 of those Selected Areas, although HD 155026 was not actually on the programme but is near to a genuine programme star; it was initially observed just out of curiosity. The magnitudes of the four stars treated here range from about $8^{m}\cdot7$ to $9^{m}\cdot9$. HD 143688 and HD 153722 (only) are *Hipparcos* stars, but all four have good magnitudes and colour indices determined by the satellite's *Tycho* programme. Their orbital periods are inconveniently close to integral numbers of years — four in the case of HD 153722, two in the cases of HD 143688 and 155026, and one in the case of HD 153302, where the coincidence is so close (the discrepancy between the orbital period and one year is $1{\cdot}8 \pm 1{\cdot}8$ days) that a serious gap in the phase coverage of the orbit is unavoidable.

Introduction

Some recent papers in this series have presented orbits for stars that were observed in the course of the Cambridge programme on the 'Clube Selected Areas' radial-velocity programme[1]; this one is another. Like three of those in the immediately preceding paper[2] in this series, the stars treated here are all within Area 1 of the Clube Areas; another point of similarity is that one of the stars — in this case HD 155026 — is not itself eligible to be on the programme, but was initially observed casually, simply because it is close to a genuine programme star.

HD 143688

HD 143688 is to be found in the northern ('Caput') section of the constellation Serpens, slightly preceding and nearly 2° north of the fifth-magnitude A-type star π Serpentis. Although it is listed in the *Henry Draper Catalogue* as being of spectral type K0 (that being one of the defining selection criteria for the 'Clube' programme), a probably more acceptable classification of F6 V was made on the basis of slit spectrograms by Duflot, Figon & Meyssonnier[3]. The present writer has not seen any spectra of the star himself, but his ideas of acceptability are based on the measured colour index of the star, whose photometry has been given by Eggen[4] as $V = 8^{m}{\cdot}82$, $(B-V) = 0^{m}{\cdot}47$, $(U-B) = 0^{m}{\cdot}01$. Values transformed from *Tycho* are $V = 8^{m}{\cdot}80$, $(B-V) = 0^{m}{\cdot}50$. The $(B-V)$ index is far too blue to correspond to a spectral type of K0, but is nicely in line with the F6 classification.

There is a published radial velocity[5] of $+27{\cdot}2$ km s^{-1} for HD 143688 (the star is also noted as A.G. 7441 but the origin[6] of that designation is not noted); it came from the David Dunlap Observatory more than half a century ago and represents the mean from five photographic spectrograms obtained with a prism instrument giving 66 Å mm^{-1} on the 74-inch reflector. The 'probable error' of the mean is given as $3{\cdot}4$ km s^{-1} — it is the equal-seventh-worst value among all those of almost 1000 stars treated in that paper and not specifically noted as having variable velocities. The individual values are not available and so cannot be discussed in connection with the orbit presented below.

HD 143688 was placed on the Cambridge radial-velocity programme in the summer of 2003; the first observation showed a rotational velocity of 11 km s^{-1}, which might well have been related to a short orbital period; a second observation was made only three days later, but it agreed with the first one. The star was not observed again for a year, but then it had changed velocity by as much as 12 km s^{-1}, so after that it was observed more regularly — usually once a month during the season when it was readily accessible in the sky. There are now 63 Cambridge measurements, set out in Table I. They show an obvious period of a little over two years; the computed orbital elements are in the first numerical column of Table VI towards the end of this paper, and a

TABLE I

Radial-velocity observations of HD 143688

All the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O – C)* $km\ s^{-1}$
2003 Aug. 16·94	52867·94	+28·7	0·387	+0·8
19·88	870·88	28·0	·391	0·0
2004 Sept. 15·86	53263·86	40·6	0·899	+0·5
18·80	266·80	41·0	·903	+0·9
Oct. 7·77	285·77	39·4	·927	−0·4
2005 Jan. 23·28	53393·28	31·1	1·066	−0·3
Apr. 19·12	479·12	26·0	·177	−0·9
May 28·01	518·01	26·8	·227	+0·4
June 23·00	544·00	26·0	·261	−0·5
July 16·93	567·93	26·1	·292	−0·6
Aug. 15·88	597·88	27·2	·330	+0·1
Sept. 12·84	625·84	28·2	·366	+0·6
Oct. 20·76	663·76	27·4	·415	−1·0
Nov. 12·72	686·72	29·3	·445	+0·3
2006 Mar. 2·19	53796·19	32·6	1·587	+0·3
Apr. 5·10	830·10	32·8	·630	−0·7
May 3·07	858·07	35·0	·666	+0·5
June 1·04	887·04	34·5	·704	−1·1
July 3·98	919·98	36·5	·746	−0·4
Aug. 1·99	948·99	37·6	·784	−0·4
Sept. 8·87	986·87	40·6	·833	+1·3
Oct. 24·76	54032·76	38·9	·892	−1·2
2007 Mar. 2·23	54161·23	31·8	2·058	−0·2
27·12	186·12	30·7	·090	+0·8
Apr. 12·12	202·12	28·6	·111	−0·2
30·09	220·09	27·5	·134	−0·4
May 19·06	239·06	27·2	·159	0·0
July 7·00	288·00	26·6	·222	+0·2
2008 Mar. 5·21	54530·21	31·7	2·535	+0·7
31·16	556·16	32·0	·568	+0·2
May 3·09	589·09	32·2	·611	−0·7
Aug. 1·89	679·89	36·4	·728	+0·1
Oct. 2·83	741·83	38·3	·808	−0·3
21·75	760·75	39·2	·832	−0·1
Nov. 11·72	781·72	40·5	·860	+0·7
2009 Feb. 4·28	54866·28	38·0	2·969	−0·3
Mar. 6·23	896·23	36·3	3·007	+0·5
21·18	911·18	34·1	·027	−0·2
Apr. 2·14	923·14	33·2	·042	0·0
May 20·03	971·03	29·7	·104	+0·5
July 27·93	55039·93	26·7	·193	+0·1
Aug. 15·88	058·88	26·2	·218	−0·2
Sept. 10·84	084·84	26·6	·251	+0·2
2010 Apr. 8·15	55294·15	30·1	3·521	−0·6
July 17·97	394·97	34·4	·652	+0·3
Aug. 17·88	425·88	34·9	·692	−0·3
30·85	438·85	+36·0	·708	+0·3

TABLE I (*concluded*)

Date (UT)		*MJD*	*Velocity km s^{-1}*	*Phase*	*(O – C) km s^{-1}*
2012	Apr. 16·13	56033·13	+29·8	4·476	+0·2
	May 12·02	059·02	30·4	·510	0·0
	Aug. 15·87	154·87	33·8	·633	+0·3
2013	Apr. 28·08	56410·08	38·3	4·963	–0·3
	June 4·07	447·07	35·9	5·011	+0·3
	14·00	457·00	34·5	·024	–0·1
	July 5·01	478·01	32·7	·051	+0·2
	6·98	479·98	32·7	·053	+0·4
	Sept. 6·85	541·85	28·0	·133	0·0
2014	June 13·06	56821·06	30·0	5·494	0·0
	July 21·92	859·92	30·4	·544	–0·8
	30·91	868·91	32·0	·556	+0·5
2015	May 13·07	57155·07	39·7	5·925	–0·2
	July 5·97	208·97	36·5	·995	–0·2
	22·95	225·95	34·8	6·017	–0·3
2016	June 7·04	57546·04	+29·4	6·430	+0·7

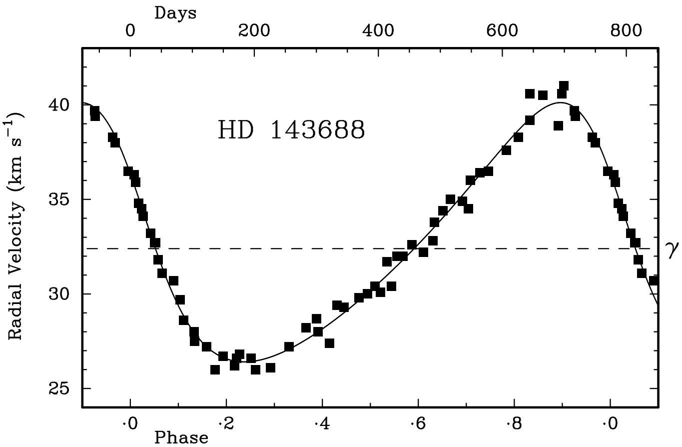

FIG. 1

The observed radial velocities of HD 143688 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All of the 63 radial-velocity observations were made by the writer with the Cambridge *Coravel*.

plot of the velocities against orbital phase appears here as Fig. 1. The projected rotational velocity, whose mean value from the 63 observations proved to be 9·3 km s^{-1}, with an unrealistically small standard error, is clearly much too fast to be synchronized with the orbital revolution, so no great significance can be read into it, although such a rotational velocity is of quite the usual order for a mid-F star.

HD 153302

This star is to be found about 4° preceding α Herculis, though there are enough stars of comparable brightness in its vicinity that a chart is needed to identify it. The *Tycho*-2-based magnitude and $(B - V)$ colour index are $9^{m}\cdot17$ and $1^{m}\cdot63$, respectively. Although the *HD* type is K0, the colour index is red enough to indicate a late-K type — the discrepancy between the colour and the *HD* type is as bad as for HD 143688 but of opposite sign. *Simbad* knows of no papers (apart from catalogues) that refer specifically to HD 153302, so no discussion of the literature detains us here.

The first observation of the radial velocity of HD 153302 was made with the Cambridge *Coravel* in 2003, and revealed an unusually high (negative) velocity of about –84 km s^{-1}. The rather deep 'dip' in the radial-velocity trace immediately drew a comment by the observer that the star must be of later type than the K0 of the *HD*. High velocities are normally associated with old objects that tend to be metal-poor, so the combination in HD 153302 of a high velocity with a deep dip is unusual. There is another star, HD 153250, that (being of *HD* type K0) is also on the Clube programme, only about 4′ south-preceding HD 153302; it was initially observed on the same night as the latter star, and to the observer's amazement, it gave an even higher negative velocity, beyond –100 km s^{-1}!

