THE OBSERVATORY

Vol. 133 2013 APRIL No. 1233

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2012 October 12 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

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

The President. Ladies and gentlemen, I'd like to welcome you all to the new session of meetings with the Society. I'm afraid my first duty is a sad one, which is to announce the death of Sir Alfred Charles Bernard Lovell, world-renowned radio astronomer, and former President of the Society. He founded and was the first director of the Jodrell Bank Observatory. In 1981, he was awarded the Gold Medal of the Royal Astronomical Society. He passed away on 2012 August 6, and might I ask that we observe silence in memory of him, and ask you to stand for that purpose. Thank you very much.

The next process to be undertaken is a very happy one, and a very unusual one. And I would like to ask Professor William Gutsch, who is President of the Board of Directors of the Astronomical Society of the Pacific, to make an award, the Klumpke-Roberts Award, to one of our Fellows, Ian Ridpath.

Professor W. Gutsch. Thank you. It's an honour to have been allowed to come to your meeting today. I am a university professor these days, just outside of New York City, and also have the honour of being the current President of the Board of the Astronomical Society of the Pacific, which was founded in 1889 in San Francisco, primarily by astronomers and others out there who set upon themselves the task of showing that they can do much better astronomy in California than they could in those places like Harvard and Yale and Princeton, back on the East Coast of the United States; and obviously some good stuff has been going on at observatories and universities in California. But the Society is actually international, and among the many things we do is to build bridges between the astronomical research community and the teaching community — kindergarten through 12, community college as we call it in the States, and universities — bringing research astronomers together with educators, amateur astronomers with educators and each other, to get more and more folks excited about the Universe, which is something we all have in common.

Each year, the Astronomical Society of the Pacific presents a series of awards; they range from 'Lifetime Achievement' in astronomy and astrophysics research, that's the Bruce Medal — which this year, for example, was given to Professor Sandy Faber at the University of California at Santa Cruz — to awards that relate to achievements in college teaching, high-school teaching, outstanding research done by amateurs astronomers, and so on. We have among these awards one which we refer to as the Klumpke-Roberts Award, which is for 'Outstanding contributions to the public understanding and appreciation of astronomy'. This year's award winner is my old friend and colleague Ian Ridpath. And now I'm going to tell you about Ian; I'm sure you know about Ian, who for three decades has been one of the most respected and widely-published authors in the popularization of astronomy. His contributions to astronomy education comprise a rich catalogue of accessible books, articles, television and radio appearances, and lectures. His many popular sky-atlases and guides have gone through a number of editions and are considered models of clarity and facility for use, including the Collins pocket guides to stars and planets, *The Monthly Sky Guide*, and several editions of *Norton's Star Atlas*. So, having laid the background on this, I want to invite Ian to come up. Ian, we are happy to present you the Klumpke-Roberts Award for 'Outstanding contributions to better public understanding and appreciation of astronomy'. [Applause.]

The President. I would now like to make an announcement: the Council of the Society today, in a step that is a little unusual, decided on the first James Dungey Lecturer and on the timing of the Lecture. This normally would have been at a later occasion, but because Jim Dungey is 90 in January next year, we thought that we should expedite the decision on who would be the first Lecturer. The first Lecture will be given on Friday, January 11. The day before, there will be organized, in fact in this very place, a *Festspiel* for Jim, going over his work and his career. That will be on Thursday, January 10.

The first two lecturers on the programme today are the Winton Capital Award winners, and may I call upon Thomas Kitching, from ROE, to give his presentation of his work: '*Euclid*, mapping the geometry of the dark Universe'.

Dr. T. Kitching. Euclid is a mission in ESA's Cosmic Vision Programme, whose primary scientific objectives are to determine the nature of dark energy, and to map the dark-matter distribution of the Universe. The impact of this science can scarcely be exaggerated: dark energy, the phenomenon that is causing the expansion of the Universe to accelerate, but whose nature is entirely unknown, accounts for approximately 75% of the mass–energy content of the Universe; and dark matter, expected to be a new type of particle beyond the standard model of particle physics, accounts for the majority of the remaining 25%.

Euclid will use two methods to achieve these scientific objectives: the mapping of galaxy clustering on large scales, and a technique called weak gravitational lensing that I focus on in this presentation. Weak gravitational lensing is the effect where the image of background galaxies is slightly distorted by the presence of matter (dark matter in our Universe) along the line of sight. The effect depends on both the distribution of large-scale structures in the Universe, exactly how the dark matter forms a cosmic web, and on the geometry of the Universe; this dependence on both of these effects results in it being a particularly sensitive probe of dark energy. *Euclid* will be the ideal experiment to measure weak lensing; this is because from space the telescope will enable the resolved imaging of very faint galaxies and the lack of an atmosphere means that systematic effects can be controlled to the required accuracy.

Euclid is scheduled to launch in 2020; it will survey 15 000 square degrees of the sky, imaging 1·5 billion galaxies with *Hubble Space Telescope*-like resolution back in time over 75% of the age of the Universe. Not only will this data set allow the nature of dark energy to be determined, but it will also serve the astronomical community as a resource that will be used for generations to come.

The President. Thank you very much; any relatively quick questions?

Mr. M. Hepburn. You're saying 15 000 square degrees, but that's only about 35 to 40 per cent of the sphere, which has 41·3 thousand square degrees.

Dr. Kitching. Unfortunately the Galaxy is in the way.

Mr. Hepburn. Sure, it's a fantastic achievement, but it's not 50 per cent of the Universe, it's 35 per cent of the sphere.

Dr. Kitching. Yes, it's 50 per cent of the galaxies we can hope to detect.

Mr. Hepburn. The impression given was that all the galaxies that would be there, but I quite take the point that you wouldn't see the galaxies in the Galactic plane.

Dr. Kitching. You can, perhaps, imagine sending a probe to halfway between the Milky Way and Andromeda to get around that problem!

Professor Gutsch. A quick question: you're looking for weak-lensing effects as a function of, or *via*, changes in ellipticity of galaxies. So how do you differentiate between what the weak-lensing effect is doing and simply the orientation — or are you doing it statistically?

Dr. Kitching. It's the statistical effects. There is an assumption, but you can actually relax this assumption.

Professor Gutsch. And you're doing this across morphological types as well? Spirals, ellipticals, and so on?

Dr. Kitching. Yes, the simple way of explaining it, although we can relax this assumption, is that if you averaged over all possible galaxies in the Universe, their mean ellipticity would be zero.

The President. I think we have to finish at that point; thank you very much, and congratulations once again on the award. [Applause.]

The next speaker is Dr. Juliet Biggs, from Bristol, on 'Active tectonics and volcanism in the East African Rift: a satellite perspective'.

Dr. Juliet Biggs. It was a great honour to receive the Winton Capital Award for my work using satellite technology. Today I would like to talk about the East African Rift, which provides a variety of scientific and personal challenges as well as rewarding opportunities for both. The Rift Valley is an active plate boundary, extending from Djibouti in the north to Botswana in the south. The Nubian and Somalian plates are diverging and the result is a line of active volcanoes and earthquakes.

East Africa is the ideal location to study how diverging plate boundaries develop. The Rift is youngest in the south, and the slight stretching of the plate is taken up on faults, just as it once was in the North Sea. However, further north, the Rift is more mature and parts of the Afar depression resemble mid-ocean ridges; the plate motion is taken up by the intrusion of vertical walls of magma known as 'dykes'. One of the fundamental questions remaining in Earth sciences is at what stage of rift maturity does magmatism become more important than faulting? And conversely, is this the only control on this transition or are differences in plate thickness, geology, and inherited structures equally influential? Unfortunately, it would not be possible to deploy a dense network of ground instrumentation along 6000 km of the Rift.

Satellite technology is providing global coverage of many of the parameters that are important to understanding the Earth's system. Many of the instruments are similar to those used by planetary scientists and astrophysicists to study the Solar System and beyond, but in this case they are pointing back towards the Earth. Interferometric Synthetic Aperture Radar, known as InSAR for short, is one such technique. It uses the phase shift of successive radar images to measure small movements of the Earth's surface (< 1 cm) at a high spatial resolution (1 – 20 m). The result is continental-scale maps of surface displacements caused by natural processes such as volcanoes, earthquakes, faults, landslides, and glaciers, as well as human-induced signals such as urban subsidence, oil extraction, and aquifer depletion. Over the past five or six years, I've been using InSAR to study the active processes in the East African Rift.

My interest began in 2005 when a seismologist at the University of Addis Ababa contacted scientists around the world describing an odd swarm of small earthquakes he was detecting in the Afar region of Ethiopia. My PhD supervisor, Tim Wright, and I collected InSAR data over the area, and to our great surprise saw a much, much larger deformation pattern than we'd expected. It turns out that the earthquakes were caused by the subsurface injection of a huge volume of magma along a dyke that was 60 km in length and nearly 8 m wide. Although such things happen at the mid-ocean ridges on a regular basis, the last one to occur on land was in Iceland in the 1980s, before satellite radar was available. I was fortunate enough to visit the area, putting out ground-based instruments to investigate in more detail.

Although working on other projects, I continued to keep one eye on activity in East Africa, and was rewarded when in 2007 there was another swarm of earthquakes, this time in Tanzania. Once again, we turned to the satellite images and saw a large deformation pattern associated with the intrusion of a dyke. Although we were now accustomed to the idea of dyke intrusions, this one occurred in a much-less-mature part of the Rift, in an area where we might have thought faulting to be more dominant. Even better, we were able to use several satellites and beam modes, thus capturing snapshots as the sequence progressed. For the first time, we were able to see the temporal relationship between faults, dykes, draining of the magma chamber, and surface collapse.

The next earthquake swarm to occur was even further south in 2009, this time on the western shore of Lake Malawi, an area far from the nearest volcano, but close to several very large faults, including the 6-km high Livingstone Fault. The initial earthquake locations were very close to a geomorphological scarp thought to be associated with an east-dipping fault known as the Karonga Fault. Although our satellite images showed a pattern that was broadly consistent with slip on this fault, none of our models could explain the finer details. Closer inspection showed that the earthquake had actually occurred on another structure, a west-dipping fault with no obvious surface features. Although the fault had been mapped to the north and south of the earthquakes, a fan of sediments coming off the mountain had buried it in just this spot. It was temporarily named 'the Biggs fault', but fortunately it has since found a more permanent and fitting name.

By this time, it was clear that there was plenty of tectonic activity occurring in the East African Rift, but it was being seriously under-reported owing to a lack of instrumentation and trained scientists. My solution was to undertake a systematic survey, trawling through the archives of the European Space Agency. The results have so far revealed that eight of the 25 volcanoes studied have experienced some sort of deformation between 2003 and 2010. None of these volcanoes has an eruptive history or any monitoring equipment, and a recent World Bank report highlighted the enormous uncertainty associated with their potential hazard and risk. What is clear, however, is that they lie close to major population centres, including Nairobi and Addis Ababa. Furthermore, many of these volcanoes are sites of geothermal exploitation or exploration. Among them is Alutu Volcano in Ethiopia, which shows one of the largest and most persistent deformation patterns of any volcano globally, and at which a new geothermal power station is currently being constructed. My research group is now using airborne and ground-based geophysics alongside geological and volcanological approaches to identify the processes responsible for the deformation.

In summary, the volcanoes and tectonics of East Africa are fascinating to study, both from the ground and from space. These studies are contributing to our understanding of the development of major plate boundaries, to the processes that drive individual events, and the hazards and risks associated with living on an active planet. Many thanks to the Royal Astronomical Society for supporting my continuing work in this area.

The President. Any quick questions?

Mr. M. Osmaston. Can I draw to your attention the fact that in 2008 I published a paper showing that if you put one Joule into the middle or lower crust, the amount of volume increase is between 12 to 40 times more than you get with pure thermal expansion. And this depends on the petrological make-up of the deep or lower crust. So what I would urge you to think of, in terms of these apparent movements that you see, is the heat being put in, producing these bottom increases which are producing the uplifts, but also producing new earthquakes but with delayed time, because it takes time for the expansion effects to spread out.

Dr. Biggs. Yes, they have got a long way to go to get the lower crust up to here. But that's very well worth thinking about, thank you!

Professor D. Lynden-Bell. You haven't really talked about the left-hand side of the Rift.

Dr. Biggs. Oh yes, that's the Western branch. Actually there is a reason why I haven't talked about that, because that's where the Virunga volcanoes are, which is Nyiragongo and Nyamuragira. These are already fairly well studied by the Belgians. They've been there for quite some time. And that's where the city of Goma is. One of the reasons I tend to not talk about that is that the Belgians are already doing it.

Professor Lynden-Bell. Is it moving or is it active?

Dr. Biggs. A little, yes; a year ago it was very active near Nyamuragira. And both of those are very active — they erupt very frequently.

Professor Lynden-Bell. Is it moving apart, too?

Dr. Biggs. It's moving apart, yes.

The President. I have one last task, which is to give you an envelope, as an award winner.

Dr. Biggs. Thank you very much! [Applause.]

The President. I would now like to move on with the programme. Professor Gerald Roberts will talk about 'Marsquakes: evidence from rolled-boulder populations, Cerberus Fossae, Mars'.

Professor G. Roberts. Mars is a small planet which will have cooled quickly, and I first thought that when I started working on it that it would also be an inactive world. Recent high-resolution images received from Mars have a pixel size equivalent to 20 cm and for the first time we can see boulders directly on the Martian surface. They resemble those on Earth, in particular at the site of the l'Aquila earthquake, on which I have been working. Is there any way in which the spatial distribution of the boulders could be used to constrain seismicity on the planet; in other words, are there or have there been marsquakes? I have been looking at the boulder trails along the line of a fault and by determining the density of the spatial variation it may suggest that we are moving towards or away from an epicentre.

Although we may not expect volcanoes or seismic activity on Mars, there are faults which appear to be cutting through recently formed surfaces. The example I show is Cerberus Fossae — a down-drop graben feature which shows trails made by falling or rolling boulders. We determine the ages of the craters in the vicinity by crater counting and estimate that they are not more than two million years old — the faults which cut across them are clearly younger than that. Because the faults appear to be pointing towards the volcano Elysium Mons, it may be that the volcano is driving this activity.

There are alternative ways of moving boulders around, however. An ice cliff in the north of Mars showed five simultaneous rock-fall events within a few seconds — perhaps this is due to ice melting but the coincidence seems unlikely and seems to point to a physical effect.

Cerberus Fossae is 5 degrees north of the Martian equator — is what we see due to melting ice or marsquakes? The recent example of l'Aquila in Italy shows that there are lots of big boulders and few little ones. This leads us to look for large boulders on Mars which are isolated from little boulders and which are sitting in a layer of dust. In the case of earthquakes the number and size of boulders decreases with distance from the epicentre and in l'Aquila the boulders get smaller the further they are from the epicentre. With high-resolution images we can measure boulder sizes and test this hypothesis.

Looking at the faulting area in Cerberus Fossae we can see colluvial fans of material coming off it, and the fans are offset by surface faulting. Some of the large boulders have left trails whereas wind and dust have covered others. Some of the boulders deform round sand dunes. How long do the trails last? This is a measure of the age of the boulder run.