Repeated observations demonstrated that the radial velocity of HD 153302 (the star that this section is really about) was slightly variable, although the variation proved to be so small (the amplitude is less than 1 km s^{-1}) and of such an inconvenient period (extremely close to one year) that it took a lot of observations to obtain a tolerable approximation to the orbit. They are set out in Table II here; there are 136 of them, but the first one has the largest residual of all and has not been included in the derivation of the orbit. There are some other bad residuals (four of them in excess of 1 km s^{-1}) among the 25 most recent measurements; there is no obvious specific reason for them, and they have been allowed to stand with full weight in the solution of the orbit. There is, however, a clear reason why observations of high-velocity objects in general are liable to be more ragged than those of other stars. The expression for the Doppler shift for velocity v at wavelength λ is $\Delta\lambda = \lambda(v/c)$, so in the spectrum it is everywhere proportional to wavelength, whereas the linear dispersion of a conventional spectrograph (and in particular that of the *Coravel* one) is nearly constant with wavelength. A consequence, therefore, of high velocity is a mismatch in linear dispersion between the Doppler-shifted spectrum of the star and the mask in the *Coravel* (which looks like a high-contrast negative photograph of a star spectrum); that makes the measurement unusually sensitive to errors of guiding the star image upon the entrance slit of the spectrometer. (Owing to atmospheric dispersion, guiding errors can favour one or other end of the considerable wavelength range accepted by the mask.) To add to that difficulty, there is the fact that the orbital period is, within its own uncertainty, exactly one year, so there is an unfortunate but inevitable gap in the phase coverage of the orbit. The adopted orbit is plotted in Fig. 2 and its elements are included in Table VI, with those of the other binaries whose orbits are given in this paper.

The 'dip' given by HD 153302 in radial-velocity traces is slightly broader than the minimum width found for stars with small rotational velocities. The broadening, which might in the ordinary way be said to correspond to a projected rotational velocity of about 5 km s^{-1}, may well be at least partly due to the high velocity causing the scale of the displaced spectrum not to match that of the mask that is an integral part of the *Coravel* instrument, so the apparent rotational velocity is expected to be an over-estimate.

TABLE II

Radial-velocity observations of HD 153302

All the observations were made with the Cambridge Coravel

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O−C) km s⁻¹
2003 Aug. 30·89*	52881·89	−84·4	$\bar{1}$·219	−1·6
2004 Oct. 25·78	53303·78	−82·8	0·368	+0·6
2005 May 12·10	53502·10	−82·1	0·909	0·0
June 1·00	522·00	−81·7	·963	+0·2
Sept. 8·89	621·89	−83·0	1·235	−0·1
14·83	627·83	−82·8	·252	+0·2
Oct. 25·75	668·75	−83·1	·363	+0·3
2006 May 11·08	53866·08	−83·0	1·901	−0·9
July 16·04	932·04	−81·9	2·080	+0·1
17·04	933·04	−81·9	·083	+0·1
Sept. 10·89	988·89	−83·6	·235	−0·7
20·81	998·81	−83·7	·262	−0·7
Oct. 24·77	54032·77	−84·1	·355	−0·7
2007 Feb. 4·27	54135·27	−82·9	2·634	+0·5
Apr. 2·15	192·15	−81·9	·789	+0·8
10·13	200·13	−82·5	·811	+0·1
16·15	206·15	−81·9	·827	+0·6
30·12	220·12	−82·3	·866	0·0
May 1·11	221·11	−82·3	·868	0·0
2·09	222·09	−82·4	·871	−0·1
8·09	228·09	−82·3	·887	−0·1
19·08	239·08	−81·9	·917	+0·1
31·03	251·03	−82·8	·950	−0·9
June 5·00	256·00	−81·6	·963	+0·3
16·01	267·01	−82·0	·993	−0·2
21·00	272·00	−82·2	3·007	−0·4
27·96	278·96	−82·0	·026	−0·2
July 7·01	288·01	−81·9	·051	0·0
13·02	294·02	−82·3	·067	−0·3
18·97	299·97	−82·4	·083	−0·4
24·98	305·98	−81·8	·099	+0·3
Aug. 4·92	316·92	−83·3	·129	−1·0
9·94	321·94	−82·8	·143	−0·4
30·91	342·91	−83·2	·200	−0·5
Sept. 6·84	349·84	−83·2	·219	−0·4
11·86	354·86	−83·1	·233	−0·2
22·84	365·84	−82·9	·263	+0·1
Oct. 4·78	377·78	−83·0	·295	+0·2
15·78	388·78	−83·2	·325	+0·1
20·78	393·78	−84·0	·339	−0·7
29·75	402·75	−83·3	·363	+0·1
2008 Apr. 8·15	54564·15	−82·2	3·803	+0·5
May 19·06	605·06	−82·2	·914	−0·2
July 1·03	648·03	−81·9	4·032	0·0
9·03	656·03	−82·2	·053	−0·3
20·97	667·97	−81·6	·086	+0·4
21·93	668·93	−81·4	·089	+0·7
23·97	670·97	−82·0	·094	+0·1
24·92	671·92	−81·6	·097	+0·5
28·91	675·91	−82·0	·108	+0·2
30·90	677·90	−82·2	·113	0·0

*Rejected

TABLE II (*continued*)

Date (UT)			MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2008	Aug.	2·90	54680·90	−82·3	4·121	−0·1
		10·91	688·91	−81·9	·143	+0·5
		12·90	690·90	−81·8	·148	+0·6
		14·96	692·96	−82·2	·154	+0·2
		25·90	703·90	−81·8	·184	+0·8
		30·85	708·85	−82·1	·197	+0·6
	Sept.	3·83	712·83	−82·5	·208	+0·2
		12·85	721·85	−82·4	·233	+0·5
		13·85	722·85	−82·5	·235	+0·4
		18·87	727·87	−82·8	·249	+0·2
		19·83	728·83	−82·5	·252	+0·5
		26·84	735·84	−82·9	·271	+0·2
	Oct.	2·84	741·84	−82·8	·287	+0·3
		5·78	744·78	−82·9	·295	+0·3
		8·77	747·77	−83·7	·303	−0·5
		11·77	750·77	−83·8	·312	−0·6
		13·79	752·79	−83·7	·317	−0·4
		16·76	755·76	−82·5	·325	+0·8
		21·75	760·75	−82·8	·339	+0·5
		22·75	761·75	−82·8	·341	+0·6
		27·74	766·74	−84·2	·355	−0·8
		31·73	770·73	−84·3	·366	−0·9
	Nov.	7·72	777·72	−83·3	·385	+0·2
		11·72	781·72	−83·9	·396	−0·4
		18·71	788·71	−83·9	·415	−0·4
2009	Feb.	4·28	54866·28	−82·7	4·626	+0·7
	Mar.	21·19	911·19	−83·8	·749	−0·8
		27·20	917·20	−83·2	·765	−0·3
		30·19	920·19	−83·0	·773	−0·2
	Apr.	22·14	943·14	−83·3	·836	−0·8
		29·13	950·13	−83·1	·855	−0·8
	May	20·08	971·08	−82·3	·912	−0·3
		29·10	980·10	−82·2	·936	−0·3
	June	1·05	983·05	−81·9	·944	0·0
		12·01	994·01	−81·8	·974	0·0
	July	1·99	55013·99	−81·5	5·029	+0·4
		12·97	024·97	−81·5	·059	+0·4
		22·98	034·98	−81·9	·086	+0·1
	Aug.	7·89	050·89	−81·8	·129	+0·5
		11·90	054·90	−82·2	·140	+0·1
		15·93	058·93	−82·5	·151	−0·1
		17·88	060·88	−82·7	·157	−0·3
		18·92	061·92	−82·4	·159	+0·1
		19·91	062·91	−82·3	·162	+0·2
		21·86	064·86	−82·5	·167	0·0
2009	Sept.	9·87	55083·87	−82·9	5·219	−0·1
		18·83	092·83	−82·8	·244	+0·1
		25·80	099·80	−82·5	·263	+0·5
	Oct.	8·77	112·77	−82·7	·298	+0·5
	Nov.	9·73	144·73	−83·8	·385	−0·3
		17·71	152·71	−83·7	·407	−0·2
2010	Apr.	8·17	55294·17	−83·1	5·792	−0·4
		13·12	299·12	−83·0	·806	−0·4
		17·16	303·16	−83·0	·817	−0·4
	May	12·10	328·10	−81·8	·885	+0·4
		16·08	332·08	−82·5	·896	−0·4
		17·09	333·09	−82·6	·898	−0·5

TABLE II (*concluded*)

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2010 May 20·08	55336·08	–82·6	5·906	–0·5
22·07	338·07	–81·9	·912	+0·1
June 4·07	351·07	–81·9	·947	0·0
15·04	362·04	–81·3	·977	+0·5
July 18·94	395·94	–80·8	6·070	+1·2
Aug. 30·89	438·89	–82·6	·187	0·0
Nov. 10·73	510·73	–84·4	·382	–0·9
2011 Sept. 29·78	55833·78	–83·3	7·263	–0·3
2012 Feb. 19·26	55976·26	–82·6	7·651	+0·8
May 28·08	56075·08	–81·7	·920	+0·3
July 23·96	131·96	–82·3	8·075	–0·3
2013 Mar. 14·19	56365·19	–83·5	8·711	–0·4
Apr. 7·17	389·17	–83·1	·776	–0·3
28·11	410·11	–82·0	·833	+0·5
30·13	412·13	–81·1	·839	+1·3
May 1·13	413·13	–81·4	·841	+1·0
3·09	415·09	–82·0	·847	+0·4
5·12	417·12	–81·8	·852	+0·6
7·10	419·10	–81·9	·858	+0·4
9·10	421·10	–82·1	·863	+0·2
July 1·03	474·03	–82·4	9·007	–0·6
18·97	491·97	–82·5	·056	–0·6
2014 Mar. 12·23	56728·23	–83·7	9·700	–0·5
Apr. 8·17	755·17	–83·9	·773	–1·1
July 31·92	869·92	–81·8	10·086	+0·2
2015 Apr. 15·15	57127·15	–82·7	10·787	0·0
May 20·11	162·11	–82·7	·882	–0·5
2016 Apr. 26·12	57504·12	–82·6	11·814	0·0

Although the field star HD 153250 does not really qualify for discussion in a paper on binary stars, now that it has been mentioned its unusually high radial velocity seems to be of sufficient interest that the seven measurements available are given here in Table III. There is no indication of variability beyond the measuring errors. The mean velocity is $-102{\cdot}2 \pm 0{\cdot}2$ km s^{-1}.

TABLE III

Cambridge radial-velocity observations of HD 153250

Date (UT)	Velocity km s⁻¹
2003 Aug. 30·88	–102·2
2004 Oct. 25·78	–103·2
2005 May 12·09	–102·0
29·06	–101·6
Sept. 8·88	–102·4
2006 July 16·03	–102·3
2015 Sept. 19·83	–101·9

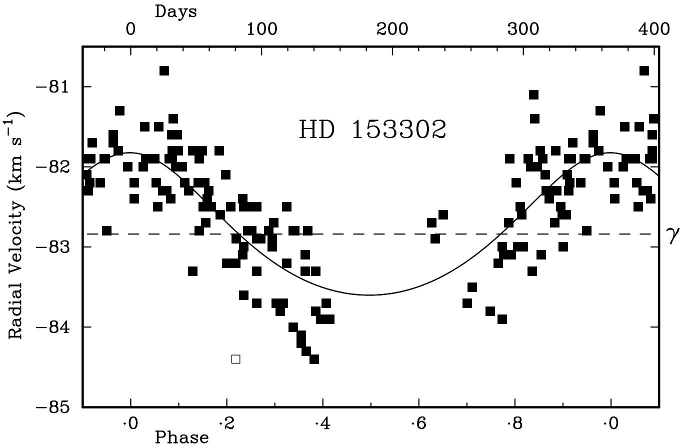

FIG. 2

The observed radial velocities of HD 153302 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All of the 136 radial-velocity observations were made by the writer with the Cambridge *Coravel*; the first one of all, which has the largest residual, is plotted with an open symbol and was not included in the solution of the orbit. The unusually large number of observations is warranted by the smallness of the radial-velocity amplitude, which is less than 1 km s^{-1} and is less than twice the r.m.s. residual. It also represents an effort partly to offset the poor phase distribution of the data, which though regretted is unavoidable, owing to the extraordinary approximation of the orbital period to one year (it is 1·005 ± 0·005 years) and the position of the object in the sky, which renders it inaccessible to observation (or almost so) for part of the year.

HD 153722

HD 153722 is to be seen a little more than 3° following and slightly south of the 3½^{m} G-giant star η Herculis. There is a 9^{m}·8 *Tycho* star (*Tycho 2* 3071-142-1) about 4′ south-preceding the star of immediate interest, as well as a much fainter one (*Tycho 2* 3071-189-1) only about 1½′ north-preceding. The V magnitude and $(B-V)$ colour index of HD 153722, inferred from *Tycho 2* photometry, are 8^{m}·68 and 1^{m}·00, so in this case the *HD* classification of K0 is agreeably supported by the colour index. The (revised[7]) *Hipparcos* parallax of 2·80 ± 0·60 milliseconds of arc translates to a distance modulus of about 7·8 magnitudes. A distance of 357·140 pc found in the literature is an absurdly literal inversion of the observed parallax, whose listed 1-σ uncertainty is about 21% of the parallax itself, so the corresponding uncertainty in distance is about 75 pc and that in M_V is about half a magnitude. Thus the absolute magnitude appears to be in the neighbourhood of +1, putting the star rather on the faint side of the luminosity range of giant stars.

The radial velocity of HD 153722, as of so many stars in Area 1, was first measured in 2003 September. A year later, the second observation exhibited a definite discordance of more than 4 km s^{-1}; the new velocity was maintained throughout that observing season, but had changed considerably more by the start of the third season. By now the orbit is securely determined by 58 measurements, set out in Table IV and reasonably uniformly distributed in phase, and the period is seen to be just over four years. The elements are

TABLE IV

Radial-velocity observations of HD 153722

All the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O–C)* $km\ s^{-1}$
2003 Sept. 19·83	52901·83	−38·3	0·507	0·0
2004 Sept. 15·90	53263·90	−42·8	0·750	0·0
Nov. 4·79	313·79	−43·3	·784	0·0
13·75	322·75	−43·6	·790	−0·2
2005 May 8·06	53498·06	−43·6	0·908	0·0
June 1·03	522·03	−43·4	·924	−0·2
Nov. 9·77	683·77	−37·9	1·033	0·0
2006 Apr. 4·14	53829·14	−34·6	1·131	−0·2
May 3·09	858·09	−34·1	·150	0·0
June 1·06	887·06	−34·0	·170	0·0
July 3·98	919·98	−34·0	·192	0·0
Aug. 2·00	949·00	−34·0	·211	+0·1
Sept. 10·88	988·88	−34·1	·238	+0·2
Oct. 4·88	54012·88	−34·5	·254	−0·1
Nov. 3·76	042·76	−34·8	·274	−0·1
Dec. 2·71	071·71	−35·4	·294	−0·5
2007 Mar. 27·16	54186·16	−36·2	1·371	−0·2
Apr. 30·13	220·13	−36·4	·394	0·0
June 21·01	272·01	−36·7	·429	+0·3
July 13·01	294·01	−36·8	·443	+0·4
Aug. 5·92	317·92	−37·1	·459	+0·4
Sept. 6·85	349·85	−38·1	·481	−0·2
Oct. 4·81	377·81	−38·3	·500	−0·1
Dec. 12·70	446·70	−39·1	·546	0·0
2008 Mar. 31·17	54556·17	−40·3	1·620	+0·1
Apr. 24·11	580·11	−40·5	·636	+0·2
May 19·06	605·06	−41·1	·653	−0·1
June 26·04	643·04	−41·7	·678	−0·2
July 21·93	668·93	−41·7	·696	+0·1
Aug. 30·90	708·90	−42·4	·722	−0·1
2009 Feb. 7·27	54869·27	−43·6	1·830	+0·3
Mar. 27·19	917·19	−44·1	·862	−0·1
Apr. 22·15	943·15	−44·1	·880	−0·2
May 30·07	981·07	−43·9	·905	−0·3
Aug. 3·88	55046·88	−42·2	·950	+0·2
Sept. 9·87	083·87	−41·2	·975	0·0
Oct. 8·78	112·78	−40·1	·994	0·0
Nov. 3·77	138·77	−39·0	2·012	+0·1
2010 Mar. 23·20	55278·20	−35·0	2·105	−0·1
Apr. 8·17	294·17	−34·4	·116	+0·2
May 12·11	328·11	−34·5	·139	−0·2
June 3·08	350·08	−33·6	·154	+0·5
2011 June 17·06	55729·06	−36·8	2·409	−0·2
Sept. 12·86	816·86	−37·8	·468	−0·1
Dec. 3·70	898·70	−38·8	·523	−0·2

TABLE IV (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2012 Feb. 19·26	55976·26	−40·1	2·575	−0·5
2013 Apr. 7·17	56389·17	−43·9	2·853	+0·1
Sept. 14·90	549·90	−41·6	·961	+0·3
Oct. 9·84	574·84	−41·1	·977	0·0
16·77	581·77	−40·5	·982	+0·3
Nov. 12·72	608·72	−40·2	3·000	−0·4
2014 Feb. 16·22	56704·22	−36·5	3·064	−0·2
Mar. 12·23	728·23	−35·7	·081	−0·1
June 19·03	827·03	−34·0	·147	+0·2
2015 Apr. 15·16	57127·16	−35·7	3·349	0·0
2016 Apr. 17·17	57495·17	−39·7	3·596	+0·3
Aug. 7·91	607·91	−41·2	·672	+0·2
9·92	609·92	−41·5	·674	−0·1

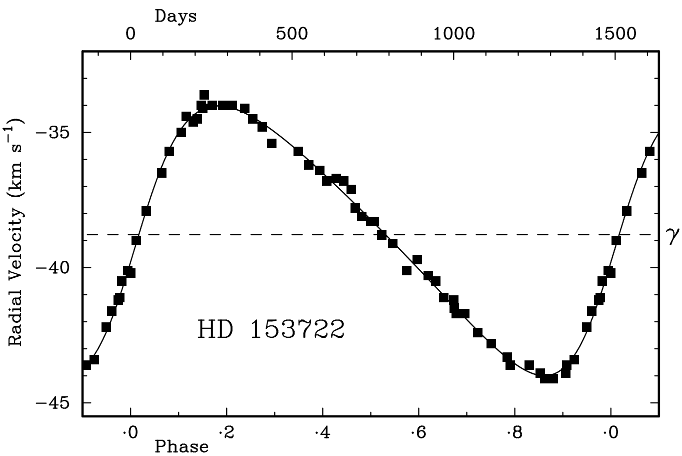

FIG. 3

The observed radial velocities of HD 153722 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The 58 radial velocities were all obtained with the Cambridge *Coravel*.

included in Table VI below, while Fig. 3 illustrates the moderate amplitude and eccentricity of the orbit. The mass function, while not nearly as small as that of HD 153302, is not large enough to raise any hope of detecting the companion star in the system.

HD 155026

This star came to the observer's attention casually, as an object in the field of the Clube star HD 155043; it is about 3′·25 from that star in p.a. 212°, and is a little fainter. HD 155043 is itself lucky to have been on the Clube programme, because its *HD* magnitude is 9·3 and therefore within the $9^{m}\cdot0 \pm 0^{m}\cdot5$ magnitude criterion for that programme, whereas the more reliable *Tycho 2* magnitude is 9·67 — too faint. HD 155026 is listed in the *HD* as magnitude 10·1 and with a spectral type of Ma. Its *Tycho 2* magnitudes are $V = 9^{m}\cdot88$, $(B-V) = 1^{m}\cdot18$; the colour index seems remarkably small for an M-type star, if that is what HD 155026 is.

Simbad knows of no references giving information about HD 155026, but here we can supply some information regarding its radial velocity. The observations, listed in Table V, were all obtained with the Cambridge *Coravel*; they began in 2005 and now number 46. The second observation, obtained nearly a year after the first, disagreed with it by 7 km s^{-1}, so the star was promptly transferred to the binary programme and observed relatively frequently. In the next six months a change of 15 km s^{-1} was recorded, and in due course the period of a little over two years became apparent. The orbit is plotted in Fig. 4 and its elements are given in the final column of Table VI. Seven observations were made of the actual Clube star HD 155043, and will probably be reported in detail in a future paper on that programme; meanwhile it can be mentioned that the velocity appears to be constant and is about –48·3 km s^{-1}.