We know from the on-board imaging cameras on the *Spirit* and *Opportunity* rovers that some of the trails made by the rover wheels lasted about 20 days, so the rolled-boulder tracks seem to be very young and we need to see if they were made by melting ice or by marsquakes. We have measured hundreds of boulder sizes along the 350-km length of the fault and the ten largest ones range from 2 to 4 metres in diameter. We can determine the boulder trail density per km. The problem comes with high densities because then the trails coalesce. If marsquakes are occurring, are the faults due to dyke emplacement meaning that volcanism is still in action? The *Viking* spacecraft actually carried seismometers but the pressure of Martian winds on the spacecraft meant that it was not possible to determine if there was any seismic activity. It is planned to send a seismometer to Mars with the *InSight Mars 2016 Lander* spacecraft (NASA/ESA). In addition to placing seismometers on the surface the mission will also insert a heat-flow probe into the soil.

Rev. G. Barber. Could you have a third hypothesis — that it's a temperature-controlled melting of vast ice deposits underneath the surface, so in fact, it is not hot enough to melt rock, but it is melting ice, and that's causing the marsquake.

Professor Roberts. That would be very exciting, wouldn't it? Yes, why not!

Rev. Barber. But if there's not enough heat to melt rock, and there are marsquakes, there might be an alternative hypothesis.

Professor Roberts. Well, that would be great — I'm interested in that!

Professor D. W. Hughes. You could have a fourth hypothesis [laughter]. Most of the moonquakes are tidal. Mars will have solar tides and the variation in the eccentricity also changes the solar tides, and so they could quite easily give the surface a decent shake now and then.

Professor Roberts. Yes, the moonquakes are every 27 days or so, so they are indeed tidal. The moment magnitudes are quite small — we're talking about magnitudes 2 to 4 on the Moon. This area of elevated boulder sizes is something like 200 km across. Now on the Earth, to move boulders over a distance of a couple of hundred kilometres, you're looking at a magnitude 8 earthquake. So, with your fourth hypothesis it would be a tidally-forced magnitude, a big magnitude. I don't want to put a number on it, but it would be big.

The President. I think we should move on. Thank you very much. The final speaker of the day is Professor Martin Barstow, from the University of Leicester, on 'White dwarfs: why all astronomers should love them'.

Professor M. Barstow. We live in an era of very exciting science and I would like to remind you of some very important objects which we don't understand as much as we ought to and whose ubiquity is helping to solve astrophysical problems.

The contributions of white dwarfs (WD) are many and varied. They represent one of a number of stellar end-points and are actually the most numerous — more than 90% of stars in the Galaxy will end up like this, and because they cool so slowly they are also some of the oldest objects in the Milky Way. If we can measure their age, it will give us a handle on the age of the Galactic disc and ultimately the Universe. They contain half of the mass of the Sun in a volume whose radius is that of the Earth, and so the exotic matter contained therein can be studied under extremes of temperature and density which cannot be achieved on Earth. Of more recent interest is the discovery of exoplanets and the existence of what appears to be the remnants of planetary systems in orbit around WDs. They can also be used to study interstellar lines, and, last but not least, they are responsible for Type Ia supernovae.

Hanson has shown that globular clusters have a beautiful WD cooling sequence and the turnover point yields an accurate age of the cluster, but this depends on some assumptions which are not sufficiently and accurately understood. We need to know more about the mass–radius relationship, the internal structure, and the physics of cooling. My collaborators and I have been looking at the mass–radius relationship but there are a number of complex interactions going on in the stars which we need to quantify.

The best known WD is Sirius B, and this is very useful in defining the mass–radius relationship. We can get an accurate value of the mass from the orbital elements. By measuring the flux, and knowing the accurate parallax, we can get the radius, and from a knowledge of the gravity we can measure the gravitational redshift which also depends on mass and radius. Using *ROSAT* we found a lot of WDs in binary systems but to see the stars directly needs the *HST* because the stars are too close together to resolve from the ground. Regular observations are needed to define the apparent orbit of each binary. In the case of Sirius we have watched the apparent orbit around three of the 50-year orbits so the orbital elements are very well known. In space we can get spectra of Sirius B which allow us to measure the gravitational redshift. That was first done (from the ground) by Greenstein in the 1960s but we can do it much better with *HST*.

The error bars on the observed parameters can help to distinguish between various models using different equations of state. We need to know how thick is the hydrogen layer and what is the cooling rate and we are now looking at those for Sirius and other systems. Spectra will tell us a lot about the atmospheric composition, and both the interstellar and circumstellar material, but any interpretation depends on good stellar-atmosphere calculations.

From 100 WDs we have been looking at the highly excited interstellar lines of O VI and it seems that that ion exists at relatively great distances outside the local interstellar bubble (LIB). It was believed that the LIB was filled with hot gas which resulted in a hot X-ray background. Perhaps that emission comes from charge exchange in the heliopause, *i.e.*, locally.

A continuing theme of the work at Leicester is the composition of WDs and why they don't resemble their theoretical picture. The basic theory says that under strong gravity most of the heavy elements should sink straight out of the atmosphere. In 1917 van Maanen discovered a star now named after him which contains Ca, Mg, and Fe in the atmosphere. Recent observations by *FUSE* have allowed us to examine WDs with a much greater range of temperature than previously. In the hotter objects we would not expect to see much Si whereas in the cooler stars we do see it. There is no correlation between the Si abundance that is predicted and that which is observed, so where are the metals coming from? Cooler stars such as GD 56 show evidence for a dusty disc. There is good evidence for circumstellar material from the C IV line and there is increasing evidence that this is accreting planetary debris continuously raining down onto the star's atmosphere.

In conclusion, WDs can contribute to many areas of astrophysics, but we need to improve the observational samples and refine the theoretical underpinning. [Applause.]

The President. Very *quick* questions?

Miss Mandy Bailey. Coming back to the local bubble, the background soft-X-ray emission is indicative of temperatures of 10^6 K. Have you any idea of what the temperature is in the rest of the bubble — beyond the heliosphere — if it's not hot?

Professor Barstow. Well, the local bubble is really just empty. It's probably full of warm gas, at a few tens of thousands of degrees. But it's such a low density that there's not much of it. But there's clearly very little, if any, hot gas, of the sort of half-million- to a million-degree plasma. Where it exists at all is actually towards the boundary. So, some of that outside the local bubble will be responsible for soft-X-ray background, and there are many components with the soft-X-ray background. But the supposed local component probably doesn't exist. The local component is much closer to home than people thought.

Miss Bailey. The walls of the bubble with the sodium and calcium mapping — I think that indicates there is an interface of a cold-wall denser region. So do you think the hot part of the bubble is warm right up to the edges rather than in the bubble centre?

Professor Barstow. There is certainly interaction at the edges of the bubble, so there are interface regions at higher-temperature, but there is none in the interior. The charge exchange — it isn't about hot gas, that's a different process, so it's where you get X-rays arising from interactions of heavy ions, actually at the heliopause. I have to say I'm not an expert in that, and you probably need to talk to somebody else about the actual mechanism. But it's not particularly an implication of very hot gases — that's a different process.

Professor I. Crawford. So the idea is that the local bubble at one point was thought to be possibly a supernova remnant — has that gone away?

Professor Barstow. I don't think that's gone away, but it actually swept material out. It's probably not one remnant in any case, it's probably many historical supernovae, and you see the imprint of the most recent ones actually, but it wasn't the subject of my talk today. But on the local cloud, which is actually relatively highly ionized, there is a small, few-parsec-sized cloud surrounding the Solar System. And the helium in that cloud is 30 or 40% ionized, and you can only get that if you hit it very hard with a shock wave. So that hasn't gone away. But our understanding of the interaction of these — probably repeated — explosions over time doesn't actually give you the hot phase anyway.

The President. I think time has run out for us; thank you very much! [Applause.] I'm happy to remind you that we will now have the usual drinks party in the RAS library across the way, and the next monthly A&G Open Meeting of the Society will be on Friday, 2012 November 9th.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 229: HD 26081, HD 125728, HD 134047 (HR 5631), AND HDE 228188

By R. F. Griffin
Cambridge Observatories

The four stars were all discovered to be spectroscopic binaries by de Medeiros & Mayor; the writer's observations of them began in 2002, when they were selected from a listing deposited with the Centre de Données Stellaires by those authors. HR 5631 has an MK type of K0 III; the other three stars have been classified as G-type 'bright giants' (luminosity class II), but the parallaxes of HD 26081 and HD 125728 suggest that their luminosities are within the class-III range (there is no parallax known for HDE 228188). Both HD 26081 and HDE 228188 are about half a magnitude 'too red' in $(B - V)$ for their spectral types, and give radial-velocity traces more in keeping with their colours than with their classified types. Their traces also show very significant line-broadening, unusual among late-type stars, equivalent to projected rotational velocities of about 8 and 21 km s^{-1}, respectively.

HD 125728 has an orbit of moderate eccentricity (0·29) and a period of about 2½ years. The other three stars all have periods inconveniently close to integral numbers of years (6, 5, and 8, respectively), so the phase distributions of their radial-velocity observations have regular gaps. The gaps are of no consequence as far as the determinations of the orbits are concerned, except in the case of HDE 228188, which has an orbit of high eccentricity (0·86) and lacks data on the approach to the node; the *lacuna* cannot be filled in until 2027. The eccentricities of the orbits of HD 26081 and HR 5631 are 0·47 and 0·30, respectively.

Introduction

The four stars treated in this paper were all discovered to be binaries by de Medeiros & Mayor[1], who in 1999 published rotational- and radial-velocity measurements for about 2000 late-type stars, which they had mostly observed just twice each. Naturally there were cases of discordance that probably identified spectroscopic binaries, many of which had not previously been recognized, although there were a few cases of Cepheids, δ Scuti variables, *etc*. Three years later, those authors deposited with the Centre de Données Stellaires (CDS) a listing of their individual radial-velocity observations, making it easier for an interested party such as the present writer to identify stars that might promise to yield spectroscopic orbits of reasonable amplitude within a reasonable time. Sixty such objects were selected for addition to the Cambridge observing programme, which already included a few other objects that were also to be found in the de Medeiros & Mayor listing. So far, orbits have been presented in this series of papers (including *this* paper) for 33 of the 60 objects, as indicated in Table I; one other (that of HR 1908) has appeared[2] elsewhere. Despite their careful selection, four of the 60 stars (HDE 276743[3], HD 146815 and 64 Aql[4], and 56 Peg[5]) were put on the writer's programme as a result of errors (probably of identification) in ref. 1. That was, however, beneficial in the last case, prompting the determination[5] quite quickly of the low-amplitude orbit of 56 Peg, which had defied previous specific efforts made not only by de Medeiros and Mayor themselves but also at Lick[6,7] and at the Dominion Astrophysical Observatory, Victoria[8]. The writer's programme still retains 24 of the original 60 stars; one (HR 8078) was dropped when it transpired that observations of it were well advanced elsewhere, but two stars (HD 14415 and HR 3112) whose orbits have already been presented have been retained because they proved to be triple systems warranting continued long-term monitoring.

TABLE I

Bibliography of orbits published in this series of papers for stars selected from de Medeiros & Mayor[1]

Star	*Paper*	*Vol.*	*Page*	*Star*	*Paper*	*Vol.*	*Page*	*Star*	*Paper*	*Vol.*	*Page*
58 Psc	207	**129**	198	δ Aur	205	**129**	54	HD 180660	224	**132**	156
60 Psc	220	**131**	294	HR 3112	189	**126**	338	HD 181386	213	**130**	232
HR 396	223	**132**	76	HR 3567	225	**132**	234	HD 183791	224	**132**	156
HD 10332	226	**132**	309	HR 3907	225	**132**	234	HR 7636	223	**132**	76
HD 14415	189	**126**	338	HR 4427	205	**129**	54	HDE 228188	229	**133**	65
HD 14544	188	**126**	186	HD 125728	229	**133**	65	31 Vul	207	**129**	198
HR 738	204	**129**	6	HR 5631	229	**133**	65	HR 8149	222	**132**	16
HR 770	196	**127**	313	HR 5692	204	**129**	6	HD 216218	188	**126**	186
HDE 237201	188	**126**	186	HR 6239	225	**132**	234	56 Peg	186	**126**	1
HD 26081	229	**133**	65	HR 6886	214	**130**	299	6 And	223	**132**	76
HR 1313	225	**132**	234	HR 7252	204	**129**	6	70 Peg	207	**129**	198

Three of the four stars discussed in the present paper — HR 5631 is the exception — were selected by de Medeiros & Mayor with a view to increasing the representation of high-luminosity stars in their programme*. The three have all been classified as being of luminosity class II. The parallaxes[10], however, of HD 26081 and HD 125728 indicate that those stars (unless indeed they are seriously dimmed by interstellar absorption) are only slightly brighter than zero absolute magnitude and are thus within the range of luminosity shown by Keenan & Barnbaum's post-*Hipparcos* diagram[11] to belong to luminosity class III.

*Supergiants (luminosity class Ib) were described separately[9]; the paper[1] that is relevant here was intended to be restricted to luminosity classes II–IV.

HD 26081

HD 26081 is an eighth-magnitude star about 5° north-following the Pleiades; it is only about 40′ from HD 25768, a star treated recently in Paper 219[12] of this series, and scarcely further from the fifth-magnitude star 44 Tau. Its photometry has been provided by Guetter[13], as $V = 7^{m}{\cdot}18$, $(B-V) = 1^{m}{\cdot}42$, $(U-B) = 1^{m}{\cdot}26$. A spectral type of G8 II was published for it long ago by Heard[14] (who, as Director of the David Dunlap Observatory (DDO) was acting as mouthpiece for his staff; the classifications in his paper were actually made by Mrs. V. Gaizauskas). The discrepancy between the measured $(B-V)$ colour index and the spectral type is noteworthy: the tabular[15] colour index for G8 II is only $0^{m}{\cdot}99$. Interstellar reddening can scarcely be the principal cause of the discrepancy, because the parallax of 2·77 ± 0·75 arc-milliseconds, though of low proportional precision, shows the star to be 'only' 300–500 pc away, and at about –19° it is not at a particularly low Galactic latitude. The distance modulus is about $7^{m}{\cdot}8 \pm 0^{m}{\cdot}6$, giving the star an absolute magnitude (nett of any interstellar absorption) of about $-0^{m}{\cdot}6 \pm 0^{m}{\cdot}6$, putting it within the band of luminosity included within class III in Keenan & Barnbaum's diagram[11].

It is distinctly troublesome that HD 26081 is getting on for half a magnitude redder in $(B-V)$ than the tabular value[15] for its spectral type. It gives very deep dips in radial-velocity traces; they would be appropriate to a late-K giant or early-K supergiant and are quite definitely deeper than would be expected for a G8 star that is little, if any, more luminous than a normal giant. The dips are significantly broadened, as can arise from axial rotation or from the 'turbulence' that seems often to be associated with really high luminosity but would be anomalous at the luminosity indicated by the parallax. The breadth of the dips repeats very well from observation to observation, and expressed as a rotational velocity its mean value is 7·91 km s^{-1} with a formal standard error (not to be accepted as the true external error) of only 0·10 km s^{-1}. The G8 II classification was made on a slit spectrogram, but there is also an objective-prism classification[16] of G5 III, for which the redness of the star would be even more excessive. The discordance between the spectral type, on the one hand, and the colour index plus parallax, supported by the nature of the radial-velocity traces, on the other, is something that cannot be settled here by reference to the literature but which warrants investigation.