TABLE V

Radial-velocity observations of HD 155026

All the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s^{-1}*	*Phase*	*(O–C)* *km s^{-1}*
2005 Sept. 14·86	53627·86	−23·5	0·543	−0·2
2006 July 14·04	53930·04	−16·5	0·931	+0·5
15·05	931·05	−17·2	·932	−0·2
17·96	933·96	−17·2	·936	+0·1
Aug. 7·96	954·96	−18·9	·963	+0·6
Sept. 20·84	998·84	−25·1	1·020	+0·2
Nov. 3·75	54042·75	−31·2	·076	−0·8
20·71	059·71	−31·3	·098	+0·5
2007 Feb. 4·25	54135·25	−34·7	1·195	−0·8
Apr. 30·13	220·13	−31·5	·304	+0·4
June 21·04	272·04	−29·8	·371	−0·1
July 18·98	299·98	−28·2	·406	+0·2
Sept. 7·88	350·88	−26·0	·472	0·0
2008 Apr. 8·17	54564·17	−15·8	1·746	0·0
May 19·07	605·07	−13·6	·798	+1·0
June 26·05	643·05	−14·3	·847	−0·1
July 20·98	667·98	−14·9	·879	−0·3
Aug. 2·94	680·94	−15·7	·896	−0·6
Sept. 19·84	728·84	−19·3	·958	−0·3
Oct. 8·78	747·78	−21·8	·982	−0·5
21·77	760·77	−23·2	·999	−0·1
Nov. 18·72	788·72	−26·5	2·034	+0·3
2009 Apr. 29·14	54950·14	−33·5	2·242	−0·1
May 24·06	975·06	−32·8	·274	−0·1
July 9·98	55021·98	−31·1	·334	−0·2
Sept. 25·79	099·79	−27·2	·434	+0·2
Nov. 17·72	152·72	−25·0	·502	−0·2

TABLE V (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2010 Apr. 13·13	55299·13	−17·7	2·690	−0·1
June 12·05	359·05	−15·0	·767	+0·2
Nov. 16·72	516·72	−20·0	·970	+0·1
2012 Feb. 19·25	55976·25	−22·4	3·560	+0·2
Apr. 16·15	56033·15	−19·3	·633	+0·4
May 12·09	059·09	−19·1	·667	−0·6
June 19·06	097·06	−17·0	·716	−0·2
Aug. 20·89	159·89	−14·4	·796	+0·2
Sept. 13·85	183·85	−14·5	·827	−0·3
2013 Mar. 14·22	56365·22	−29·7	4·060	−0·5
Apr. 18·16	400·16	−31·9	·105	+0·3
21·13	403·13	−32·4	·109	0·0
May 9·11	421·11	−33·2	·132	0·0
June 4·10	447·10	−34·1	·165	−0·2
July 7·00	480·00	−33·0	·208	+0·9
11·98	484·98	−33·8	·214	0·0
2014 May 15·11	56792·11	−20·9	4·609	−0·2
2015 Apr. 20·16	57132·16	−27·5	5·046	+0·4
2016 June 7·07	57546·07	−21·9	5·577	0·0

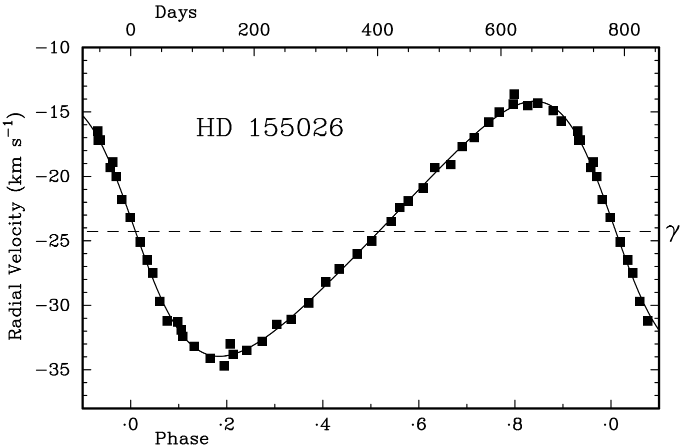

FIG. 4

The observed radial velocities of HD 155026 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The 46 radial velocities were all obtained with the Cambridge *Coravel*.

TABLE VI

Orbital elements for HD 143688, HD 153302, HD 153722, and HD 155026

Element	HD 143688	HD 153302	HD 153722	HD 155026
P (days)	774·2 ± 0·9	367·0 ± 1·8	1486·8 ± 2·2	778·3 ± 0·7
T (MJD)	54890 ± 6	55003 ± 33	55122 ± 6	55540 ± 4
γ (km s^{-1})	+32·40 ± 0·07	−82·84 ± 0·07	−38·78 ± 0·03	−24·27 ± 0·06
K_1 (km s^{-1})	6·86 ± 0·11	0·89 ± 0·11	4·99 ± 0·04	9·89 ± 0·09
e	0·280 ± 0·014	0·14 ± 0·09	0·289 ± 0·008	0·248 ± 0·008
ω (degrees)	63·2 ± 3·0	1 ± 32	261·0 ± 1·7	85·1 ± 2·1
$a_1 \sin i$ (Gm)	70·1 ± 1·1	4·4 ± 0·5	97·7 ± 0·9	102·6 ± 1·0
$f(m)$ ($M_\odot$)	0·0229 ± 0·0011	0·000026 ± 0·000009	0·0168 ± 0·0005	0·0712 ± 0·0020
R.m.s. residual (wt. 1) (km s^{-1})	0·51	0·48	0·21	0·37

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(7) F. van Leeuwen, *Hipparcos, the new reduction of the raw data* (Springer, Dordrecht), 2007.

REVIEWS

Starlight Detectives: How Astronomers, Inventors, and Eccentrics Discovered the Modern Universe, by Alan Hirshfeld (Bellevue Literary Press, New York), 2014. Pp. 399, 23 × 15 cm. Price $19·95 (about £15) (paperback; ISBN 978 1 934137 78 9).

Author Hirshfeld's previous book *Parallax* (W. H. Freeman, 2001) effectively ended in 1838 December, with Friedrich Bessel's publication, in *Astronomische Nachrichten*, of the *Entfernung* (distance, parallax) of 61 Cygni. Fittingly, the time-line of *Starlight Detectives* begins in 1839 January with the announcement by François Arago to the French Academy of the process called Daguerrotype. William Fox Talbot told the Royal Society 24 days later about his process, the calotype (whose images were initially much less sharp, but came from negatives that could be reproduced many times). Actually the first surviving photograph came in 1825 from Nicéphore Niépce (1765–1833) and we should probably be grateful not to have to pronounce some derivative of his name each time we mention images drawn by light, dubbed photographs by John Herschel.

First the nitty gritty: there really is a time-line from Arago (1839) to Hubble and Humason (1931), a glossary of names, from Walter S. Adams to Maximillian Wolf (accidentally omitting W. A. Miller, Huggins's buddy in his spectroscopic endeavours), and a very good index. James Nasmyth is in the index only for his reflecting telescope (speculum, not silvered glass, in 1845) and his book on the Moon because he is in the text only for those and not for his focus. Well, we have to have some excuse for referring you to T. A Hockey *et al.*'s *Biographical Encyclopedia of Astronomers* (2nd edition, Springer 2015)!

As for the body of the book, Part I traces photography from near its origins to routine use of dry plates, with an extended stop at the *Carte du Ciel*, which was supposed to map and catalogue the entire sky. Beginning in 1888, the astronomers involved (no Americans) completed the photography in 1964 and much of the deep catalogue was never finished. Meanwhile, John Franklin-Adams (1843–1912) photographed the entire sky by himself (the atlas appearing posthumously in 1912–14), though he is not mentioned in the present volume. And the Palomar Observatory Sky Survey is 'out of period'.

Part II provides the same sort of very complete chronology of the development of spectroscopy, swinging back to pick up Fraunhofer and his lines, then moving forward with Bunsen, Kirchhoff, and all the rest. And Part III begins the story of astrophysics, as the union of photography and spectroscopy. Before I forget, there are 12 pages of scholarly notes and an excellent set of references, including both original papers and modern discussions. The third period begins with "Mr. Hale of Chicago" and covers both the move of astronomy (*etc.*) to large telescopes in California and the transition from the last amateurs making significant research contributions to the professionalization of the field.

Starlight Detectives is an enormously enlightening and entertaining book! My marginal scrawls include many more "aha!"s than "No!"s. And the author is generally very careful about writing "first" and "discover", preferring "announce" and "publish" (which give documentable dates) to the former. But I really do not think that the Paris 1887 April Astrographic Congress was the "first-ever" international conference of astronomers. Consider the 1798 assembly of von Zach's 'celestial police' in Seeberg, with participants from England, France, Italy, and many places in what we now just, once again, call Germany.

Staying on an international track, I would also quarrel with the Carte du Ciel meetings giving rise to the International Astronomical Union in 1919 (p. 142). That is the right year, and Commission 23 was called Carte du Ciel (under the presidency of Herbert Hall Turner, who by then was turning his attention largely to seismology). But the IAU (the first of the international unions to get its affairs in order after treaties ending WWI put an end to previous international scientific collaborations) was very much inspired by George Ellery Hale, whose International Solar Union was among the organizational victims.

A couple of favourite "aha!"s are (*i*) Kirchhoff (writing in English in *Philosophical Magazine* in 1861) describing the heavy elements in the Sun as "metals", as we do to this day, and (*ii*) Wolf's 1911 25-hour exposure of the spectrum of Andromeda, accumulated over 20 nights, and preceding by a year Slipher's 14-hour, 1912 December 3–4 effort. There are lots of drawings and photographs, not all familiar; the telescopes, observatories, and nebulae are generally better looking than the astronomers, but all worth looking at!

Conflict of interest: my copy of *Starlight Detectives* was a gift from the author at the 2017 January meeting of the American Astronomical Society meeting. It is worth a significant fraction of the cost of participating. — VIRGINIA TRIMBLE.

Observatories and Telescopes of Modern Times, by D. Leverington (Cambridge University Press), 2017. Pp. 490, 25·5 × 18 cm. Price £110/$175 (hardbound; ISBN 978 0 521 89993 2).

I found this book an exceptionally important contribution to the history of observational astronomy in the second half of the 20th Century. This is David Leverington's fifth book documenting progress in astronomy. Following the success of his two books for Cambridge, one tracing the subject from the V2 to the *Hubble Space Telescope*, and the second encapsulating planetary astronomy in the space age, he's now come back to Earth. On offer here is a masterly overview of the development of ground-based optical and radio astronomy since 1945. The first 15 chapters give exhaustive coverage of the growth of optical facilities in the Americas, Europe, and Australia. A further nine chapters describe radio observatories on those three continents, with three nods to India, Japan, and the South Pole. With few exceptions, each chapter is devoted to the facilities at specific geographical locations: for example, Mount Wilson and Palomar, Kitt Peak, Mauna Kea, the European Southern Observatory, radio astronomy at Cambridge, Jodrell Bank, Green Bank, and Owens Valley. The coverage of optical astronomy includes two chapters on instrumentation devoted to mirror design and adaptive optics.

I applaud the author for the enormous amount of primary research he has put into this book. This is not a travel guide compiled from press releases to the media, or glossy brochures from the sales points of observatories, or surfing the internet. This is serious history: the product of countless hours of study using primary sources and archives. There are informative footnotes on almost all pages. The large number of excellent photographs adds to the pleasure of turning the pages. Every chapter has full references. There are almost 500 entries in the Name Index, another 200 in the Observatory and Telescope Index, and about 600 in the General Index. Overall, this is a splendid guide to the professional observatories of the modern age, with an emphasis on covering innovation in the broadest sense. The author has done very well to address the challenge of being too self-indulgent with fine detail, while giving sufficient information to make this book an indispensable starting place for historians of science, science writers, professional astronomers and their graduate students, and indeed the general public. It is an essential purchase for libraries. — SIMON MITTON.

From the Realm of the Nebulae to Populations of Galaxies: Dialogues on a Century of Research, edited by M. D'Onofrio, R. Rampazzo & S. Zaggia (Springer, Heidelberg), 2016. Pp. 815, 24 × 36 cm. Price £170·50/$279 (hardbound; ISBN 978 3 319 31004 6).

This is one of a series of similar books consisting of authors' replies to questions posed by the editors with the aim of reviewing the topic in question, and thus similar to another volume in the series reviewed in these pages[1]. The title is a good short summary of the contents; a reasonable summary of such a big book would be too large for this review. As such, a review of the content itself, which covers the history of extragalactic astronomy, the Milky Way, the Local Group, galaxy anatomy and classification, surveys, high-redshift galaxies, new developments in galaxy formation and evolution, and cutting-edge instrumentation, is difficult. Perhaps more interesting is the question as to what such a book can offer, since its price and size will probably put off many casual readers, and those who work in the field will already be familiar with much of the material.

While it can be read cover to cover — despite the range of authors, there is little overlap between the various sections — many readers might be interested in a short review of an unfamiliar topic, or a list of references as a basis for more detailed studies. I particularly enjoyed the more historical chapters and current thinking on old ideas, such as variations on Hubble's tuning-fork classification scheme. I think that this book, and others in the series, will be perhaps even more valuable in the future, for historians of science. Journal papers are fine if one wants to know *what* the authors thought about their topics of study, but the interview-like structure of the contributions in this book provides personal insights and something about the *why* as well. (Another good source of these are conference proceedings, especially those which document questions and answers: the material of the contribution itself is probably best explored in the corresponding journal paper, but the Q&A provides much better insight into what people thought at the time and why and which questions were considered important, information which often does not make it into journal papers.)

The book is well produced, with black-and-white and colour figures within the text. Each chapter has contributions from several authors, with references collected at the end of the chapter. The 17-page index is divided into Atlases and Catalogues, Instruments, Names (of people), (astronomical) Objects, Observatories, Radio telescopes, Space telescopes, Subjects (the usual topical index), and Telescopes. Since the book is only loosely organized by subject matter, a good index is essential.

I seem to be part of the target readership: I have never worked in this field, but have much more interest in it than in, say, planetary geology, interstellar matter, active galaxies, or X-ray astronomy. The book provides a good overview for those with some knowledge of the field. My recommendation cannot be completely enthusiastic, however, because I have never read a book with such bad editing — or perhaps complete lack thereof. In addition to the usual (too high) number of typos, *etc.*, the quality of English is very bad, with several errors per page on average and only a very few pages error-free. While one cannot expect all non-native speakers to write high-quality prose, one should be able to expect a major academic publisher to provide the necessary support. — PHILLIP HELBIG.

Reference

(1) P. Helbig, *The Observatory*, **133**, 302, 2013.

Introduction to Cosmology, 2nd Edition, by Barbara Ryden (Cambridge University Press), 2016. Pp. 264, 24·5 × 16·5 cm. Price £34·99/$49·99 (hardbound; ISBN 978 1 107 15483 4).

Barbara Ryden's first edition appeared in 2003, published by Addison-Wesley and costing almost twice as much as this 2nd edition. Its pages were about 2 cm wider, consisting entirely of blank, right-hand margins. My copy has these filled with additional ideas, short calculations, and so forth, presumably their intent, but American students today simply refuse to write in their books. Where would we be if the purchasers of the first edition of *De Revolutionibus* had felt the same way?!

The 2003 *Introduction to Cosmology* won the Chambliss Astronomical Writing Award from the American Astronomical Society, and the 2016 edition shares many of its virtues. Students are still expected to be as good as modern major-generals at differential and integral calculus. Shoes, ships, sealing wax, cabbages, kings, and galaxies are still made of baryons, but we have lost the annotated bibliography of suggestions for further reading. And the author has gained a husband. The first preface ended with an extended 'thank you' to her colleague, Rick Pogge. The second ends "Reader, I married him", another quote, which, I fear, the average astronomy junior or senior will not recognize. The numerical value of Hubble's variable parameter has been updated from 70 ± 7 km/sec/Mpc to 68 ± 2 km/sec/Mpc, but there is no discussion of possible 'tension' between the numbers coming from Cepheid and supernova distances and from fitting details of the cosmic microwave background.

Of the 12 chapters (in each edition), 11 still have exercises at the end, 56 and 63 in the 1st and 2nd editions, respectively; too few for ten weekly homework assignments, giving the instructor the frequent pleasure of interrupting lectures to say, "You now know enough to calculate thus-and-so. Please do it." The largest change in emphasis is an additional chapter on structure formation (balanced by running two on exact solutions of the Friedmann equation into one, given our increased confidence in what Ryden calls the "benchmark model", sometimes known as the standard model, or ΛCDM). American academic minds are closely tied to "one chapter per week", so Barbara's suggestion to leave out structure formation for a 10-week quarter is probably good advice.

This is, in any case, what I intend to do, having selected *Introduction to Cosmology, 2nd Edition*, as the text for Physics 137, also called 'Introduction to Cosmology', for the winter quarter (January–March) here at UC Irvine. This means that my copy was a free one (received after adoption — conflict of interest!), and by the time this review appears, I will know whether the choice was a good one. I'm very optimistic! — VIRGINIA TRIMBLE.

Light after Dark I: Structures of the Sky, by C. Francis (Matador, Kibworth Beauchamp), 2016. Pp. 250, 23·5 × 15·5 cm. Price £14·99 (paperback; ISBN 978 1 78589 932 4).

This is the first in a series of three books. The next two have the same title but different subtitles, namely *The Large and the Small* and *The Mathematics of Gravity and Quanta*. I don't plan to read the next two. The author, who has a first in mathematics from the University of Cambridge and a PhD in mathematics from London, has published a handful of papers in respected journals such as *MNRAS* and even this *Magazine*, but ADS indicates that most of his publications are at arXiv only.

Allowing for the possibility that it might be the case that an 'outsider' might have trouble publishing in respected journals*, and taking into account the fact that he doesn't seem to have turned to crackpot journals as an alternative, nor to viXra (though I didn't waste much time trying to find him there), I decided to read the book cover to cover and form my own opinion, though in this case it confirmed my impression raised by various red flags.

*From personal experience, no longer having an affiliation myself, I know that, sadly, this is indeed the policy of some otherwise respectable journals, and is a criterion for rejection which is applied before the manuscript is even looked at.

The book is concerned mainly with cosmological structure formation, galaxy formation, the Milky Way (especially the distance to the centre), and Galactic and galactic dynamics (with an emphasis on spiral structure). The ordering of the chapters is somewhat odd: while the general order of large to small is neither uncommon nor problematic, following this with a final chapter on cosmology is a bit strange. The level of detail also varies greatly; some chapters are just brief summaries of a broad topic, while others go into detail in a sub-field, often one in which the author has published. While it is fine to discuss one's own work in a book for the general reader, it shouldn't take up too much room nor be much more detailed than the bulk of the text.

Although he does alert the reader to the fact, on many occasions the author contradicts established knowledge on a topic: cosmological structure formation, density-wave theory, *etc*. While in general this is fine in itself, and sometimes even necessary, I see three problems with it in the context of this book. First, the tone is unnecessarily pejorative with respect to the standard view. Second, I find it out of place in a book which is otherwise a general introduction to the topic. (There is nothing wrong with discussing alternative views in a book for the general reader, but in such a case it is better to have a book dedicated to such discussion, such as the book by Sanders on MOND recently reviewed[1] in these pages.) Third, I am not convinced. In cases where I am reasonably familiar with the topic, such as cosmology, I am sure that the author is mistaken. When I am not, such as the distance to the Galactic centre, I am not convinced by the exposition in the text. (The former case is more serious; our understanding of the Universe would not be seriously affected if the distance to the Galactic centre were revised.) The author could have done better there, by toning down the criticism, even on a topic of dispute. Non-scientific aspects of the debate, even if true, are not something the reader can check, and detract from the argument. Since I am not an expert on this topic, I discussed it with someone who is, who came to the conclusion that, while some aspects of the discussion of the distance to the Galactic centre are not mainstream, they are certainly not completely wrong and might be worth looking into. This should stand on its own, without being unnecessarily harsh on opposing viewpoints. The main reason I was unconvinced, though, is because a chapter in a popular book doesn't allow the fine points of such a debate to be presented in enough detail that a general reader — even someone with a background in (other areas of) astronomy — can form an opinion. (It is certainly no coincidence that the author's papers in respectable journals are on this topic and not on cosmology.)

Other debates, such as on the usefulness of the Lagrangian and Hamiltonian forms in teaching physics, are arguably matters of taste, though I don't agree that those who emphasize these topics do so because they don't realize that there are better methods, or do so in order to disguise their ignorance. Describing the Einstein static universe as "steady state" is perhaps correct in some sense, though anyone with a basic familiarity with cosmology will immediately associate this with the steady-state model, which is not static. Thus, I became sceptical already on page 2. It is always difficult to discuss new but tentative results, such as the association of the CMB cold spot with a 'supervoid'. At best, the jury is still out on whether the cold spot is caused by the supervoid; my feeling (fine for a review but not for a book) is that it isn't. Such discussion can date quickly, and can create the impression that ideas which support some agenda are taken over uncritically, while others are ignored. Another example is the claim that there are galaxies with rotation curves declining more rapidly than expected from the baryon content, falsifying both dark matter and MOND. More serious are nonmainstream claims in cosmology — not because they are not mainstream, but because they are wrong, and the text provides no indication that the author has some deeper understanding on these topics or that experts in the field have seriously overlooked something. Some examples: cosmological anisotropies (as seen in the CMB and baryon acoustic oscillations) were created during Big Bang nucleosynthesis, the observable Universe is spatially flat but on even larger scales the shape is analogous to a polyhedron, the measured temperature of the CMB depends on the assumed value for the Hubble constant, 'wrong' choices for the Nobel Prize (about which one can certainly have good discussions in the pub) are due to the Prize committee's limitations in theoretical physics, tidal tails in galaxies are "an absurdity", galaxy clusters are not gravitationally bound, atomic nuclei are surrounded by positively curved space as an effect of the uncertainty principle, the cosmological constant is not possible since "distance exists because of interactions between matter and matter". Some might seem plausible at first to the uninitiated: great walls in large-scale structure cannot be great attractors because of Newton's shell theorem — this creates the impression that essentially all cosmologists have overlooked something which should be obvious.