The Cambridge radial-velocity observations began ten years ago and have been maintained tolerably systematically; their frequency decreased in the later years but their dates then were more carefully chosen, in order to reduce gaps in their phase distribution as much as possible. Regular gaps in phase coverage inevitably remain, however, because the period is close to an integral number of years (6·09 years), and since the star is within 5° of the ecliptic it is unobservable for a considerable time each year (most of April, and May, June, and July). Obviously, the gaps can be closed only at a rate of 0·09 years every six years, so it would take several six-year cycles to close them altogether. They do not, however, significantly detract from the quality of the orbit determination, only from the cosmetic appearance of the plotted illustration of the orbit (Fig. 1).

The 46 Cambridge observations, listed in Table II, by themselves yield an orbit with a period of 2220 ± 6 days. Heard[14] noted that radial velocities had been measured from four plates at the DDO; the results were, however, given only as a mean value (–11·1 km s^{-1}, with a 'probable error' of 0·9 km s^{-1}) and so cannot be entered in Table II or taken into account in the orbit. There are five OHP radial velocities, which have been retrieved from the CDS and listed at the head of Table II. When they are included in the solution of the orbit,

TABLE II

Radial-velocity observations of HD 26081

The sources of the observations are as follows:
1986–1999 — OHP Coravel; 2002–2012 — Cambridge Coravel (both weight 1)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
1986 Nov. 18·98*	46752·98	−5·0	0·834	+1·1
1987 Sept. 15·16	47053·16	−0·1	0·969	+0·1
1988 Mar. 5·78	47225·78	−1·1	1·047	0·0
1997 Sept. 4·07	50695·07	−8·8	2·606	−0·2
1999 Jan. 19·84	51197·84	−6·5	2·832	−0·3
2002 Sept. 30·15	52547·15	−8·7	3·439	0·0
Oct. 28·12	575·12	−8·9	·451	−0·2
Dec. 11·12	619·12	−8·5	·471	+0·3
2003 Feb. 19·86	52689·86	−8·7	3·503	+0·1
Apr. 7·82	736·82	−9·2	·524	−0·4
Sept. 18·17	900·17	−8·6	·598	0·0
Nov. 13·09	956·09	−8·4	·623	+0·1
2004 Jan. 16·97	53020·97	−8·6	3·652	−0·2
Sept. 6·19	254·19	−7·5	·757	0·0
Nov. 14·05	323·05	−6·6	·788	+0·5
2005 Jan. 4·95	53374·95	−6·3	3·811	+0·3
Mar. 17·86	446·86	−6·3	·843	−0·4
Aug. 16·15	598·15	−3·5	·911	−0·1
Sept. 8·19	621·19	−3·2	·922	−0·4
Nov. 4·10	678·10	−1·2	·947	+0·2
Dec. 10·93	714·93	−0·4	·964	+0·1
2006 Jan. 25·87	53760·87	+0·7	3·985	+0·3
Feb. 25·81	791·81	+0·6	·998	0·0
Apr. 4·83	829·83	0·0	4·016	−0·4
Sept. 8·16	986·16	−2·7	·086	+0·5
Oct. 3·17	54011·17	−4·0	·097	−0·2
Nov. 1·07	040·07	−4·0	·110	+0·4
Dec. 6·13	075·13	−5·0	·126	0·0
2007 Jan. 1·98	54101·98	−5·6	4·138	−0·2
11·89	111·89	−5·4	·142	+0·1
Feb. 7·83	138·83	−5·5	·154	+0·4
Mar. 3·84	162·84	−6·5	·165	−0·4
Aug. 3·12	315·12	−7·5	·234	−0·1
Sept. 16·15	359·15	−7·8	·253	−0·2
Oct. 19·11	392·11	−8·2	·268	−0·4
Nov. 12·02	416·02	−8·2	·279	−0·3
Dec. 11·01	445·01	−7·8	·292	+0·2
2008 Jan. 24·89	54489·89	−8·0	4·312	+0·2
Feb. 26·88	522·88	−8·2	·327	+0·1
Mar. 30·81	555·81	−8·3	·342	+0·1
Sept. 20·17	729·17	−8·6	·420	+0·1
Dec. 7·04	807·04	−8·7	·455	0·0

TABLE II (*concluded*)

Date (UT)			MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2009	Jan.	6·89	54837·89	−8·6	4·469	+0·2
	Feb.	21·87	883·87	−8·7	·489	+0·1
	Oct.	12·12	55116·12	−8·5	·594	+0·1
2010	Nov.	24·01	55524·01	−7·0	4·777	+0·2
2011	Apr.	8·82	55659·82	−6·0	4·838	0·0
	Oct.	20·11	854·11	−2·5	·926	+0·1
	Nov.	18·04	883·04	−1·9	·939	0·0
2012	Jan.	3·91	55929·91	−0·6	4·960	+0·1
	Feb.	11·82	968·82	−0·1	·977	−0·2
	Aug.	31·16	56170·16	−2·4	5·068	−0·1

*Rejected — see text.

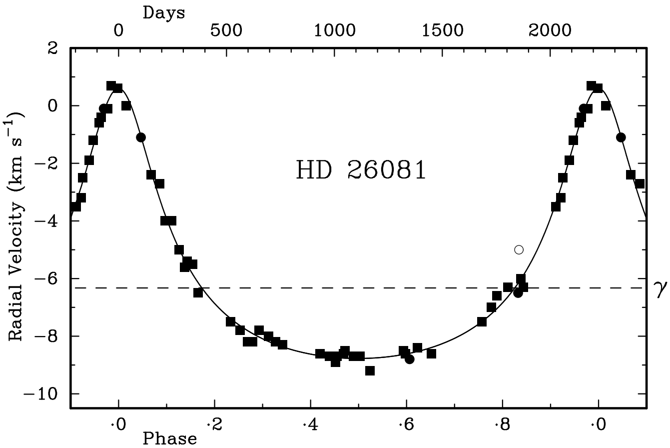

FIG. 1

The observed radial velocities of HD 26081 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Filled squares represent measurements made by the writer with the Cambridge *Coravel*; circles plot the five velocities reported by de Medeiros & Mayor[1] from the OHP *Coravel*. The open circle identifies one that is rejected here (see text); the others were attributed full weight (equal to that of the Cambridge data) in the solution of the orbit.

they merit weight ¼, and the orbital period is refined to 2225·5 ± 3·6 days. The first of the five measurements, however, gives a residual that is much larger than the others — more than 1 km s^{-1}, which is unusually large by modern standards. The CDS listing gives internally computed standard errors for each observation, and that of the offending first entry is considerably larger than the others. It is obvious from the listing as a whole that the uncertainties that were actually computed, from the relationship between the depth of the 'dip' and the Poisson uncertainties in the photon counts in the individual 'bins' of the trace, have been added quadratically to a constant amount of 0·25 km s^{-1} which must be the number adopted to represent additional non-statistical sources of error. By undoing the quadratic addition, one finds that the computed statistical mean-square uncertainty of the first OHP velocity was larger by factors ranging from 2·4 to 4·2 than the other four. There is no way for a 'user' to discover what was bad with it, but *here* we have taken the liberty of rejecting it. The remaining four OHP measures then warrant the same weight as the Cambridge ones, and the orbital period becomes 2224·4 ± 2·3 days. The other elements are presented in Table VI towards the end of this paper, grouped with those of the other three stars treated here.

The mass function is quite small and does not require the companion star to be more massive than about 0·45 $M_\odot$ (equivalent to about M0 V) if the primary is supposed to be 2 $M_\odot$; even if the primary is really as luminous as its classification suggests and has a mass of (say) 4 $M_\odot$, the secondary still would not need to be more than about 0·7 $M_\odot$, the mass of a main-sequence star near type K5. In either case it may be so much fainter than the primary that it is far from surprising that it has not been apparent in the radial-velocity traces. If the secondary object is anywhere near the minimum mass (or equivalently, if the orbital inclination is anywhere near 90°), then the mass ratio of something like 4 means that the projected separation of the stars on the sky is of the order of five times the value of $a_1 \sin i$, or about 4 AU. At the distance of about 400 pc implied by the parallax it would subtend an angle of about 0″·01, and with a Δm of possibly nine or ten magnitudes it would be far from an attractive prospect for interferometric resolution. If the orbital inclination is far from 90° the companion would be brighter, but the smaller mass ratio would mean that it would be even closer.

HD 125728

This star is bright enough to feature in the *Supplement to the Bright Star Catalogue*[17]; it is to be found in Boötes, about 7° north of Arcturus and just over 1° following. The photometry in the *Supplement*, $V = 6^{m}\cdot78$, $(B - V) = 0^{m}\cdot91$, evidently comes from Bakos[18]; later measurements, by Fernie[19] and Andruk *et al.*[20] do not agree very well, giving $V = 6^{m}\cdot82$ and $6^{m}\cdot81$, $(B - V) = 0^{m}\cdot95$ and $0^{m}\cdot97$, and $(U - B) = 0^{m}\cdot51$ and $0^{m}\cdot42$, respectively. The spectral type of G8 II was assigned by Mrs. Gaizauskas and published by Heard[14], exactly as for HD 26081. In this case, however, there is no conflict between the measured colour index and the one tabulated[15] for the spectral type. The parallax shows the distance modulus to be just seven magnitudes, with an uncertainty of about $0^{m}\cdot4$, so the absolute magnitude of HD 125728 is about –0·2 ± 0·4, and notwithstanding the published spectral classification[14] the star has the luminosity of a normal giant.

The same 1956 DDO paper[14] as gives the spectral type also notes that the radial velocity had been measured on four plates, giving a mean of +26·1 km s^{-1}. The 'probable error' of the mean is given as 1·9 km s^{-1}, implying that the r.m.s. spread of the four individual plate velocities (which are not available separately) is about 5 km s^{-1}. That is a quite modest uncertainty by the standards of the relevant observing programme, and does not in any way suggest real variability: the error listed for HD 125728 is exceeded by the corresponding values for 18 out of the 44 other stars whose results are listed on the same page of the paper. It makes an interesting comparison with velocities obtained by the cross-correlation procedure to recall that the spectra that gave 5-km s^{-1} precision were noted as taking between half an hour and two hours to expose at the DDO 74-inch reflector.

TABLE III

Radial-velocity observations of HD 125728

The sources of the observations are as follows:
1986/7 — OHP Coravel; 2002–2012 — Cambridge Coravel (both weight 1)

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O–C)* $km\ s^{-1}$
1986 May 30·93	46580·93	+24·1	$\overline{6}$·352	−0·3
1987 May 4·04	46919·04	32·3	$\overline{6}$·726	−0·3
8·97	923·97	32·3	·732	−0·3
2002 May 29·94	52423·94	32·8	0·810	+0·3
July 13·94	468·94	31·5	·860	+0·1
Aug. 12·89	498·89	29·9	·893	−0·1
Sept. 10·83	527·83	27·8	·925	−0·2
2003 Feb. 18·18	52688·18	17·7	1·102	+0·1
Mar. 19·07	717·07	18·1	·134	+0·2
Apr. 16·07	745·07	18·7	·165	+0·2
May 20·07	779·07	19·5	·202	−0·1
June 20·98	810·98	20·7	·238	0·0
July 15·93	835·93	21·7	·265	+0·1
Sept. 13·81	895·81	23·5	·331	−0·3
2004 Jan. 9·29	53013·29	27·7	1·461	+0·2
Mar. 2·21	066·21	29·3	·520	+0·3
Apr. 3·15	098·15	30·0	·555	+0·2
20·06	115·06	30·3	·574	+0·1
May 17·04	142·04	30·9	·604	+0·1
June 12·97	168·97	31·7	·633	+0·3
Aug. 7·86	224·86	32·4	·695	+0·1
Sept. 7·81	255·81	32·4	·729	−0·2
Dec. 27·30	366·30	31·7	·851	+0·1
2005 Jan. 19·23	53389·23	31·0	1·877	+0·3
Mar. 23·17	452·17	26·3	·946	−0·1
Apr. 19·08	479·08	23·8	·976	0·0
May 5·03	495·03	22·4	·994	+0·1
23·04	513·04	20·7	2·014	−0·1
June 6·97	527·97	19·7	·030	0·0
22·98	543·98	18·7	·048	−0·1
July 9·90	560·90	18·1	·066	0·0
2006 Jan. 29·25	53764·25	22·6	2·291	+0·1
Apr. 5·09	830·09	24·6	·364	−0·2
26·04	851·04	25·5	·387	0·0
May 17·02	872·02	25·9	·410	−0·2
June 3·99	889·99	26·5	·430	−0·2
23·00	909·00	27·5	·451	+0·2
Aug. 7·89	954·89	28·6	·502	0·0
Sept. 8·81	986·81	29·3	·537	−0·1
2007 Jan. 14·28	54114·28	32·1	2·678	0·0
Feb. 6·22	137·22	32·5	·703	+0·1
Mar. 22·15	181·15	32·4	·752	−0·3
Apr. 30·02	220·02	32·7	·795	+0·1
May 30·02	250·02	32·1	·828	−0·1
Aug. 10·87	322·87	28·9	·909	−0·2
2008 Feb. 2·22	54498·22	17·4	3·102	−0·2
2010 Mar. 23·14	55278·14	25·0	3·964	+0·1
2012 Jan. 6·30	55932·30	31·8	4·687	−0·4
Aug. 20·85	56159·85	+27·2	·939	+0·2

The DDO was not the first observatory to measure the radial velocity of HD 125728: Andriesky[21] reported in 1948 that three measurements had been obtained in the Crimea and that they showed that the star is a binary. Again, however, the individual measurements were not published, although it was noted that the range of the velocities was from +29 to +9 km s^{-1}. There is one later observation by Yoss *et al.*[22], at +21·4 ± 0·8 km s^{-1}, and also a mean of +27 ± 2·3 km s^{-1} from four objective-prism measurements[23], before de Medeiros & Mayor[1] noted a definite discordance on the basis of three measures obtained with the OHP *Coravel*. When the three were made available individually through the CDS, the last two of them were seen to have been made only five nights apart and to be in mutual agreement, but the first one, obtained a year before, differed by 8 km s^{-1}. The OHP *Coravel* observations are listed at the head of Table III, the rest of which records the 45 velocities obtained by the writer with the Cambridge *Coravel*. The two sources have been given equal weights in the solution of the orbit, which is illustrated by Fig. 2. The period is 904 days or about 2½ years, so (alone among those determined in this paper) it facilitated, both by its shortness and its half-integral value in terms of years, uniform phase coverage by the observations. The elements are included in Table VI below.

If the mass of the observed star is estimated at 2 $M_\odot$, then the mass function found from the orbital elements demands a mass that is not less than about 0·6 $M_\odot$ for the companion star, corresponding to a very late K type with an absolute magnitude near +8. If the companion is near that minimum mass, the major axis of the relative orbit of the components would be about 2½ AU; the angular separation at the 250-pc distance of the system would reach only about 0″·01.

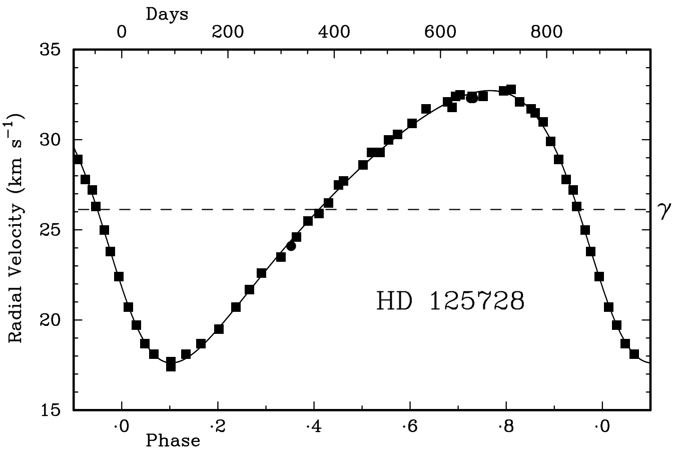

FIG. 2

As Fig. 1, but for HD 125728; the coding of the plotted points is the same, but here no data are rejected.