However, this is not a typical crackpot book. It is obvious that the author has a good understanding of many aspects of astronomy, much of the book is rather conventional, and some parts that are not are might even present something important. This is drowned out, though, by the unconventional aspects that are also wrong. Knowledgeable readers will notice these even if the author doesn't point them out (though he often does). Less-knowledgeable readers might be led astray, though, since there is a coherent, albeit very probably wrong, framework underlying the various aspects discussed in the book; debunking it thus requires much more work than debunking an isolated wrong claim.

The book is reasonably well produced. Footnotes contain both supplementary information as well as references. Some of the black-and-white illustrations are repeated in colour on a few pages of glossy 'plates' (two-thirds of the way through the book). A six-page index ends the book. There are too many typos and examples of bad style, but not more than the average for books I review here.

Obviously, I can't recommend the book. It would be easier not to recommend a book which is perhaps less wrong but where this is due to carelessness, or a book which took even more effort to produce but is completely out of touch with reality. The author obviously has a good understanding of astronomy, and by concentrating on what he does well could have been much more productive. — PHILLIP HELBIG.

Reference

(1) P. Helbig, *The Observatory*, **137**, 91, 2017.

Asteroids: Astronomical and Geological Bodies, by Thomas H. Burbine (Cambridge University Press), 2017. Pp. 367, 25·5 × 18 cm. Price £49·99/$79·99 (hardbound; ISBN 978 1 107 09684 4).

Far too little praise is heaped on university types for producing a good lecture course. It is not easy. And the effort is often underappreciated. The topic has to be made appealing to a student audience (a cohort usually hard to satisfy), the salient points have to be selected, important things need emphasizing and minor aspects have to be bypassed, and (just like baby bear's bed) the course must not be too hard or too soft. Well, Burbine *has* produced a superb university course on the minor bodies in the Solar System for his final-year students at Mount Holyoke College, Massachusetts, and we know this because the book under review is an expanded version of the lecture notes.

This excellent text-book is engagingly written, clear, readable, comprehensive, and just the right length and level for a masters' course. It is well illustrated and well referenced and has a question section at the end of each chapter together with worked examples. I liked especially the way in which the author related meteorites and their mineralogy to asteroids and their spectroscopy and taxonomy. I was also impressed by the way in which he did not fight shy of introducing the historical aspect of the subject and the complexity of such things as the Yarkovsky effect and orbital migration. He also relates asteroids to other minor Solar System bodies such as comets, dwarf planets, and Edgeworth–Kuiper Belt objects. Burbine revels in the problems associated with near-Earth asteroids and the impact effect on Earth. The book is up to date and has a detailed discussion of the host of space missions that have flown by asteroids and are now going into orbit around some and returning with samples.

If you know little about asteroids and want to learn, I can recommend no better way to start than with this extremely impressive book. — DAVID W. HUGHES.

Early Investigations of Ceres and the Discovery of Pallas, by Clifford Cunningham (Springer, Heidelberg), 2016. Pp. 412, 24 × 16 cm. Price £112/$179 (hardbound ISBN 978 3 319 28813 0).

To discover one minor planet in the region between the orbits of Mars and Jupiter was expected. To discover more than one was not. Asteroid number 1, Ceres, was found on 1801 January 1. This caused major excitement at the time. It was regarded as the eighth planet of the Solar System. Just over a year later the German medic and amateur astronomer Heinrich Olbers (1758–1840) was trying to find Ceres in the constellation Virgo. To his amazement he found another moving, seventh magnitude, star-like body close by. He was soon convinced that this was another minor planet — and he was right. It was subsequently named Pallas. Carl Gauss, the German mathematician, calculated Pallas' orbit and found it had parameters fairly similar to the orbit of Ceres. To quote Olbers, the two orbits "cross each other like the interlocked rings of a chain". He immediately suggested that Ceres and Pallas were fragments of a larger planet in that region that had broken into bits — possibly after being struck by a comet! From that time on the complexities of the asteroid belt multiplied.

Interestingly, the investigation of the orbits, sizes, and origins of the first two asteroids was an example of both astronomical harmony and cooperation, and also astronomical rivalry and mistrust between the astronomers and mathematicians in Italy, France, Germany, and Great Britain. It is this interchange of gossip, data, results, and hypotheses that interests Cunningham and is the crux of the book under review (and was a portion of his 2014 PhD thesis). A vast number of the relevant letters are quoted in full, and these have all been carefully translated into English. Here we find revealing insights into the thoughts and attitudes of the writers away from the strictures of published research notes. The book also assembles many relevant journal reports and text-book quotes from the 1801–1802 period, together with relevant figures. Names such as Banks, Bode, Ernst, Gauss, Herschel, Lalande, Maskelyne, Méchain, Olbers, Oriani, Sniadecki, Schroeter, and Zack spring from the page. Much is made of the introduction of the word 'asteroid' and the fact that the use of 'aster' — 'star' — is inappropriate, and maybe other suggestions at the time such as planetule, planetkin, planeret, planetula, or planetoid might have been more apt.

The book is a fascinating description of what was taking place at the time in this field of astronomy. But I must emphasize the word 'description'. There is little discussion. Clearly the finding of two minor planets where one planet was expected took astronomers completely by surprise. It would have been interesting to hear Cunningham's views as to why this was. Also surprising was the large inclination of Pallas' orbit. At 34°·8 this was more comet-like than planet-like and it took a time to convince observers that they had found a non-cometary body. (Needless to say, this large inclination is still a matter of considerable puzzlement.)

I would also have liked to read more on why the planetary-explosion theory was so readily accepted. Interestingly, when it came to Ceres and Pallas, Olbers wrote to Lalande in 1802 May saying that "I believe without doubt we will find others". And Juno was discovered in 1804 and Vesta in 1807. By the mid-19th Century the floodgates were open.

Cunningham thinks that the discovery of Pallas was "one of the most important astronomical discoveries ever made". Well, I love asteroids but I think he is being over-generous. This book is, however, a work of great bibliographic scholarship and as a detailed collection of relevant material from this brief period in asteroidal research will be extremely useful, thought-provoking, and referred to for many years to come. — DAVID W. HUGHES.

The Sun — Shining Light on the Solar System, by N. R. Taylor (Observatoire Solaire, Great Stainton), 2017. Pp. 188, 29·5 × 21 cm. Price £27·50 (includes p. & p. *via* the publisher's web site) (paperback; ISBN 978 1 907931 64 2).

A new textbook on the Sun should always be welcome, if only to highlight what is known and being discovered about our nearest star. The aim of this book is to provide a "transitional step" between descriptive, introductory books and advanced, graduate-level treatises. It is stated that no particular background knowledge is required and the mathematics included is at an undergraduate level and should not be off-putting. Unfortunately, although there are useful parts to the book, it will disappoint readers on several levels. Most importantly, the content is quite unbalanced. In Chapter 1, for instance, there is a discussion about determinations of the astronomical unit dating back to the 17th Century, taking up eight pages. But in Chapter 3 (Solar Form and Structure), the entire solar atmosphere (chromosphere, corona, and solar wind) is squeezed into five pages, while helioseismology gets a meagre one page. Again, in Chapter 4 (Observations and Features of the Sun), although there is a reasonably full account of sunspots and other photospheric features, there are just a few pages on flares, coronal loops, and coronal mass ejections. There is barely a mention of space weather, currently a hugely important aspect of solar physics. There is a general lack of the role of space-based observations, with just a half-page-long list of a few solar spacecraft on p. 94.

Chapters 5 and 6 deal with the Sun's place in the Milky Way galaxy and its formation and evolution, with good introductions on nuclear fusion as the Sun's energy source. But it seems strange to devote so much room to pulsars, neutron stars, and black holes when none of these will be the fate of the Sun.

There the book text comes to an abrupt end, with the final chapter (Chapter 7) being more in the nature of an appendix, with some facts and figures and derivations of mathematical formulae stated earlier. The book has a desperate need of an index, while the list of contents at the beginning with section headings has no page numbers. The figure quality is variable; the one illustrating model magnetic fields on p. 81 could be just about anything, though the line drawings are mostly clear. The bibliography and reading list, which come rather obscurely after Chapter 7, has a total of seven books, few of which could be considered standard, while the reference list will hardly be informative to any student. The book feels as if it has been privately produced; a copy editor would have dealt with the several glaring misprints or mis-statements (*e.g.*, on p. 10 the Sun is one of "a hundred million stars" in our galaxy, but this is corrected on p. 114 to 10^{11} stars). In summary, the book is far from an ideal textbook for the stated readership and would benefit from extensive revision. — KEN PHILLIPS.

Celestial Mechanics and Astrodynamics: Theory and Practice, by P. Gurfil & P. K. Seidelmann (Springer, Heidelberg), 2016. Pp. 552, 24 × 16 cm. Price £93/$149 (hardbound; ISBN 978 3 662 50368 3).

I have to say from the outset that my interest in this book comes more from the area of celestial mechanics than that of astrodynamics. The preface emphasizes the links between the older science of celestial mechanics and the newer science of astrodynamics and the attempt to deal with those two topics in a unified manner. The book is also "designed as an introductory text and reference book for graduate students, researchers and practitioners in the fields of astronomy, celestial mechanics, astrodynamics, satellite systems, space sciences, and astrophysics".

If you have a fear of equations, then this book is probably not for you. It contains a total of eighteen chapters starting with introductory material ranging from the property of conics, stability determination and chaos, to sources of observational data. A review chapter on vectors follows, as well as a very useful chapter on reference systems and relativity. A chapter on central-force motion leads into another on the two-body problem. Methods of orbit determination are described, including those of Laplace and Gauss, before moving on to the *n*-body problem and the restricted three-body problem. All of this material is enhanced by the addition of good-quality graphics chosen carefully to illustrate the material in the text.

An introduction to numerical procedures covering topics such as Runge–Kutta methods and integration of orbits is followed by a chapter on canonical equations in the solution of the equations of motion. General perturbation theory is covered in some detail, followed by motion around oblate planets. Semi-analytical orbit theory and its use in the calculation and comprehension of the orbital dynamics of satellites is followed by a chapter on orbit transfers using impulsive manoeuvres. The closing chapters of the book cover orbit-data processing, which includes useful material on analysis techniques such as least-squares approximations, orthogonal polynomials, Chebyshev series, and Fourier analysis. This is followed by material on space debris and a final chapter on areas of future development for the topics covered in the book.