HR 5631

HR 5631 is in an easterly excrescence of the constellation Virgo, at a declination of +5°; it is in an area of sky that looks rather barren to the naked eye, even one whose owner is not handicapped by serious light pollution, and its situation is best described as being about 9° preceding α Ser. Its photometry[24–27] has been determined at three observatories independently, with results agreeing closely with $V = 6^{m}\cdot16$, $(B-V) = 0^{m}\cdot94$, $(U-B) = 0^{m}\cdot71$. Its spectrum has been classified twice by Harlan[28], first as K0 III and then as G8 II. The natural expectation that the *Bright Star Catalogue* would adopt the (chronologically) later classification as superseding the earlier one was not fulfilled, so the type has been widely quoted as K0 III. The colour indices would be consonant with either, but the parallax is decidedly in favour of the type adopted in the *Bright Star Catalogue*, as it equates to an M_V of $+0^{m}\cdot05 \pm 0^{m}\cdot12$. Keenan, however, in the *Perkins Catalog*[29], gave the type as "G7 IIIa: Fe-0·5".

The radial velocity of HR 5631 was first published in 1932, in the *Monthly Notices*, by Shajn & Albitzky[30], who obtained four spectra with the Grubb 40-inch reflector at Simeis and gave a mean result of +4·5 km s^{-1} with a 'probable error' of 1·7 km s^{-1}. The data were subsequently presented individually in the *Poulkovo Publications*[31]. Meanwhile, five other observations, taken with the DAO 72-inch telescope, were published by Harper[32]; they are given separately in the paper, as well as by a mean. There is a comment, "Second plate shows to be a s[pectroscopic] b[inary]." Whether it really did so is open to question: it differs from the first one by 16 km s^{-1}, but the actual change of velocity between the first two observational epochs, computed back from the orbit derived here, was only 7·5 km s^{-1}. That is the exact value (to 0·1 km s^{-1}) found for the r.m.s. residuals of the five DAO measures from the orbit that is presented here and which might therefore be taken as the true r.m.s. error for those observations. So it would seem to need an apparent change $3\sqrt{2}$ times as great, or about 32 km s^{-1} — double the discrepancy that Harper found — between two observations for the difference to be significant at the 3σ level.

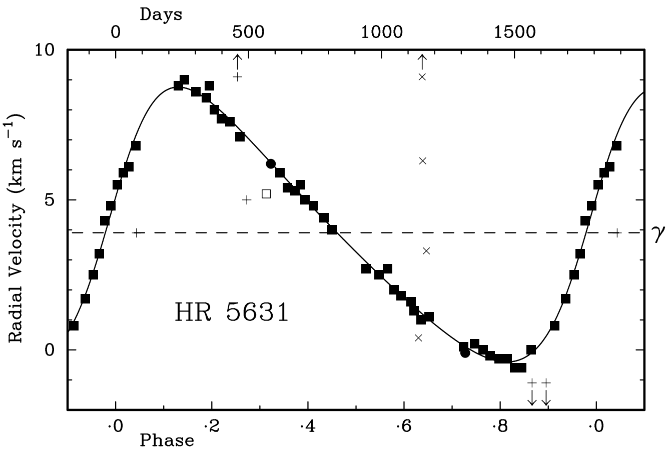

FIG. 3

As Fig. 2, but for HR 5631. Here there are two additional data sources, both of which, however, are zero-weighted, so the solution still depends mainly on Cambridge data with slight assistance from just two OHP observations[1]. One Cambridge observation, identified by the open square, is rejected. Five DAO observations by Harper[32] (three of which are beyond the limits of the diagram, as indicated) are represented by plusses, while four measures by Albitzky & Shane[31], all made within an interval of a month, are shown as crosses.

TABLE IV

Radial-velocity observations of HR 5631

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

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
1923 June 29·24*	23599·24	+11·8	$\overline{16}$·253	+4·4
1930 Apr. 21·98†	26087·98	+0·4	$\overline{15}$·630	–0·9
May 5·96†	101·96	+11·2	·638	+10·0
7·93†	103·93	+6·3	·639	+5·1
21·89†	117·89	+3·3	·646	+2·2
1931 June 23·28*	26515·28	–4·1	$\overline{15}$·866	–4·0
Aug. 15·19*	568·19	–14·7	·896	–15·2
1932 May 8·41*	26835·41	+3·9	$\overline{14}$·043	–3·3
1933 June 27·22*	27250·22	+5·0	$\overline{14}$·273	–2·1
1988 Mar. 10·05‡	47230·05	+6·2	$\overline{3}$·323	0·0
1990 Mar. 11·14‡	47961·14	–0·1	$\overline{3}$·727	–0·2
2002 May 29·94	52423·94	+8·8	0·195	+0·5
July 13·94	468·94	+7·7	·220	–0·2
Aug. 14·86	500·86	+7·6	·238	–0·1
2003 Feb. 18·19	52688·19	+5·9	0·342	0·0
Mar. 19·08	717·08	+5·4	·358	–0·2
Apr. 16·08	745·08	+5·3	·373	–0·1
May 6·03	765·03	+5·5	·384	+0·3
24·06	783·06	+5·0	·394	0·0
June 24·96	814·96	+4·8	·412	+0·1
Aug. 3·88	854·88	+4·4	·434	+0·1
2004 Jan. 9·29	53013·29	+2·7	0·521	–0·2
Mar. 30·15	094·15	+2·7	·566	+0·5
Apr. 22·13	117·13	+2·0	·579	0·0
May 19·03	144·03	+1·8	·594	0·0
June 25·92	181·92	+1·6	·615	+0·1
Aug. 1·88	218·88	+1·0	·635	–0·2
Sept. 1·81	249·81	+1·1	·652	+0·1
2005 Jan. 9·27	53379·27	+0·1	0·724	0·0
Mar. 23·18	452·18	0·0	·764	+0·2
Apr. 19·09	479·09	–0·2	·779	+0·1
May 23·05	513·05	–0·3	·798	+0·1
June 22·98	543·98	–0·3	·815	+0·1
July 20·92	571·92	–0·6	·830	–0·2
Aug. 15·86	597·86	–0·6	·845	–0·3
Dec. 17·28	721·28	+0·8	·913	–0·1
2006 Jan. 29·27	53764·27	+1·7	0·937	–0·1
Mar. 1·18	795·18	+2·5	·954	–0·1
23·15	817·15	+3·2	·966	0·0
Apr. 12·12	837·12	+4·3	·977	+0·5
May 6·09	861·09	+4·8	·990	+0·2
30·01	885·01	+5·5	1·003	+0·2
June 21·95	907·95	+5·9	·016	–0·1
July 11·95	927·95	+6·1	·027	–0·4
Aug. 7·88	954·88	+6·8	·042	–0·3

TABLE IV (*concluded*)

Date (UT)		MJD	Velocity km s^{-1}	Phase	(O–C) km s^{-1}
2007	Jan. 14·29	54114·29	+8·8	1·130	0·0
	Feb. 6·23	137·23	+9·0	·143	+0·3
	Mar. 22·16	181·16	+8·6	·167	0·0
	Apr. 30·05	220·05	+8·4	·189	0·0
	May 30·03	250·03	+8·0	·205	−0·1
	Dec. 11·28§	445·28	+5·2	·313	−1·2
2008	Aug. 14·85	54692·85	+4·0	1·450	−0·1
2009	Feb. 7·25	54869·25	+2·5	1·548	0·0
	June 20·02	55002·02	+1·3	·621	−0·1
2010	Feb. 1·28	55228·28	+0·2	1·746	+0·3
	Sept. 1·82	440·82	0·0	·864	+0·1
2012	Aug. 15·85	56154·85	+7·1	2·259	−0·2

*Simeis observation[30,31]; weight 0.
† DAO observation[32]; weight 0.
‡ OHP *Coravel* observation[1]; wt 1.
§ Rejected

De Medeiros & Mayor[1] asserted that HR 5631 is a binary on the strength of just two radial velocities made two years apart and listed as having a mean of +1·91 ± 3·15 km s^{-1}, from which we could deduce that the actual velocities observed were 1·91 ± 3·15, *viz.*, −1·24 and +5·06 km s^{-1}. When those authors deposited the listing of the individual velocities, with dates, with the CDS, the values differed appreciably from that expectation, being −0·89 and +5·39 km s^{-1}; here we adopt those latter ones as superseding those implied by the actual paper[1]. They are listed near the head of Table IV, after the Simeis and DAO velocities. All the published velocities have been increased by 0·8 km s^{-1} before entry into Table IV, in an effort to align them more closely with the zero-point[33] normally adopted in this series of papers. The rest of the table consists of the writer's 46 measurements, all made with the Cambridge *Coravel*. By themselves, those measurements* yield an orbit with a period of 1799 ± 9 days; inclusion of the two OHP[1] measures with equal weighting refines it to 1808 ± 5 days. The two early sets of velocities[31,32] are too ragged to help with the orbit at all: they both exhibit variances of the order of a thousand times those of the photoelectric velocities. The elements of the final orbit are listed in Table VI below, and a plot is shown in Fig. 3.

The mass function is small, practically the same as the one found above for HD 26081, and requires the secondary to have a mass only of 0·45 $M_\odot$ — about that of an M0 V star, which would be nine magnitudes fainter than the primary — if the latter were supposed to have a 2-$M_\odot$ mass. Even if the secondary were near the minimum mass, the separation of the components could be only about 4 AU, subtending at most about 0″·025 at the 160-pc distance of the system; if it were more massive it would be closer still. The lines in the spectrum of HR 5631 exhibit slight broadening, equivalent to a projected rotational velocity of 3·6 km s^{-1}; the value repeats very well from one observation to another, and the mean has a formal standard deviation of only 0·16 km s^{-1}, although that should not be accepted as the real uncertainty in the rotational rate.

*One has been rejected — it gives a residual more than twice as great as any other and nearly six times the r.m.s. value of the remaining 45.

HDE 228188

This 8½^{m} star was unlucky not to feature in the original *Henry Draper Catalogue*; that may have happened because it is in a crowded region of the sky at a Galactic latitude less than +2°, close to (but outside) the preceding margin of the Cygnus Rift in the Milky Way. It is nearly halfway from 28 to 29 Cyg, two 5^{m} stars a little over one degree apart, that are themselves about 4° south-following γ Cyg. It was catalogued in the first *tranche* of the *Henry Draper Extension*[34], in which it appears as no. 228188*. The star is listed in the *HDE* as having photographic magnitude 9·8 and spectral type K0. It next features in the Warner & Swasey Observatory survey of the northern Milky Way[36], in a field designated LF 3a, the LF standing for 'Luminosity Function', whose assessment was the nominal purpose of the investigation. Different fields were discussed by different authors, in the relevant instance by Annear[37] (whose discussion of the results occupies but four lines and makes it clear that he did not consider them to merit more!). HDE 228188 is listed as LF 3a +36 52, the designation being by declination and a running number, by analogy with the *BD*[38]. The (photographic) magnitude and type are given as 9^{m}·78 and G8 III.

Madame Barbier, in a paper[39] on the 'Structure de la Galaxie dans le region de P Cyg', based (like the *HDE* and the LF investigation) on objective-prism spectra, found the spectral type of HDE 228188 to be G2:II:, and it was owing to that rather doubtful assignment of high luminosity that the star found its way into the de Medeiros & Mayor paper[1] in which its spectroscopic-binary nature was recognized.

In those authors' published paper they reported the existence of four radial velocities which had a mean of −4·17 and an r.m.s. spread of 1·39 km s^{-1}. Later, when they deposited the listing of the individual data with the CDS, there were actually nine velocities: the original four had been obtained in 1986/7, but then the star had evidently been restored temporarily to their observing programme and five more had been obtained in 1997/8 — still before their paper had been submitted, though not reported in it. The second lot of velocities increased the overall spread somewhat, as can be seen from Table V here, where the nine OHP observations are listed at the head.

The remaining 43 entries in Table V represent the writer's observations made with the Cambridge *Coravel*. The *ensemble*, with the OHP data half-weighted, yields the orbit that is plotted in Fig. 4; its elements appear in the last column of Table VI. It is immediately apparent from Fig. 4 that the phase distribution of the data leaves a lot to be desired, owing to the complete absence of points on most of the descending 'branch' of the velocity curve. Normally the writer would not countenance the publication of an orbit exhibiting such a fault, but in this case he has little option. The published observations, and his own in the first year, showed only small and slow variations in velocity, seemingly warranting observations only at intervals of a month or two, so he was taken aback to discover that an enormous change took place in the second season (2003), just between late May and mid-July. It transpired that almost three-quarters of the whole velocity range had been traversed in that interval, which represents less than two per cent of the orbital period, and the node had been reached in an orbit with the very high eccentricity of 0·86. It became apparent

*The HDE numbers follow straight on from those of the *HD*[35] itself, which finishes at no. 225300: there are not 228000-odd stars in the *Extension*!

TABLE V

Radial-velocity observations of HDE 228188

The sources of the observations are as follows:
1986–1998 — OHP Coravel (weight ½); 2002–2012 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
1986 June 1·08	46582·08	−0·6	0·818	+0·8
1987 Aug. 14·95	47021·95	−3·3	0·972	+0·3
17·00	024·00	−4·0	·973	−0·3
17·88	024·88	−3·5	·973	+0·3
1997 Aug. 29·98	50689·98	−6·2	2·255	−0·2
Sept. 3·94	694·94	−6·6	·256	−0·6
18·86	709·86	−7·5	·262	−1·6
Nov. 14·75	766·75	−6·2	·282	−0·6
1998 Aug. 15·95	51040·95	−4·6	2·377	0·0
2002 July 15·05	52470·05	−0·8	2·877	+0·3
Sept. 1·97	518·97	−0·3	·894	+0·7
Oct. 4·90	551·90	−1·0	·906	0·0
2003 May 24·10	52783·10	−9·2	2·987	−0·1
July 14·04	834·04	−30·7	3·004	+0·4
20·97	840·97	−30·6	·007	−0·6
Aug. 3·07	854·07	−27·0	·011	−0·1
14·99	865·99	−23·7	·016	+0·4
24·89	875·89	−22·3	·019	0·0
Sept. 10·94	892·94	−19·9	·025	−0·1
23·90	905·90	−17·9	·030	+0·4
Oct. 17·90	929·90	−15·9	·038	+0·4
Nov. 26·86	969·86	−14·2	·052	−0·2
Dec. 28·79	53001·79	−12·6	·063	+0·1
2004 June 22·06	53178·06	−9·3	3·125	−0·3
Aug. 13·02	230·02	−7·9	·143	+0·5
Sept. 5·99	253·99	−8·4	·151	−0·3
Nov. 13·84	322·84	−7·4	·175	+0·1
2005 Jan. 8·74	53378·74	−7·9	3·195	−0·8
May 8·12	498·12	−7·7	·237	−1·4
Dec. 8·75	712·75	−4·9	·312	+0·4
2006 Aug. 29·96	53976·96	−4·0	3·404	+0·3
Oct. 26·88	54034·88	−3·4	·424	+0·7
2007 May 31·08	54251·08	−3·6	3·500	−0·1
July 30·04	311·04	−3·1	·521	+0·3
Oct. 23·84	396·84	−2·8	·551	+0·3
2008 July 4·10	54651·10	−2·9	3·640	−0·4
Sept. 18·93	727·93	−2·1	·667	+0·2
Nov. 22·79	792·79	−2·8	·689	−0·6
2009 July 2·09	55014·09	−1·5	3·767	+0·2
Sept. 3·97	077·97	−1·6	·789	−0·1
Dec. 17·76	182·76	−1·3	·826	0·0
2010 June 5·08	55352·08	−1·1	3·885	0·0
Sept. 1·00	440·00	−0·5	·916	+0·6

TABLE V (*concluded*)

Date (UT)			*MJD*	*Velocity* km s⁻¹	*Phase*	*(O – C)* km s⁻¹
2011	Jan.	18·73	55579·73	−3·5	3·965	−0·9
	May	11·10	692·10	−30·9	4·004	+0·2
		19·11	700·11	−30·4	·007	−0·2
	June	4·10	716·10	−27·1	·012	−0·8
		17·09	729·09	−23·3	·017	+0·2
		27·07	739·07	−20·8	·020	+0·9
	Dec.	9·77	904·77	−11·0	·078	+0·4
2012	Jan.	2·72	55928·72	−11·3	4·087	−0·5
	July	25·04	56133·04	−7·3	·158	+0·6

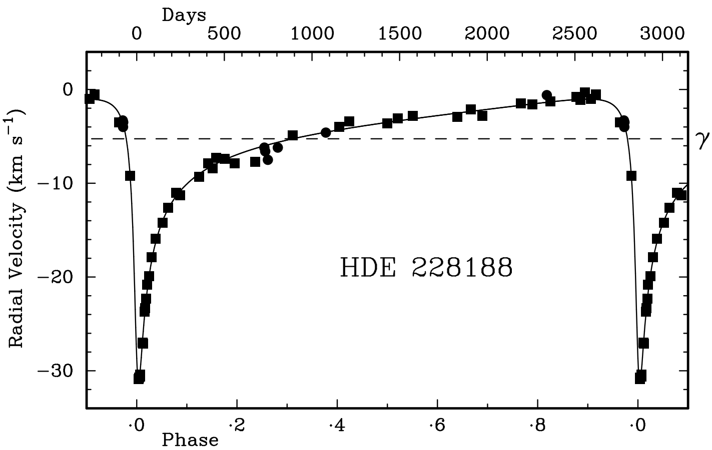

FIG. 4

As Fig. 2, but for HDE 228188. The lack of observations during the steep decline in velocity is regretted, but could not be helped because the star was inaccessible to observation at that phase when it occurred in 2011, and cannot be rectified until 2026/7.

that the missed phases would recur in early 2011, but despite efforts to reduce the seasonal gap to a minimum it was impossible to observe them. Now, with the period known almost to a day, it is clear that the same mischance will apply at the next periastron passage, in 2019, and it will not be until the following one (2026/7), when the writer, if spared so long, will be in his nineties, that the relevant phases would be observable. As a matter of practical politics, it therefore seems sensible to present the orbit, which in fact is already quite accurately constrained, *now*. Its elements are given in the final column of Table VI, and it is portrayed in Fig. 4.

Other properties of HDE 228188 are actually much more uncertain than the orbit. The V magnitude and $(B - V)$ colour index do not appear to have been measured photoelectrically from the ground, but have been inferred from *Tycho 2*[40] and recorded with the *Simbad* bibliography of the star as $8^{m}{\cdot}41$ and $1^{m}{\cdot}38$, respectively. By comparison with the tabular[15] value of the colour index for the type G2 II (the most recent classification[39], though noted with colons as

TABLE VI

Orbital elements for the four stars

Element	*HD 26081*	*HD 125728*	*HR 5631*	*HDE 228188*
P (days)	2224·4 ± 2·3	904·8 ± 0·5	1808 ± 5	2859·8 ± 1·5
T (MJD)	53795 ± 6	53500·8 ± 2·5	53879 ± 8	52821·3 ± 1·5
γ (km s^{-1})	−6·33 ± 0·04	+26·13 ± 0·03	+3·90 ± 0·04	−5·26 ± 0·09
K_1 (km s^{-1})	4·69 ± 0·06	7·55 ± 0·04	4·58 ± 0·05	15·06 ± 0·20
e	0·477 ± 0·009	0·287 ± 0·005	0·299 ± 0·011	0·8609 ± 0·0028
ω (degrees)	0·2 ± 1·5	116·3 ± 1·2	281·5 ± 2·1	146·7 ± 0·8
$a_1 \sin i$ (Gm)	126·0 ± 1·8	90·0 ± 0·5	108·6 ± 1·4	301 ± 5
$f(m)$ ($M_\odot$)	0·0161 ± 0·0007	0·0356 ± 0·0006	0·0157 ± 0·0006	0·134 ± 0·007
R.m.s. residual (wt. 1) (km s^{-1})	0·24	0·19	0·21	0·48

uncertain), it has a colour excess of more than half a magnitude; if the earlier proposal[37] of G8 III were correct, the excess would still be nearly as great. The form of the radial-velocity traces, however, makes for difficulty in accepting either of those types. The dips in the traces are extraordinarily wide, and correspond to a projected rotational velocity close to 21 km s^{-1}, as was already listed by de Medeiros & Mayor[1]; the mean and formal standard deviation of the Cambridge values are 21·27 and 0·14 km s^{-1}, respectively. Moreover, their area is much too large for any ordinary G star and is such as would characterize a mid-K giant or perhaps a G8/K0 supergiant. Since HDE 228188 was not measured by *Hipparcos*, its distance is uncertain, but its seemingly excessive redness cannot be put down merely to reddening arising in a long light path at low Galactic latitude, because that would not add strength to the radial-velocity 'dips' and cause them to mimic those of stars that are intrinsically much redder and/or more luminous.

The mass function is considerable, and would set a minimum mass of about 1·1 $M_\odot$ for the companion star if the primary has a mass of 2 $M_\odot$ such as might be typical of a normal giant; if the primary is really of higher luminosity and has a mass, say, of 4 $M_\odot$, the corresponding minimum for the secondary would be 1·6 $M_\odot$. The types of main-sequence stars with the masses just mentioned would be about G0 and F0; such companions would be much fainter than the respective primaries, so it is not surprising that the radial-velocity traces have shown no sign of them.

The extreme eccentricity of the HDE 228188 orbit makes it worthwhile to consider the possibility that the substantial rotational velocity of the primary simply represents a rotation pseudo-synchronized to the orbital revolution. There is, perhaps, a question as to whether the secondary star could be close enough and massive enough to spin up the primary to the observed $v \sin i$ without itself being massive enough to be detectable. The most promising circumstance for that to be the case would be if the orbital inclination is high: if it is not, the $\sin i$ factors in the size of the orbit (the $a_1 \sin i$ in the set of orbital elements) and in the projected rotational velocity operate against that interest, by increasing the separation of the stars and thereby reducing tidal effects while requiring further-increased rotational velocity. At the observed eccentricity of the orbit, the angular velocity for pseudo-synchronism is[41] about 22 times the mean angular velocity in the orbit, so it would imply a period of axial rotation shorter by that factor than the orbital period, *viz.*, about 130 days. Rotation in that period at an equatorial speed of 21 km s^{-1} would require the stellar radius to be about 54 $R_\odot$. That is quite an acceptable radius for a late-type bright-giant of luminosity class II; one could point to the reasonably well determined radii of the primary stars in certain composite-spectrum systems such as 22 Vul[42] (G5 II, 77 $R_\odot$) and HR 2030[43] (K0 IIb, 41 $R_\odot$). The absolute magnitude would be near –3, the apparent distance modulus about eleven magnitudes.

There are several additional sources of considerable uncertainty in estimating the probable angular separation, but if we suppose that the orbital inclination is high, and the secondary star is hardly half the mass of the primary (so the major axis of the relative orbit is something like three times the value of $a_1 \sin i$ deduced from the orbit, *i.e.*, three times 2 AU), then that major axis would subtend an angle of about four arc-milliseconds at the suggested distance. Owing to the extreme eccentricity of the orbit, the actual separation of the components would be approaching double the length of the major axis for much of the apastron side of the orbit, in which the system is found most of the time. Even so, with the large Δm that is expected, it does not appear to be an encouraging object for direct resolution.

References

(1) [Announced by] J. R. de Medeiros & M. Mayor, *A&AS*, **139**, 433, 1999.
(2) J.-L. Prieur, J.-M. Carquillat & R. F. Griffin, *AN*, **327**, 686, 2006.
(3) R. F. Griffin, *The Observatory*, **128**, 407, 2008.
(4) R. F. Griffin, *The Observatory*, **132**, 234, 2012 (Paper 225).
(5) R. F. Griffin, *The Observatory*, **126**, 1, 2006 (Paper 186).
(6) W. W. Campbell & J. H. Moore, *Publ. Lick Obs.*, **16**, 336, 1928.
(7) Ref. 5, pp. 12, 13.
(8) R. E. Stencel, J. E. Neff & R. D. McClure, in R. D. Chapman & Y. Kondo (eds.), *Future of Ultraviolet Astronomy Based on Six Years of IUE Research* (NASA CP–2349) (Goddard Space Flight Center, Greenbelt), 1984, p. 400.
(9) [Announced by] J. R. de Medeiros & M. Mayor, *A&A*, **395**, 97, 2002.
(10) F. van Leeuwen, *Hipparcos, the new reduction of the raw data* (Springer, Dordrecht), 2007.
(11) P. C. Keenan & C. Barnbaum, *ApJ*, **518**, 859, 1999 (see Fig. 1).
(12) R. F. Griffin, *The Observatory*, **131**, 225, 2011 (Paper 219).
(13) H. H. Guetter, *PASP*, **92**, 215, 1980.
(14) J. F. Heard, *PDDO*, **1**, 105, 1956.
(15) T. Schmidt-Kaler, in K. Schaifers & H.H. Voigt (eds.), *Landolt-Börnstein* (Springer-Verlag, Berlin), **2b**, 15, 1982.
(16) M. D. Metreveli, *Abastumani Astr. Obs. Bull.*, **38**, 93, 1968.
(17) D. Hoffleit, M. Saladyga & P. Wlasuk, *A Supplement to the Bright Star Catalogue* (Yale Univ. Obs., New Haven), 1983, p. 66.
(18) G. A. Bakos, *AJ*, **73**, 187, 1968.
(19) J. D. Fernie, *ApJS*, **52**, 7, 1983.
(20) V. Andruk *et al.*, *AN*, **316**, 225, 1995.
(21) A. A. Andriesky, *Izv. Crimea Astrophys. Obs.*, **3**, 31, 1948.
(22) K. M. Yoss *et al.*, *PASP*, **88**, 949, 1976.
(23) M. Duflot *et al.*, *A&AS*, **94**, 479, 1992.
(24) A. W. J. Cousins, *MNASSA*, **22**, 12, 1963.
(25) H. L. Johnson *et al.*, *Commun. Lunar & Planet. Lab.*, **4**, 99, 1966.
(26) J. D. Fernie, *ApJS*, **52**, 7, 1983.
(27) A. W. J. Cousins, *SAAO Circ.*, **8**, 59, 1984.
(28) E. A. Harlan, *AJ*, **74**, 916, 1969; **79**, 682, 1974.
(29) P. C. Keenan & R. C. McNeil, *ApJS*, **71**, 245, 1989.
(30) G. Shajn & V. Albitzky, *MNRAS*, **92**, 771, 1932.
(31) V. A. Albitzky & G. J. Shajn, *Poulkovo Publ.*, Ser. 2, **43**, 43, 1933.
(32) W. E. Harper, *PDDO*, **6**, 149, 1934.
(33) R. F. Griffin, *MNRAS*, **145**, 163, 1969.
(34) A. J. Cannon, *HA*, **100**, 1, 1925.*
(35) A. J. Cannon & E. C. Pickering, *HA*, **91–99**, 1918–25.

*The reference in the *Simbad* bibliography is wrong — it is the one to the second *Extension*.

(36) S. W. McCuskey & C. K. Seyfert, *ApJ*, **106**, 1, 1947.
(37) P. R. Annear, *ApJ*, **118**, 77, 1953.
(38) F. W. A. Argelander, *Astronomische Beobachtungen auf der Sternwarte zu Bonn* (Adolph Marcus, Bonn), **3**, 1859–62.
(39) M. Barbier, *J. des Obs.*, **45**, 57, 1962.
(40) [Announced by] E. Høg *et al.*, *A&A*, **355**, L27, 2000.
(41) P. Hut, *A&A*, **99**, 126, 1981.
(42) R. E. M. Griffin *et al.*, *A&A*, **274**, 225, 1993.
(43) R. & R. Griffin, *MNRAS*, **319**, 1094, 2000.

THE RECURRENT NOVA T CrB DID *NOT* ERUPT IN THE YEAR 1842

By Bradley E. Schaefer
Department of Physics and Astronomy, Louisiana State University

The recurrent nova T CrB was one of the first well-observed nova eruptions, in 1866, and 80 years later it erupted again, in 1946. Just after the 1866 eruption, Sir John Herschel reported to the *Monthly Notices* that he had seen the same star in his naked-eye charting of the sky on 1842 June 9, implying that there was a prior eruption 24 years earlier. Unfortunately, the chart in the *Monthly Notices* was ambiguous and misleading, so it has long been unclear whether T CrB did indeed have an eruption in 1842. To resolve this, I have searched the various archives containing Herschel material, and have found his original correspondence. In one letter from 1866 to William Huggins, Herschel enclosed his own copy of his original observations, and with this all the ambiguities are resolved. It turns out that Herschel's indicated star was at the same position as a steady background star (BD +25° 3020, $V = 7^{m}\cdot06$, G8 V) and not that of T CrB, and Herschel regularly was seeing stars as faint as $V = 7^{m}\cdot5$ because he was using an opera glass. With this, there is no evidence for a T CrB eruption in 1842.

Introduction

A recurrent nova (RN) is a close binary star where one star spills matter, through its Roche lobe, onto a white dwarf, where the material accumulates until a runaway thermonuclear explosion is triggered. RNe are distinct from ordinary novae primarily owing to their recurrence time-scale being less than a century or so[1]. To achieve this fast recurrence, the white dwarf must be near the Chandrasekhar mass and the accretion rate must be relatively high. These conditions are exactly as expected to lead to the white dwarf gaining mass until it would explode as a Type Ia supernova. As such, RNe are among the best candidates for being supernova progenitors. The identity of the progenitors has been one of the keystone problems in stellar evolution for over three decades, and since the late 1990s has become of even higher importance because the progenitor must be known so as to calculate the evolution of Type Ia supernovae to high redshift, with this now being the dominant uncertainty in the several very-large-scale programmes of high-precision cosmology.

One of the primary uncertainties as to whether RNe are progenitors is their recurrence time-scales, as this determines whether their white dwarfs are gaining or losing mass over each eruption cycle; another is the number of RNe in our Milky Way and hence whether the RNe death rate matches the Type Ia supernova rate[2,3]. For this reason, I have spent roughly a year examining plate archives for prior eruptions of known RNe and looking for second eruptions on candidate RNe, with the result of discovering one new RN, six RN eruptions, and predicted/confirmed one more[1,4]. A conclusion from this work is that the average recurrence time scale has been shortened by roughly a factor of three.