This is a fine text-book covering a wide range of material in its 522 pages. I found it to be very readable and an interesting introduction to the field of astrodynamics. I think it succeeds in its intention to emphasize the similarities between celestial mechanics and astrodynamics as well as the problems involved in dealing with real data. It is well-illustrated and is supported by good reference material. This book would have been a fine introduction to the work of an almanac office or those involved in the generation of astronomical data. Perhaps the only real drawback, particularly for the younger cash-strapped astronomer, is its price. Nevertheless, the authors are to be congratulated on generating an excellent text-book which should find its place on any astronomer's bookshelf. — STEVE BELL.

Cosmic Magnetic Fields, by P. P. Kronberg (Cambridge University Press), 2016. Pp. 283, 26 × 18 cm. Price £112/$140 (hardbound; ISBN 978 0 521 63163 1).

Philipp Kronberg is a serious investigator of cosmic magnetic fields, and this is a serious book. Equation 1.1 on the first text page extends across the full width of the paper. It provides the emissivity of synchrotron radiation as a function of magnetic field strength, B, and density of relativistic electrons, $n^r{}_e$. The reader learns immediately that quantities will be given in cgs units, with field in gauss and output in ergs cm^{-2} Hz^{-1} sterad^{-1}. Well, actually it says ergs^{-1} but I think that is a misprint and should say erg s^{-1} with a space. Also missing from that page is the co-discoverer of interstellar polarization of starlight, John Hall, with credit being given exclusively to William Hiltner. They started out working together, but published separately, in adjacent papers (I don't know why), and died within a year of each other.

The author's preface indicates that he plans to describe how extragalactic magnetic fields can be measured or inferred and the basic physical processes by which they are regenerated. These goals are definitely met. Kronberg also addresses the issue of the origin of large-scale magnetic fields, bottom up (from events and processes associated with active galaxies and stars) *versus* top down (connected somehow with inflation and the pre-re-ionization universe), making the point that these early processes are important to the Universe we actually observe around us.

The Crab Nebula gets its due for Faraday rotation in a 3-D reconstruction, with credit for the basic idea to a 1966 paper by B. J. Burn that I should have cited in my thesis and did not. There is a short list of abbreviations (AGN and VLBI are what you think, but DM is dispersion measure not dark matter); a table of symbols extending over four pages (but S, the Lundqvist number, is defined on page 35, not page 33, which has the Schwarzschild radius); and an excellent index with most of the effects you might think to look for (Hall, GZK, and Davis-Greenstein, which, in Chapter 2, explains the interstellar polarization discovered in Chapter 1). There is no credit to Gold for his alternative way of aligning interstellar grains, but then this is a serious book.

I don't really expect to have to teach a course on cosmic magnetism, but if I did, I would want Kronberg (or anyhow his book) by my side; indeed, I snitched his Fig. 9.9 of the Sunyaev–Zeldovich effect *versus* frequency and field orientation to show my cosmology class a few weeks ago. A colleague drifted by my office as this was being written and said "Oh yeah, Kronberg, he's a sound guy!" That is as nice as Gregory Benford gets, and perfectly true. — VIRGINIA TRIMBLE.

Bright Emissaries: Be Stars as Messengers of Dark-Disk Physics (ASP Conference Series, Vol. 506), edited by T. A. A. Sigut & C. E. Jones (Astronomical Society of the Pacific, San Francisco), 2016. Pp. 326, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 896 1).

B-type main-sequence stars present characteristics rarely found in more-common low-mass stars. Their emission-line spectra are indicative of material sitting above the stellar photosphere, typically in a disc or shell, but *not* in an accelerating wind as seen in more massive O-type stars. Exactly how material is ejected from the surface, whether assisted by the rotation of the parent star, by pulsations at the stellar surface, or by tidal assistance from a binary companion, and how it is constrained geometrically, for instance as a Keplerian disc or a shell-like envelope, remains the subject of much work.

These conference proceedings set out to explore such questions, with particular focus on the physics of the Keplerian disc. In the twenty or more years since my last Be-star conference, there has been considerable progress, not least from synoptic surveys which show the evolution of both star and disc properties over several years, and from interferometry and polarimetry, which have revealed disc structures more definitively.

The book is divided into four sections: the first three commence with an extended review paper, followed by ten contributed papers. At eight pages, the latter are long enough to report interesting results in context. A fourth section covers poster contributions. Apart from this, there is little to indicate any formal structure. Too frequently, captions refer to a colour scheme not visible in monochrome figures, but the inclusion of discussion points goes some way to compensate. Taken in the round, this volume provides an informative and accessible snapshot of the subject, representing a broad spectrum of recent observational results and theoretical progress which will be useful to starting graduate students and seasoned specialists alike. — C. SIMON JEFFERY.

Astronomy in Focus XXIXA: As Presented at the IAU XXIX General Assembly, 2015, Volume 1, edited by Piero Benvenuti (Cambridge University Press), 2016. Pp. 509, 24·5 × 16 cm. Price £79·99/$129·99 (hardbound; ISBN 978 1 107 16981 4).

The International Astronomical Union is trying bravely to fulfil its commitment to Cambridge University Press to produce each year from its conferences a certain number of publishable books. The General Assembly, held in Honolulu in 2015 August, from which this volume derives, is probably the last for which this will be the case, because the proposals for events at the 30th GA, scheduled for Vienna in 2018 August, mention only on-line proceedings. The IAU General Secretary has indicated that paper volumes will still be produced, but will not be included in registration fees, so participants will need to pay extra for them.

A 'Focus Meeting' (FM) is supposed to be interdisciplinary (meaning support from two or more of the nine divisions) and includes 9–18 hours of presentations of one sort or another. This volume contains about half of the 2015 FMs, the others appearing in Volume XXIXB, and each of the Symposia getting its own volume. Each FM was allotted the same number of pages and has filled them, under or over, with anything from one five-page summary (Global Coordination of Ground and Space Astrophysics and Heliophysics, Dave Spergel and Bob

Williams reporting on a series of panel discussions — I think you had to be there) to one with 24 mostly-extended abstracts (Astronomical Heritage).

Some of the FM topics were and are of great importance — site protection, with spectral distributions of LED lamps and much else; astronomy for development, with authors from Ethiopia, Ecuador, United Arab Emirates, Thailand, Uzbekistan, Uganda, Burkina Faso, and Zambia (plus, of course, a number of Americans).

Other focus meetings dealt with topics you might find at an ordinary EAS, RAS, or AAS session — statistics of exoplanets, solar and stellar variability, comets and asteroids. Two of my favourite articles are (*i*) 'The Chelyabinsk Event' by J. Borovicka (astounding how many folks had cameras out as it came overhead!), which shared the orbit of asteroid 86039 and left at most 1% of its initial mass as meteorites, and (*ii*) 'Behind the Spam: A "Spectral Analysis" of Predatory Publishers' by Jeffrey Beall with a screenshot of the title page of 'Combating Climate Change with Neutrinos' from an "on-line, open-access" journal called *Environmental Sciences*.

A good thing, you might feel, that this is probably the last of its lineage. Still, I will keep my copy, though it has to go on a very high shelf. Conflict of interest: my page is 105, but I paid for the volume as part of the GA registration process. — VIRGINIA TRIMBLE.

Science, Culture and the Search for Life on Other Worlds, by J. W. Traphagen (Springer, Heidelberg), 2016. Pp. 161, 23·5 × 15·5 cm. Price £16·50/$29·99 (paperback; ISBN 978 3 319 41744 8).

Books about SETI (the Search for Extraterrestrial Intelligence) are plentiful, and cover a broad set of approaches from science through to culture and religion, and draw from the factual (such as the very many life-forms on Earth and their requirements), to the imaginary (science fiction such as *Star Trek*). The angle adopted here represents the personal opinions of the author, who is a social scientist and a professor in a department of religious studies at a university in the USA.

The stated intentions of the book are noble: to "explore humanity's thoughts and ideas about extraterrestrial life, paying close attention to the ways science and culture interact ... to create a context of imagination and discovery related to life on other worlds". It starts off interestingly in that direction, but by page 46 it has to conclude that there is "absolutely no concrete evidence for life anywhere else" [other than on Earth], and "anything we say that is in any way predictive about the nature of life on other worlds falls squarely into the realm of conjecture." Add 'coloured by prejudice, both deliberate and unaware', and there you have the rest of the book.

If the author is to be believed, the activities of SETI are focussed strongly on detecting signals from advanced technological sources, rather than on evidence from astrobiology and its myriad ramifications. Considerable space is given over to defining 'civilization' and 'culture' when debating how earthlings might react to a contact from what is (not may be) out there in space, but those are the songs of the social scientist, not the scientist in the book's title. There is rather little about astronomy, except insofar as astronomers are perceived to be a trained subset of humans with a dominant adherence to science and usually little else. Bias creeps in when it is assumed that all the readers have (like the author) been avid watchers of *Star Trek*, while references to religion are more bald and ill-stated. The author makes no apology for equating Christianity with Creationism, and pokes fun at Abrahamic religions for believing their Bible to be a scientific document *and assumes that all other Christians take that view*. It is quite appalling that a professor in a department of religious studies should be so poorly aware of what religion is actually about. One feels for the students.

The writing is rather flippant in places; words like 'silly' and 'boring' do not enhance the discussions, but paint the author as more one-sided than he probably intended, and the tone tends towards the egocentric once one has got beyond that watershed page 46. The long discourses leading to definitions of words like 'culture' and 'civilization' are somewhat tortuous and would probably be just as understandable if restricted to the summaries which punctuate the book at several points. However, for someone who likes to be challenged, and to be presented with possibly a different way of approaching the topic, the book can certainly be recommended. It could have a place in a social-science library, but not in a scientific or a religious one. — ELIZABETH GRIFFIN.

A Tale of Seven Scientists and a New Philosophy of Science, by Eric Scerri (Oxford University Press), 2016. Pp. 228, 21 × 13 cm. Price £19·99/$29·95 (hardbound; ISBN 978 0 19 023299 3).

Among my favourite books around age 11 was Irving Stone's 1943 *They Also Ran*, a collective biography of about 20 men defeated for the US presidency, from Henry Clay to Thomas Dewey. Scerri's new volume has something of the same flavour — it is the stories of seven men who made, or tried to make, some contribution to atomic theory, between about 1899 and 1927, but whose profiles have been utterly eclipsed by those of Niels Bohr and Ernest Rutherford. The author describes his purpose as two-fold — to improve our understanding of the gradual development of atomic-structure theory and to propose a new way of looking at history and philosophy of science more akin to evolution than to Djoser's step pyramid.