T Coronae Borealis (T CrB) is one of the ten known RNe in our own Galaxy, with well-recorded eruptions in 1866 and 1946. T CrB is normally in quiescence at $V = 9^{m}\cdot 8$, while it peaked during its eruptions at $V = 2^{m}\cdot 5$, making it one of the brightest novae in the last two centuries. Like roughly half the RNe, the companion star is a red giant, with an orbital period of 228 days. T CrB has been monitored frequently enough from 1866 to 2012 (including roughly hourly to weekly from 1890 to 2012) that we know that an eruption cannot have been missed, because even an eruption around the time of solar conjunction would have been spotted after it comes out in the morning sky[1]. With this, the recurrence time-scale is apparently 80 years, with the next eruption expected around the year 2026.

Herschel's Monthly Notices article in 1866

Soon after the 1866 eruption of T CrB, Sir John F. W. Herschel published a short article in the *Monthly Notices*[5] pointing out that he had seen the same star on 1842 June 9. Back at the time, the recognition of novae as a class was unknown (indeed, T CrB was only the third nova seen in the previous 80 years), so the implications of his observation were not known. With the modern understanding of RNe, we see this record as possibly being of a prior nova event. Suddenly, the average recurrence time-scale for T CrB would change from 80 years to 52 years, (1946–1842)/2, with the implication that T CrB could go off anytime soon. Further, the inter-eruption interval would vary by at least a factor of 3·3 (from 24 years to 80 years), with such a variation being inexplicable. This would be substantially different from the other RNe, where the recurrence time-scales change by 20% for U Sco and 42% for RS Oph[1]. (The case of T Pyx is unique and represents a greatly different case[6].) So there is good modern astrophysics utility in knowing whether T CrB erupted in 1842.

In 1939, Dean McLaughlin examined the evidence for the 1842 eruption[7]. He had access only to the *Monthly Notices* report. McLaughlin concluded that Herschel had not actually seen T CrB in 1842, but had rather merely recorded the nearby star BD +25° 3020 (HD 144287). The sole basis for this conclusion was that the position of one of the points in the *Monthly Notices* chart is roughly one degree from the position of T CrB and is apparently coincident with the background star. One degree (*i.e.*, two full-moon diameters) is a substantial distance on the sky, so he suggested that this meant that the 1842 star recorded could not be T CrB.

This conclusion has three severe problems. First, it is unclear which of two symbols on the *Monthly Notices* chart refers to the star observed by Herschel in 1842. The star labelled as 6′ is near the *BD* star, while the asterisk is near the position of T CrB, with it being unclear what, if anything, was added by the editor. Second, the *Monthly Notices* chart has the faintest recorded star with $V = 5^{m}\cdot82$, so it seems that Herschel could not have seen BD +25° 3020 at $V = 7^{m}\cdot06$. This star is of spectral type G8 V and has never been seen to vary in brightness. Third, not only did Herschel apparently not see below sixth magnitude, but it is very unlikely for anyone to see to $V = 7^{m}\cdot06$ under any conditions. All pre-telescopic star catalogues have the 50% limiting magnitude of near fifth magnitude, and I have extensively tested large numbers of people under dark skies with the same result. (Star detection near the limit is a probabilistic task, where the detection probability falls off from near unity to near zero typically over a range of one magnitude, with the probability being 50% in the middle of this range.) This is not to say that it is impossible to see to $V = 7^{m}\cdot06$ under optimal conditions, as, for example, I have recorded Stephen O'Meara (one of the premier visual observers of the last century) as seeing stars as faint as $V = 8^{m}\cdot2$ from the top of Mauna Kea[8]. While few humans can see so faint, it is very unlikely that Herschel would have recorded the *BD* star without telescopic aid even on a clear moonless night from a near-sea-level site in humid England.

So the real status of the 1842 eruption is unknown owing to the ambiguities in the published chart. The only way to resolve this is to find the original records from 1866 or 1842.

Herschel's correspondence and diary

Sir John Herschel was amongst the greatest visual observers of his century. In 1838, he arrived back from four years in South Africa mapping out the southern skies, completing the task started by his father of cataloguing the nebulae and double stars over the whole sky. In April of 1840, he moved to Kent, to a house called Collingwood, where he continued to make a few observations with small telescopes, and to analyze and publish his South African observations[9].

At least from 1841 January to 1842 June, Herschel made naked-eye charts of the entire northern skies showing all visible stars[10–12]. This was an extension of a programme he began in South Africa to map the skies and assign magnitudes to all stars. He had divided up the sky into 738 (mostly) triangles[12], with T CrB being inside the triangle formed by α CrB, β Her, and ζ Her[11]. I have not found anywhere where those data were published, but Herschel certainly kept his charts at least until 1866. In a letter to the Reverend C. Pritchard dated 1867 April 10, Herschel says "Thanks for the care of binding up my Star allineations."[13], so apparently the star charts became bound around 1867. Herschel tells how his star charts were donated to the Royal Astronomical Society (RAS), and he provides some details on their construction[14].

In a letter to Francis Baily dated 1841 January 26, Herschel states "You will receive by Wednesday's Coach a roll containing a circumpolar projection of the Southern Stars as far as 70° SPQ [south polar distance] in which *all* the stars of Magnitudes 1.2.3.4.5 are laid down as they really appear to the naked eye and many of the magnitudes (5.6-) [*i.e.*, stars of fifth magnitude, sixth magnitude, and fainter]. When I say all I mean that I have examined seriatim every triangle of stars forming a network over the whole — about 360 triangles — carefully with naked [eye] occasionally (and usually at last) aided by an opera glass laying down in each, on great charts pricked off from Bode's maps, all the discernable stars down to 7m[ag]"[10]. What this means is that Herschel was only picking out the brighter stars (as faint as magnitude 5) with the unaided eye, but that the fainter stars were observed with a small telescope (an opera glass). This is confirmed by page headers from 1841 in Herschel's notebooks[15] summarizing magnitudes from prior star triangles, which state "Magnitudes for Naked Eye and Opera Glass as read off on the Working Charts". Unfortunately, I can find no specific information on the properties of the opera glass, but historical examples[16] suggest that it was two classical Galilean telescopes with perhaps 2-centimetre aperture mounted for binocular vision and having a fairly small (perhaps 3°) field of view. Now we have an explanation for why Herschel was able to report stars much fainter than almost all other humans, and it was simply because he was using an opera glass.

In 1866, Herschel was one of the pre-eminent scientists in the world, having made major advances in astronomy, physics, botany, chemistry, and photography. He was frequently in consultation and communication with astronomers around the world. On 1866 May 14, the eruption of T CrB was discovered by John Birmingham in Ireland, and Herschel was quickly notified by William Huggins. Herschel then looked at his 1842 chart and found a star at nearly the right position. In a letter dated 1866 May 19, Herschel tells Huggins about his old "Star-triangles" and the star at the position of the nova (labelled 6′) as observed on 1842 June 9[17]. Critically, this letter had attached a copy that Herschel made of his original 1842 chart, with this having been made by pricking the stars from the overlain original (see Fig. 1). In a letter to the Astronomer Royal George B. Airy dated May 25, he writes about his star (which he says has magnitude 6⅓) and explicitly that its position is within the "limits of error" of T CrB. Airy replied on May 26 that Herschel should place a letter into the *Monthly Notices*[18]. On May 29, Herschel complies, with a letter for publication, that must have contained a chart[5], but I have found no evidence of this letter or chart having survived. On May 29, Edward James Stone (then Chief Assistant at the Royal Greenwich Observatory and later President of the RAS) acknowledges receipt of Herschel's contribution, including the chart for publication and provides some short discussion of spectral lines visually seen by himself in the previous night[19]. Stone enclosed his version of Herschel's chart, very similar to that which appeared in the *Monthly Notices*, except that Herschel's 1842 star is explicitly identified as being the one labelled 6′ that is at the position of BD +25° 3020 (see Fig. 2), while this is distinctly separated from T CrB (labelled "variable"). Stone's copy shows that he did not reproduce most of the faint stars, hence making the impression that the limiting magnitude was not even as deep as 6. The same chart was then published in the *Monthly Notices*, except that the star labelled "Herschel" was called 6′ and the star at the position of T CrB was no longer labelled, hence leading to the ambiguity of the printed chart. Thus, Stone's simplifications of Herschel's chart created all the problems in knowing whether he had seen T CrB in 1842.

The only previously recorded magnitude for T CrB was 9·5 as given by Friedrich W. A. Argelander in the *BD* catalogue. On 1866 October 29, Argelander[20] wrote to Herschel asking whether his 1842 star could be the background star now called BD +25° 3020. On 1866 November 6, Herschel[21] replied "My star 6′ m[ag] was laid down without that particular precision as to allineations and which would of course have been given had I had any suspicion of its being a remarkable object and though its place does not agree very well

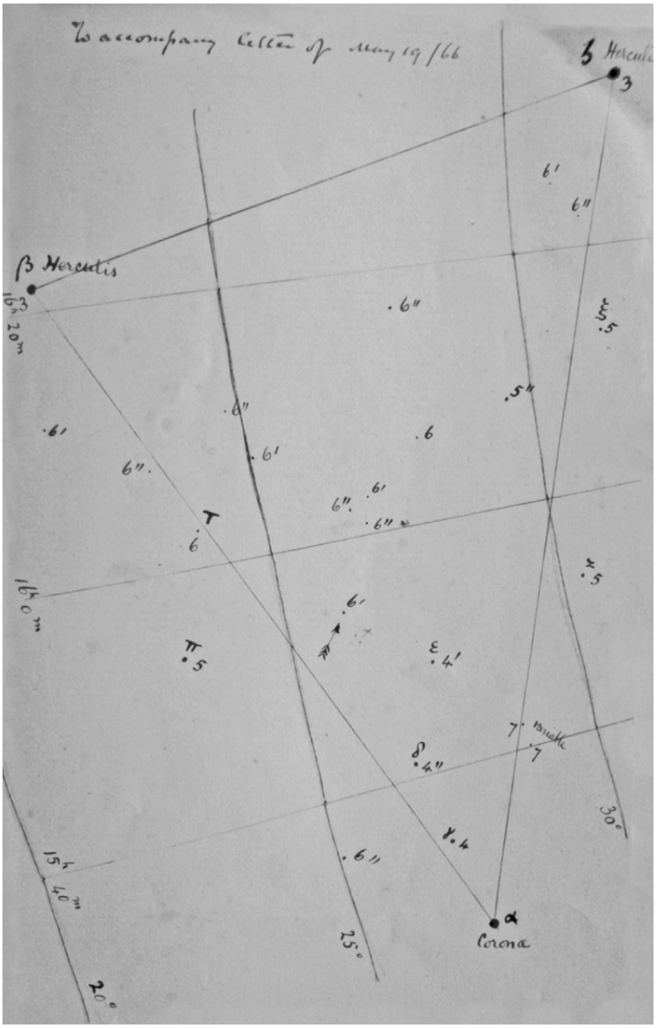

FIG. 1

This chart is from a letter sent by John Herschel[15] to William Huggins on 1866 May 19 (© Royal Astronomical Society). The basic triangle stretches from α CrB (near the bottom) to β Her (near the top left) to ζ Her (in the upper right corner). In addition to the lines giving the boundaries of the triangle, Herschel also places lines for a coordinate grid with right ascensions from $15^{h}\ 40^{m}$ to $16^{h}\ 20^{m}$ as well as declinations from +20° to +30° (for the equinox of 1860). The star that Herschel claimed was T CrB is near the centre and labelled with an arrow and the magnitude notation 6′. Importantly, this star is right at the position of BD +25° 3020 and about one degree away from the position of T CrB. The positional accuracy of this copy (relative to the 1842 chart) is ensured by Herschel having 'pricked' a needle through the original chart onto a lower sheet of paper. Just below the middle on the right are a pair of stars, R CrB (labelled "variable") and its nearby comparison star HD 141352 at $V = 7^{m}{\cdot}48$. So Herschel was certainly seeing faint enough to pick up BD +25° 3020. The brightest star that is certainly missing is $V = 7^{m}{\cdot}46$. Herschel's real limit in this chart is close to $7^{m}{\cdot}5$, with this being reasonable because we know from his correspondence and notebooks that he made his star chart with the help of an opera glass. So, Herschel could easily see BD +25° 3020, this star should appear on his chart, and the charted star is at the position of BD +25° 3020, so the evidence shows that this charted star is not T CrB in eruption in 1842.

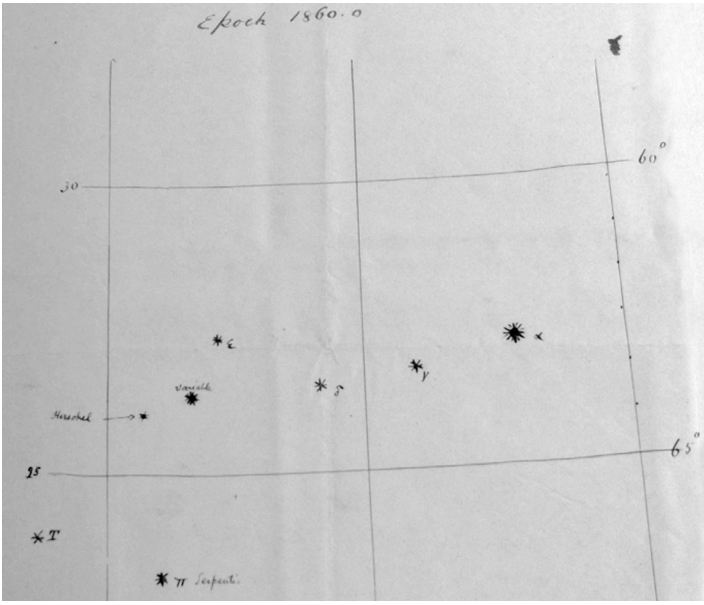

FIG. 2

This chart is from a letter sent by E. J. Stone[19] to John Herschel on 1866 May 29 (© Royal Society). Herschel had just submitted his short paper to the *Monthly Notices*, including the chart similar to that in Fig. 1, and Stone had replied back in his capacity as Chief Assistant to Airy while including this chart for Herschel's inspection. Critically, this chart clearly shows that the position of Herschel's 1842 star (labelled "Herschel") is substantially different from the position of T CrB (labelled "variable"). Also, Stone's simplification of Herschel's chart has deleted all the faint stars, thus giving evidence that the limiting magnitude of Herschel was around fifth magnitude, with the erroneous implication that Herschel could not possibly have seen BD +25° 3020 at $V = 7^{m}{\cdot}06$. Stone further compounded the confusion when the chart published in the *Monthly Notices* changed the labels, from "Herschel" to 6′ and from "variable" to blank, thus making it unclear as to the observed position of the star in 1842.

with the Variable, I do not think the difference more than <u>might</u> have occurred." The underlining is Herschel's. So the positional offset between Herschel's 1842 star and the position of T CrB (as noted by Argelander and McLaughlin) is within his normal uncertainty, although the words and the underlining suggest that the positional difference is substantially larger than is usual.

For the modern astrophysics question, the key item is Herschel's copy of his 1842 chart (see Fig. 1) that accompanied the May 19 letter to Huggins. This chart answers all the questions raised by the *Monthly Notices* chart. First, the 1842 star is clearly identified with a distinct arrow as being the one labelled 6′, and this is clearly at the position of BD +25° 3020 and roughly a degree from the position of T CrB. (In Fig. 1, the star is close to the centre and pointed at with an arrow.) Second, the chart shows many stars going very faint, including the memorable comparison star next to R CrB (HD 141352 at $V = 7^{m}{\cdot}48$), plus HD 139608 ($V = 6^{m}{\cdot}88$), HD 146604 ($V = 6^{m}{\cdot}55$), HD 145457 ($V = 6^{m}{\cdot}59$), and HD 145976 ($V = 6^{m}{\cdot}48$). The brightest star that is certainly missing from within the triangular chart area and within 5° of T CrB is HD 142053

($V = 7^{m}{\cdot}46$). So Herschel's real limiting magnitude is roughly $7^{m}{\cdot}5$. Third, this deep limit is possible simply because he was using an opera glass. With this, we see that Herschel could easily see BD +25° 3020. Indeed, given this real limiting magnitude, the *BD* star should appear on the 1842 chart, and if the arrowed star is not the *BD* star then we have the dilemma of asking why that one star was not recorded. With this, Herschel's 1842 chart makes sense only if the star recorded is BD +25° 3020, while T CrB was not visible. As such, all evidence for an 1842 eruption of T CrB vanishes.

Herschel's original 1842 chart

The 1866 copy made by Herschel by pricking through paper of his original 1842 chart has answered all the astrophysical questions. Nevertheless, there is an historical imperative to examine the original source if at all possible. To this end, I have sought long and hard for the original 1842 chart. I have flown to Austin Texas and examined all astronomy documents in the large collection of John Herschel's material at the Harry Ransom Center. The complete collection of all Herschel material now archived by the RAS has been digitally photographed and placed on 17 CDs, and I have gone through all the pages of John Herschel's material. All Herschel letters in archives worldwide have been exhaustively catalogued, with this available in book form[22] and at the Adler Planetarium web site[23]. The ~10 000 Herschel letters in the Royal Society archives have been copied and are all available on microfilm[24]. I have searched the archives at St. John's College, Cambridge[25], the Science Museum of London, and the Royal Greenwich Observatory, Cambridge. I have consulted with the current head of the Herschel family (Mr. John Herschel-Shorland), the leading Herschel historians (Drs. Michael Hoskin and Michael Crowe), and the leading astronomers who have worked on the historical T CrB (Drs. Ronald Webbink and Brian Warner). With Herschel telling us that his charts were donated to the RAS[14], the RAS archives are the most likely place to find the 1842 chart. But the entire collection has been catalogued[26] and photographed (with the CDs available for purchase from the RAS), with no chart from 1842. The late RAS librarian, Peter Hingley, authoritatively told me that there is certainly no Herschel manuscript or document that was not included in the CD version. The original 1842 June 9 chart of Herschel is not to be found.

I am convinced that the 1842 chart still exists, because the chart was saved from at least 1842 to 1866, because John Herschel showed strong interest in preserving papers from his father and himself, and because Herschel's children were actively involved in preserving his material. Apparently it was bound with other original charts and donated to the RAS and they would never get rid of such a document, but it is not now to be found in their complete collection as recorded on CDs.

Despite the 1842 chart not being found, we have a fair copy in Herschel's own hand from 1866, and this resolves the astrophysics question. In 1842, Herschel was recording stars regularly as faint as $V = 7^{m}{\cdot}5$ with the aid of his opera glass, and his 1842 chart simply showed the ordinary star BD +25° 3020. T CrB did not erupt in 1842.

Acknowledgments

I thank Brian Warner, Ronald Webbink, Michael Hoskin, Michael Crowe, Steve Ruskin, Marv Bolt, Stephen Case, Peter Hingley, and John Herschel-Shorland. I also thank the archives and staff at the Harry Ransom Center, the Royal Astronomical Society, the Royal Society, Adler Planetarium, and the Science Museum of London. This research is supported by the National Science Foundation, through grant AST-1109420.

References

(1) B. E. Schaefer, *ApJ*, **187**, 275, 2010.
(2) B. E. Schaefer, *ApJ*, **742**, 112, 2011.
(3) A. Pagnotta & B. E. Schaefer, *ApJ*, submitted.
(4) B. E. Schaefer *et al.*, *AJ*, **140**, 925, 2010.
(5) J. F. W. Herschel, *MNRAS*, **26**, 299, 1866.
(6) B. E. Schaefer, A. Pagnotta & M. M. Shara, *ApJ*, **708**, 381, 2010.
(7) D. B. McLaughlin, *Popular Astronomy*, **47**, 353, 1939.
(8) B. E. Schaefer, *Sky & Telescope*, **78**, 522, 1989.
(9) G. Buttmann, *The Shadow of the Telescope* (Scribner's, New York), 1970.
(10) J. F. W. Herschel, 1841 January 26 letter to Baily from Collingwood, original in the Royal Society Archives, catalogue HS 3.198, 1841.
(11) J. F. W. Herschel, chart in the Harry Ransom Center, Austin Texas, catalogue number osf 6, 1841.
(12) J. F. W. Herschel, yearly diary for 1842 in the Harry Ransom Center, Austin Texas, catalogue number 18.5, 1842.
(13) J. F. W. Herschel, 1867 April 10 letter to Rev. C. Pritchard, copy of a draft in the Royal Society Archives, catalogue number HS 25.15.24, 1867.
(14) J. F. W. Herschel, *MNRAS*, **27**, 213, 1867.
(15) J. F. W. Herschel, notebooks in the archives of the Royal Astronomical Society, 26–28 of folder 5/2.1, 1841.
(16) F. Watson, *Binoculars, Opera Glasses and Field Glasses* (Shire Publications, Risborough), 1995.
(17) J. F. W. Herschel, 1866 May 19 letter to Huggins from Collingwood, a fair copy in the Royal Society Archives, catalogue HS 24.156, 1866.
(18) G. B. Airy, 1866 May 26 letter to Herschel from Greenwich, original in the Royal Society Archives, catalogue HS 1.299, 1866.
(19) E. J. Stone, 1866 May 29 letter to Herschel from Greenwich, original in the Royal Society Archives, catalogue HS 17.240, 1866.
(20) F. W. A. Argelander, 1866 October 29 letter to Herschel from Bonn, original in the Royal Society Archives, catalogue HS 1.375, 1866.
(21) J. F. W. Herschel, 1866 November 6 letter to Argelander from Collingwood, copy in the Royal Society Archives, catalogue number HS 1.376, also HS 24.174, 1866.
(22) M. J. Crowe (editor), D. R. Dyck, & J. J. Kevin (associate editors), *Calendar of the Correspondence of Sir John Herschel* (Cambridge Univ. Press), 1998.
(23) http://historydb.adlerplanetarium.org/herschel/?p=intro
(24) P. Kesaris (editor), *Letters and Papers of Sir John Herschel*, microfilm (University Publications of America, Bethesda, Maryland), 1990.
(25) http://janus.lib.cam.ac.uk/db/node.xsp?id=EAD%2FGBR%2F0275%2FHerschel
(26) J. A. Bennett, *Mem. RAS*, **85**, 1, 1978.

$UBVR_cI_c$ PHOTOMETRIC OBSERVATIONS AND ANALYSIS OF THE EMISSION-LINE, SOLAR-TYPE BINARY GSC 2751–1007

By R. G. Samec, T. Shebs, A. Jaso, P. M. Smith, J. White
Bob Jones University,

D. R. Faulkner
U. South Carolina, Lancaster,

and W. Van Hamme
Florida International University

GSC 2751–1007 is a solar-type contact binary discovered by SAVS [α(2000) = $23^h\ 10^m\ 34^s{\cdot}231$, δ(2000) = +31° 42′ 53″·95]. $UBVR_cI_c$ light-curves are presented along with a period study, mass-ratio search, and a simultaneous $UBVR_cI_c$ light-curve solution. Our high-precision light-curves are of EW type, but show erratic jumps and drops in light level near the maxima and in the secondary minima. This effect is strongest in the *U* and *B* light-curves, indicating time-dependent emissions and absorptions at shorter wavelengths (3000–5400 Å) which straddle the Ca *H* & *K* lines. However, the light-curve amplitudes are nearly identical, about $0^m{\cdot}5$ at *V* in the primary and secondary eclipses, with the secondary eclipse being broader and flatter owing to a near-total eclipse. Modelled results include two hot-spot regions, found at longitude 254° on star 2 and at 310° on star 1, a 31% fill-out factor, and a somewhat extreme mass ratio of 0·27, accounting for the fairly shallow amplitudes. Indeed, a near-total eclipse was determined by the synthetic model in Minimum II. Thus GSC 2751–1007 is an active W-type (the less-massive star is on average slightly hotter) W UMa variable, a type whose spectrum shows many emission lines.

Introduction

Solar-type stars have emission lines in Ca *H* & *K* which fall at 3968·5 Å (*H*) and at 3933·7 Å (*K*). These emission lines may arise in chromospherically active solar-type stars[1]; for example, both components of the solar-age G-dwarf binary HD 191262 have Ca *H* & *K* emission lines. Hα and other Balmer lines also show up in emission in active stars[2]. Emission lines also arise in plage-like regions and hot-spot areas. UV Mg II emission in W UMa binaries has also been used to measure chromospheric activity[3]. Such binaries show photometric variability, especially in the maxima and secondary minima. This paper gives a broad-band $UBVR_cI_c$ analysis of a G-type eclipsing binary star with such a spectrum. It was observed as a part of our student/professional collaborative studies of interacting binaries from data taken in conjunction with the National Undergraduate Research Observatory (NURO) and the Southeastern Association for Research in Astronomy (SARA).

Observational history

GSC 2751–1007 (2MASS J23103423+3142539, SAVS J231034+314253, [GGM2006] 9014624) was discovered by SAVS (Semi-Automatic Variability Search) in 2004[4], which gave the ephemeris:

$$\text{HJD } T_{\min} \text{ I} = 2452885{\cdot}2469 + 0{\cdot}417461 \, E. \qquad (1)$$

They listed a *V* magnitude of $12^{m}{\cdot}34$ and an amplitude of $0^{m}{\cdot}51$. Gettel *et al.*[5], independently, give a maximum *V* of $12^{m}{\cdot}437$, an amplitude of $0^{m}{\cdot}530$, and a period of $0^{d}{\cdot}417456$. Times of minimum light are given by Paschke[6], and by Gurol *et al.*[7] and, in addition, we determined seven eclipse timings from SAVS data listed at the URL given later in this paper. The emission-line spectrum for the variable is given by Maciejewski *et al.*[4]. They classify the spectral type as Ge.

Present observations

Our 2010 $UBVR_cI_c$ light-curves were taken with the Lowell 0·81-m reflector in Flagstaff on September 26 and September 27 (UT) with a CRYOTIGER-cooled (–100° C) 2048×2048 NASACAM and standard Johnson–Cousins $UBVR_cI_c$ filters. Individual observations included 108 in the *U* filter, 203 in *B* and *V*, 199 in *R*, and 199 in *I*. The standard error of a single observation was 5 mmag in *U*, 6·5 mmag in *B*, 4·5 mmag in *V*, 6 mmag in *R*, and 8 mmag in *I*. NURO exposure times were 150 s in *U*, 25 s in *B*, 20 s in *V*, and 12 s in *R* and *I*. (The observations were taken by RS, DF, AJ, and PS; reduction and analyses were mostly done by TS, JW, and RS.)

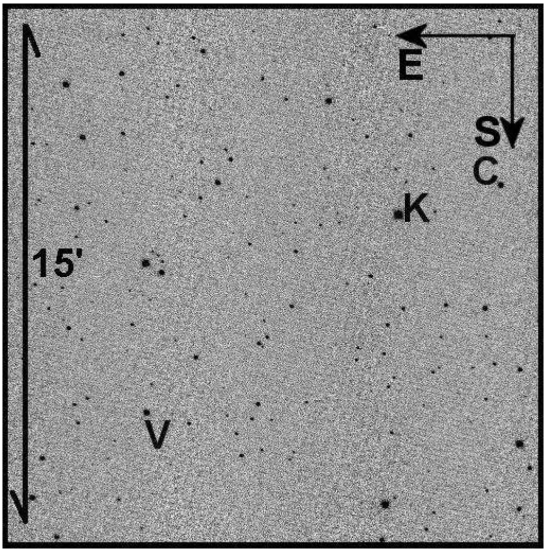

FIG. 1

Finder chart for GSC 2751–1007 (V), comparison (C), and check (K).

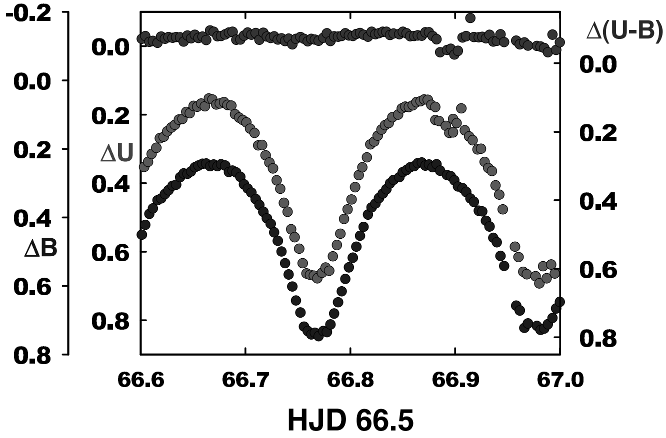

FIG. 2

U and *B* data for GSC 2751–1007 taken on 2010 September 27 (HJD – 2455400).

Images were calibrated in a standard way using biasses, darks, and $UBVR_cI_c$ sky flats. The variable, V (GSC 2751–1007), the comparison star, C (GSC 3657 0606) [α (2000) = $23^h\ 49^m\ 55^s{\cdot}910$, δ (2000) = $+51°\ 11'\ 06''{\cdot}85$], and the check star, K (GSC 3657 0633) [α (2000) = $23^h\ 50^m\ 15^s{\cdot}88$, δ (2000) = $+51°\ 11'\ 52''{\cdot}85$] are shown on the finding chart given as Fig. 1. A plot of the ΔU and ΔB data taken on 2010 September 27 is shown in Fig. 2. Absorption and emission features show in the primary and secondary eclipses. Also the colour indices rise instead of dipping, as seen in our *B*,*V* phased light-curves. Some activity, perhaps hot-spot or higher-atmospheric activity, possibly chromospheric or coronal, is represented here. This drop is seen in nearly all of $UBVR_cI_c$ W UMa light-curves and is due to the cooler 'back surface' of the Roche-lobe surface which is further away from the nuclear core than other parts of the surface. The $UBVR_cI_c$ observations in delta magnitudes, in the sense of V–C, are given at http://usclancaster.sc.edu/faculty/faulkner/GSC27511007file.pdf.

Period determination

Four times of minimum light were calculated from our present observations, using averages of parabolic fits, two primary eclipses and two secondary eclipses; they are given in Table I.