This review appears in *The Observatory* because two of Scerri's obscure chemists (*etc.*) also made contributions to astronomy of equally profound, and perhaps equally undeserved obscurity. They are John William Nicholson (1881–1955) and Edmund Clifton Stoner (1899–1963). Both studied at Cambridge (winning various awards), were elected FRS (in 1917 and 1937, respectively), and had serious health problems. I have not checked whether this is true of any of the other five, whose contributions, if any, to astronomy are so obscure that neither the author nor I have found them. Nicholson was an alcoholic who retired at age 49, living another 25 years, most of them after the 1938 dissolution of his marriage. Stoner had diabetes, diagnosed in 1919, but was saved by Banting and Best's (or Macleod's if you wish) insulin, of which he had a steady supply only after 1927, but living until 1963. For their contributions to atomic structure, you must read the *Tale* for yourself.

Now, about their contributions to astronomy, taking them chronologically. Nicholson's are two-fold. First he was a firm supporter of nebulium (which he called Nu), not only identifying a number of features in the spectrum of the Orion Nebula with it, but also predicting two new lines which were soon found. He was equally successful with the spectrum of the solar corona, identifying many lines as due to proto-fluorine and its ions. Coronium (Cn) fits in there somewhere as well. Scerri covers this story, but has nothing to say about Nicholson's theory of stellar evolution, which begins with nebulae (including both planetaries and ones like Orion) and passes through a Wolf–Rayet stage to stars like the Sun, containing elements like those found on Earth, unlike nebulium, proto-fluorine (Pf), and coronium. Star formation from (at least some kinds of) nebulae was not firmly established for about 30 years after his 1917 summary paper. In more recent times Ambartsumyan and Anne B. Underhill also put the WR stars early in stellar lives.

Stoner's astronomy is only just barely hinted at, with the remark that Pauli made one of Stoner's papers the starting point for what became Pauli's exclusion principle. But in between worrying about atomic structure and taking up studies of magnetism, which occupied most of the latter part of his career, Stoner developed the idea of degenerate electron matter. His 1929 and 1930 papers are called 'The limiting density in white dwarf stars' and 'The equilibrium of dense stars'. These are cited by Chandrasekhar in the quantum-statistics and white-dwarf chapters of his 1939 stellar-structure book and also in important secondary sources, like Werner Israel's discussion of the astrophysics that led to black holes. There is a Stoner criterion in magnetism; he continued publishing up until a few years before his death (Nicholson's final paper dates from 1925); and Michael Nauenberg of the University of California Santa Cruz has attempted to make the case that the Chandrasekhar limit to the maximum mass of white-dwarf stars should really be called the Stoner limit. Only, I think, if you prefer to call Hubble's Law 'Lemaître's Law', or many dozens of other cases.

Several possible lessons can be learned along with Scerri's view that you can't have "winners" without "losers", and both are important. One is that the same person can be a 'loser' in more than one field. You can think of win/lose combinations for yourself, and actually Nicholson was the co-author on the second edition of Arthur Schuster's *An Introduction to the Theory of Optics*. He is thus cited in the 1926 volume, Russell, Dugan and Stewart's *Astronomy*. Another is that the damage people do to themselves can easily exceed what nature does to them. The third of the anti-heroes, Richard Abegg, died at age 41 in a ballooning accident. That probably had contributions from both nature and nurture, since he had ballooned while on military duty but continued voluntarily afterwards.

Conflict-of-interest statement: my copy of *A Tale of Seven Scientists* was sent gratis by the publisher at the request of the author. I am not among the 101 colleagues and friends thanked on pp. v–vi, but the author remarked, in telling me the book had been published, that something I said at an American Physical Society meeting (mentioned in the text) had been among the triggers turning his aim toward less-celebrated scientists. — VIRGINIA TRIMBLE.

Inside PixInsight, by W. A. Keller (Springer, Heidelberg), 2016. Pp. 380, 23·5 × 15·5 cm. Price £26·99/$34·99 (paperback; ISBN 978 3 319 25680 1).

I first came across PIXINSIGHT when looking for professional-grade software to construct, for promotional purposes, some 'pretty pictures' from deep-sky imaging obtained at UCL's teaching observatory. I was attracted both by the sophisticated tools on offer and by the fact that the program runs efficiently under Linux (as well as FreeBSD, Apple OSX, and Microsoft Windows), and I have not been disappointed in its ability to generate some surprisingly respectable images from data obtained under considerably less-than-ideal circumstances. It does, though, have a couple of significant drawbacks as far as I'm concerned: the first is the licensing structure (no multi-user licensing, so it is not well suited to a teaching environment), and the second is that it presents a dauntingly steep learning curve, exacerbated by what might charitably be described as an 'inconsistent' level of documentation.

The latter issue can be addressed by the time-honoured practices of trial & error and internet searching, but now *Inside PixInsight* provides the first dedicated, printed user manual for the software (though there are other books, such as Woodhouse's *The Astrophotography Manual: A Practical and Scientific Approach to Deep Space Imaging*, that describe use of the program in a broader context), from a third-party author. It's in the Springer *Patrick Moore Practical Astronomy* series, which I see has developed from a set of basic observers' guides to a comprehensive catalogue of over 150 titles, covering what are to me some surprisingly niche topics — including the book under review, which is clearly not addressed at the series' supposed target readership of "serious newcomers to amateur astronomy … and interested general readers", but rather is a sort of 'how-to' for users of the software. This is an ambitious undertaking, as there are a lot of tools in the PIXINSIGHT box — one might think of it almost as a PHOTOSHOP for astronomical image processing — but Keller, who runs the *Image Processing for Astrophotography* (ip4ap) web site and associated businesses, organizes his presentation in a logical progression, starting with basic frame selection and preparation (bias subtraction, flat fielding), through image alignment and combination, and on to background modelling, colour combination, sharpening, and so on. Specialized techniques, such as comet (moving-target) processing, narrowband imaging, and mosaicing, are also covered.

While the volume provides extensive guidance on practical usage of the software ('click here to do this'), there are no substantial descriptions of, or references to, the underpinning algorithms, and in a book that's all about image processing, the reader is woefully poorly served by the illustrations (as is the author). These are numerous (perhaps ¼ to ⅓ of the page acreage), and, other than for a few pages at the end of the book, they are pretty much exclusively in the form of screenshots. Their presentation baffles me — nearly all are monochrome (and very poorly rendered monochrome at that), but every now and again the screenshot window decoration — or part of it — includes a blue border. The sparse, apparently random, scattering of quasi-colour images look as though they've been run off on a cheap inkjet where a couple of the toner cartridges are dying; the print quality is far poorer than that of the free newspaper that I pick up at the railway station most days. This is more than just a cosmetic issue; often the effects of important processing steps are hard to discern, as in, for example, Fig 22.13, where it's claimed that "Dramatic display of the IFN is achieved", although in fact the image shown is scarcely distinguishable from the starting point. And speaking of 'IFN' ('integrated flux nebula', whatever that means), I found the lack of a summary list of the numerous, pervasive acronyms frustrating. While I suspect that they may be defined systematically on first occurrence (and though I can manage without reminders for CCD, ADU, or FWHM), that doesn't help much if one encounters, *e.g.*, BPP, CC, EL, IFN, OSL, STF … a hundred pages after they're introduced, and the very spotty index is of only limited use.

My overall impression is of a bit of a curate's egg. The author's practical experience, enthusiasm, and expertise do come through clearly, though virtually all the material can easily be found, in one form or another, on the Web (try searching on 'Harry's Astroshed' for starters); and the disappointing production standards are certainly not such as to invite browsing for idle pleasure. Furthermore, I'm not really sure who would want to buy this book.

If you're not a PIXINSIGHT user — and it's not a program for the casual deep-sky imager — it has no attraction at all. If you're an old hand, it's probably not going to teach you much of use that you haven't already learnt: anyone who has worked through the data-processing chain to develop a workflow that suits their purposes and who wants to develop their skills further may be better served by internet resources. However, I suppose that, for around 10% the cost of the software licence, this book would be a reasonable investment for a new user; and the more experienced user may stumble across a useful tool or two that they hadn't previously known of. — IAN D. HOWARTH.

OTHER BOOKS RECEIVED

Sigma 7: The Six Mercury Orbits of Walter M. Schirra, Jr., by C. Burgess (Springer, Heidelberg), 2016. Pp. 298, 23·5 × 15·5 cm. Price £26·99/$34·99 (paperback; ISBN 978 3 319 27982 4).

This is the fifth in a series of volumes devoted to the manned Mercury missions of the early 1960s, all written by space historian Colin Burgess. Much of the book gives a detailed account of the events leading up the third US orbital flight in the Mercury series, but the author also describes the later missions flown by 'Wally' Schirra as well as his post-NASA career.

Faith 7: L. Gordon Cooper, Jr., and the Final Mercury Mission, by C. Burgess (Springer, Heidelberg), 2016. Pp. 291, 23·5 × 15·5 cm. Price £26·99/$34·99 (paperback; ISBN 978 3 319 30562 2).

This is the sixth and final volume in a series of publications devoted to the manned Mercury missions of the early 1960s, all written by space historian Colin Burgess. The book tells the story of 'Gordo' Cooper's heroic 22-orbit mission in a malfunctioning spacecraft, a feat which paved the way for future Gemini and Apollo successes. It also includes the story of his second flight on board *Gemini 5* and his post-NASA career.

In the Footsteps of Columbus: European Missions to the International Space Station, by J. O'Sullivan (Springer, Heidelberg), 2016. Pp. 391, 23·5 × 15·5 cm. Price £33·99/$44·99 (paperback; ISBN 978 3 319 27560 4).

This book provides a detailed overview of 18 European crewed missions to the *International Space Station* (*ISS*) between 2001 April and 2012 July. The author describes the experiments carried out, the phases of *ISS* construction, and the personal stories of the astronauts.

Here and There

TRY USING THE NAKED EYE THEN

Splitting the main component [of Castor] into two stars, separated by 7 arcminutes (almost a tenth of a degree) is not hard, … — *The Times*, 2017 January 28, p. 78.

SO WHAT DO ASTEROIDS USE — BUSES?

Comets are different than asteroids. … unlike asteroids — comets travel in orbits. — *Fluke: The Maths and Myths of Coincidence*, by Joseph Mazur (Oneworld Publications), 2016.

PRESUMABLY FROM HIS SPACESHIP

Around 1800, the astronaut William Herschel discovered the existence of infrared radiation — Project report, University of Applied Science, Pforzheim.

SUPERGIANT STAR IN THE SOLAR NEIGHBOURHOOD

— measured a limb-darkened angular diameter [of Vega] of 3″·24 ± 0″·07, — *ApJ*, **712**, 250, 2010.