SAVS observations of this variable were also found to be available to the public at http://www.astri.uni.torun.pl/~gm/SAVS. From those data, we performed parabolic fits to the eclipses and determined seven times of minimum light which we used in our period determination. Using all available data, we calculated the following improved linear ephemerides:

$$\text{HJD } T_{\min} \text{ I} = 2452885{\cdot}2438 \pm 0{\cdot}0046 + 0{\cdot}4174524 \pm 0{\cdot}0000011\, E, \qquad (2)$$
$$\text{HJD } T_{\min} \text{ I} = 2455466{\cdot}76926 \pm 0{\cdot}00008 + 0{\cdot}417614 \pm 0{\cdot}000058\, E. \qquad (3)$$

TABLE I

O–C residuals calculated from equation (1)

	Epochs	*Cycles*	*Weight*	*OMC*[1]	*OMC*[2]	*Reference*
1	52885·2450	−6184	0·5	0·0011	0·0029	5
2	52885·4310	−6183·5	0·2	−0·0216	−0·0198	4
3	52888·3909	−6176·5	0·2	0·0161	0·0179	4
4	52902·3850	−6143	0·2	0·0256	0·0273	4
5	52905·4720	−6135·5	0·2	−0·0183	−0·0167	4
6	52907·3900	−6131	0·2	0·0212	0·0228	4
7	52908·4010	−6128·5	0·2	−0·0115	−0·0099	4
8	52909·4320	−6126	0·2	−0·0241	−0·0225	4
9	52910·4920	−6123·5	0·2	−0·0077	−0·0061	4
10	53300·4014	−5189·5	1·0	0·0012	0·0001	6
11	53301·2365	−5187·5	1·0	0·0014	0·0003	7
12	53301·4443	−5187	1·0	0·0005	−0·0006	7
13	54452·3640	−2430	0·5	0·0042	0·0004	5
14	55465·7254	−2·5	1·0	0·0001	0·0005	This paper
15	55465·9331	−2	1·0	−0·0009	−0·0005	This paper
16	55466·7687	0	1·0	−0·0002	0·0002	This paper
17	55466·9770	0·5	1·0	−0·0006	−0·0002	This paper

OMC[1] — Linear residuals
OMC[2] — Quadratic residuals

Ephemeris (3) is from the Wilson–Devinney program which has been fitted to our recently modelled curves only. The linear O–C residuals calculated using equation (1) are shown in Fig. 3. All available timings and their O–C residuals are given in Table I. Observations taken over some 6200 orbits seem to show a fairly constant period over the 7 years it has been observed, but with the possibility of a negative quadratic term. A quadratic ephemeris was generated but yielded an insignificant negative quadratic term (at the 1-σ level). However, the system needs to be monitored by observers for at least ten years to determine the long-term evolution of the system.

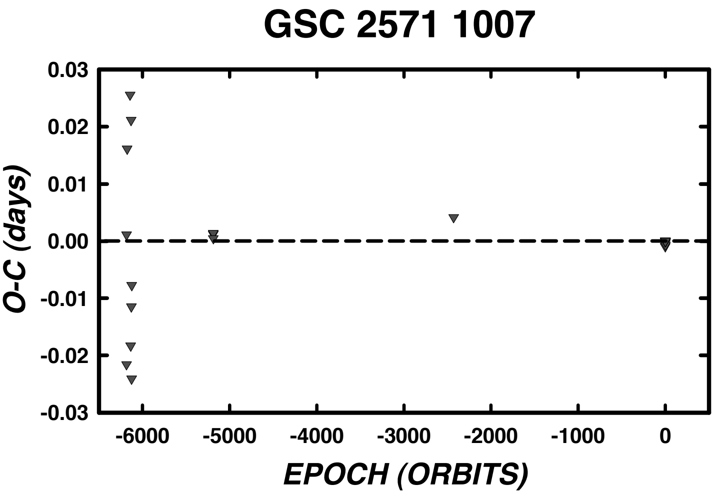

FIG. 3

O–C residuals for GSC 2751–1007, calculated from equation (1).

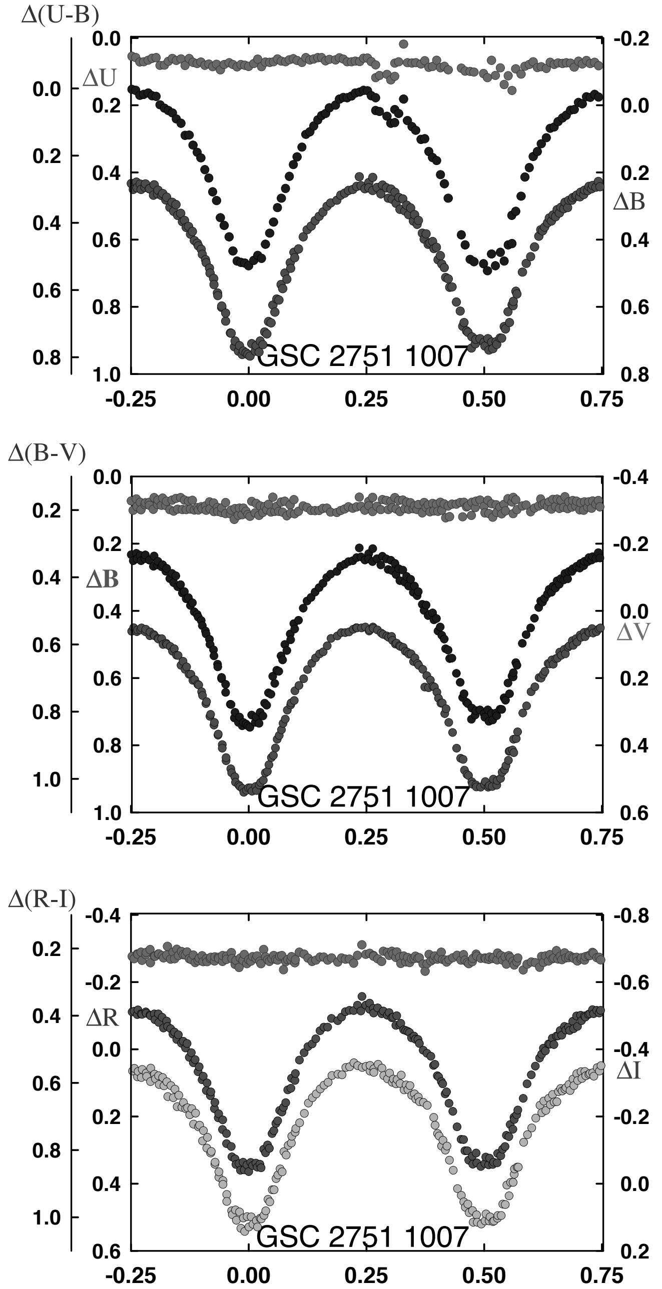

FIG. 4

Phased ΔU, ΔB, ΔV, ΔR, and ΔI differential-magnitude light-curves and $\Delta(B-V)$, $\Delta(R-I)$ colour curves.

Light-curve characteristics

Phased light-curves derived from equation (1) are given in Fig. 4. The ΔU, ΔB, ΔV, ΔR_c, ΔI_c curves are typical of a classical W UMa system with a primary amplitude of $0^{m}\cdot50$ – $0^{m}\cdot45$ in U to I_c. The O'Connell effect ranges from 2 to 15 mmags in U to I_c, respectively. We also note that the scatter (uncertainty) is nearly 50% larger at Maximum I than Maximum II (0·0147 *versus* 0·0108). This suggests magnetic activity, where a variation with time is larger for Maximum I. Otherwise, out-of-eclipse and maxima portions of the light-curve are relatively smooth. The light-curve characteristics are given in Table II.

TABLE II

GSC 2751–1007 light-curve characteristics.

Filter	phase	Maximum I mag	phase	Maximum II mag
U	0·25	0·165 ± 0·009	0·75	0·167 ± 0·010
B		0·237 ± 0·015		0·243 ± 0·011
V		0·025 ± 0·009		0·057 ± 0·005
R		–0·126 ± 0·009		–0·111 ± 0·005
I		–0·347 ± 0·009		–0·335 ± 0·011
Filter	phase	Minimum II mag	phase	Minimum I mag
U	0·5	0·670 ± 0·018	0·0	0·664 ± 0·010
B		0·670 ± 0·018		0·732 ± 0·012
V		0·517 ± 0·007		0·528 ± 0·007
R		0·339 ± 0·009		0·336 ± 0·016
I		0·104 ± 0·012		0·109 ± 0·019
Filter		Min I–Max I	Max II–Max I	Min I–Min II
U		0·505 ± 0·019	0·002 ± 0·019	–0·006 ± 0·028
B		0·459 ± 0·027	0·006 ± 0·023	0·026 ± 0·030
V		0·465 ± 0·016	0·005 ± 0·014	0·011 ± 0·014
R		0·465 ± 0·025	0·015 ± 0·014	–0·003 ± 0·025
I		0·451 ± 0·028	0·012 ± 0·021	0·005 ± 0·020

Synthetic-light-curve modelling

2MASS photometry in J, H, and K for the variable star all suggest that the system is of type ~F7 ($J - H = 0{\cdot}275 \pm 0{\cdot}061$, $H - K = 0{\cdot}039 \pm 0{\cdot}052$). This results in a temperature of about ~6250 K which we use for the primary component in our solution[8]. As noted earlier, a rough spectral-type identification of Ge is given by Maciejewski *et al.*[4]. Evidently, the forest of emission lines makes the identification difficult. We would assume that this means it has about a half-spectral-type uncertainty which overlaps F7. We first hand-fitted each light-curve individually with BINARY MAKER 3·09 using standard convective parameters and limb-darkening coefficients from reasonable values dictated by the spectral type. In these models we used dark spots to fit the asymmetries in the curves. We proceeded to compute a simultaneous four-colour light-curve solution with the 2004 Wilson–Devinney Code[10–13], which includes Kurucz stellar atmospheres, rather than black-body, two-dimensional limb-darkening coefficients, and a detailed reflection treatment. Our fixed inputs included standard convective parameters, gravity darkening, $g = 0{\cdot}32$, and albedo values of 0·5. We used Mode 3, a contact mode, in our analysis. Adjustable parameters

TABLE III

Synthetic light-curve solutions

Parameter	*Value*
$\lambda_U, \lambda_B, \lambda_V, \lambda_R, \lambda_I$ (nm)	360, 440, 550, 640, 790
$xbol_{1,2}$, $ybol_{1,2}$	0·644, 0·644, 0·231, 0·231
$x_{1I,2I}$, $y_{1I,2I}$	0·572, 0·572, 0·267, 0·267
$x_{1R,2R}$, $y_{1R,2R}$	0·655, 0·655, 0·278, 0·278
$x_{1V,2V}$, $y_{1V,2V}$	0·728, 0·728, 0·269, 0·269
$x_{1B,2B}$, $y_{1B,2B}$	0·817, 0·817, 0·215, 0·215
$x_{1U,2U}$, $y_{1U,2U}$	0·859, 0·859, 0·208, 0·208
g_1, g_2	0·32
A_1, A_2	0·5
Inclination (°)	77·7 ± 0·6
T_1, T_2 (K)	6250 ± 500K, 6248 ± 2*
$\Omega_{1,2}$	2·3666 ± 0·0012
q (m_2/m_1)	0·2710 ± 0·0004
Fill-outs: $F_1 = F_2$	31%
$L_1/(L_1+L_2)_I$	0·7547 ± 0·0253
$L_1/(L_1+L_2)_R$	0·7547 ± 0·0189
$L_1/(L_1+L_2)_V$	0·7546 ± 0·0140
$L_1/(L_1+L_2)_B$	0·7545 ± 0·0218
$L_1/(L_1+L_2)_U$	0·7551 ± 0·0202
JD_0 (days)	24 55466·769265 ± 0·000083
Period (days)	0·417614 ± 0·000058
r_1, r_2 (pole)	0·4731 ± 0·0013, 0·2689 ± 0·0032
r_1, r_2 (side)	0·5130 ± 0·0019, 0·2818 ± 0·0040
r_1, r_2 (back)	0·5419 ± 0·0027, 0·3262 ± 0·0087
Spot Parameters:	
Star 1	*Hot Spot*
Co-latitude (°)	73 ± 1
Longitude (°)	310 ± 1
Spot radius (°)	21·8 ± 0·3
Spot Factor	1·029 ± 0·001
Star 2	
Co-latitude (°)	100 ± 8
Longitude (°)	254 ± 1
Spot radius (°)	8·0 ± 0·2
Spot Factor	1·26 ± 0·01

*All errors are formal; here the error in T_2 is in relation to T_1. We expect photometric errors on T_1 to be on the order of ~500K.

include those accompanied by uncertainties (see Table III), the inclination, i, the temperature of the secondary component, T_2, the potentials, $\Omega_1 = \Omega_2$, the mass ratio, q, and the normalized flux (at 4π) in each wavelength, L, the phasing ephemeris, JD_0 and the period P, and two sets of four spot parameters including the relative spot temperature *tfact*.

Our first solution, q = 0·28, proved to be near our final solution. Not knowing this, however, we proceeded to perform a high-density q search over the interval from q (m_1/m_2) = 0·18 to 1·25. The residuals minimized at a sum of square residuals of ~0·59 at q ~0·27. We believe that this is due to the fact that the eclipses are very near to total. Additional iterations were run from the minimized q with the mass ratio allowed to adjust to our final solution. Our final solution shows a W UMa binary, with equal-temperature components.

Our complete solution is given in Table III and the curves are shown in Fig. 5, where the solution is overlying the normalized-flux light-curves. The Roche-lobe surfaces arising from the calculation are displayed at quadratures in Fig. 6.

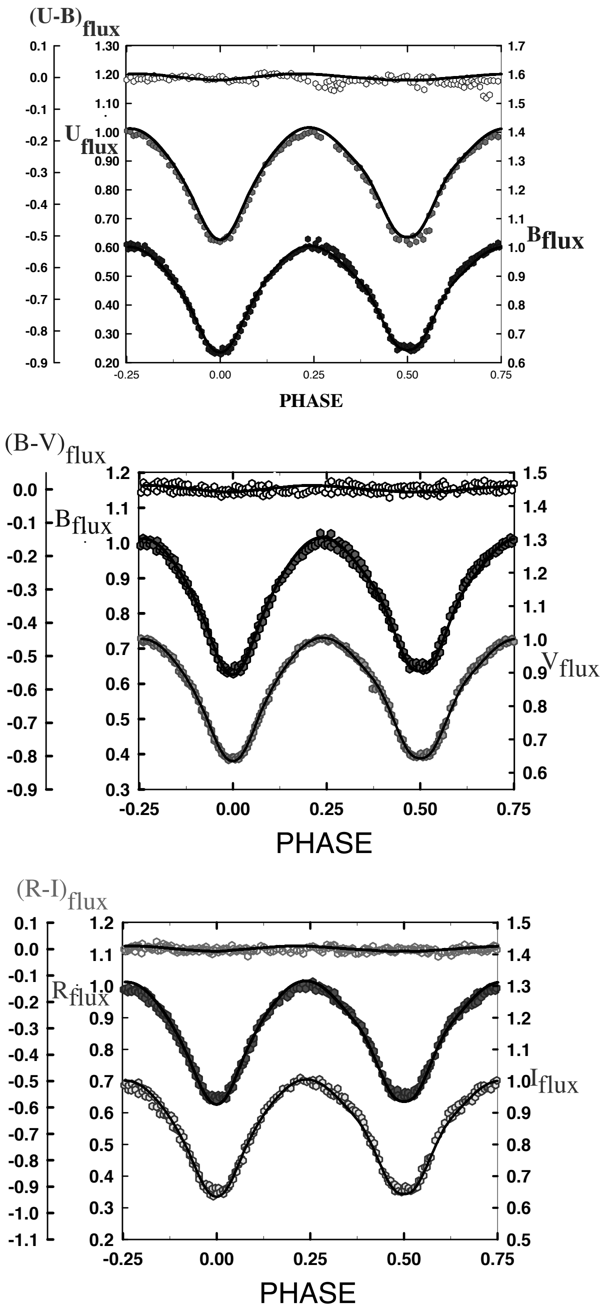

FIG. 5

U, B, V, R, and I normalized flux curves and $U-B$, $B-V$, $R-I$ colour curves overlain by our solution.

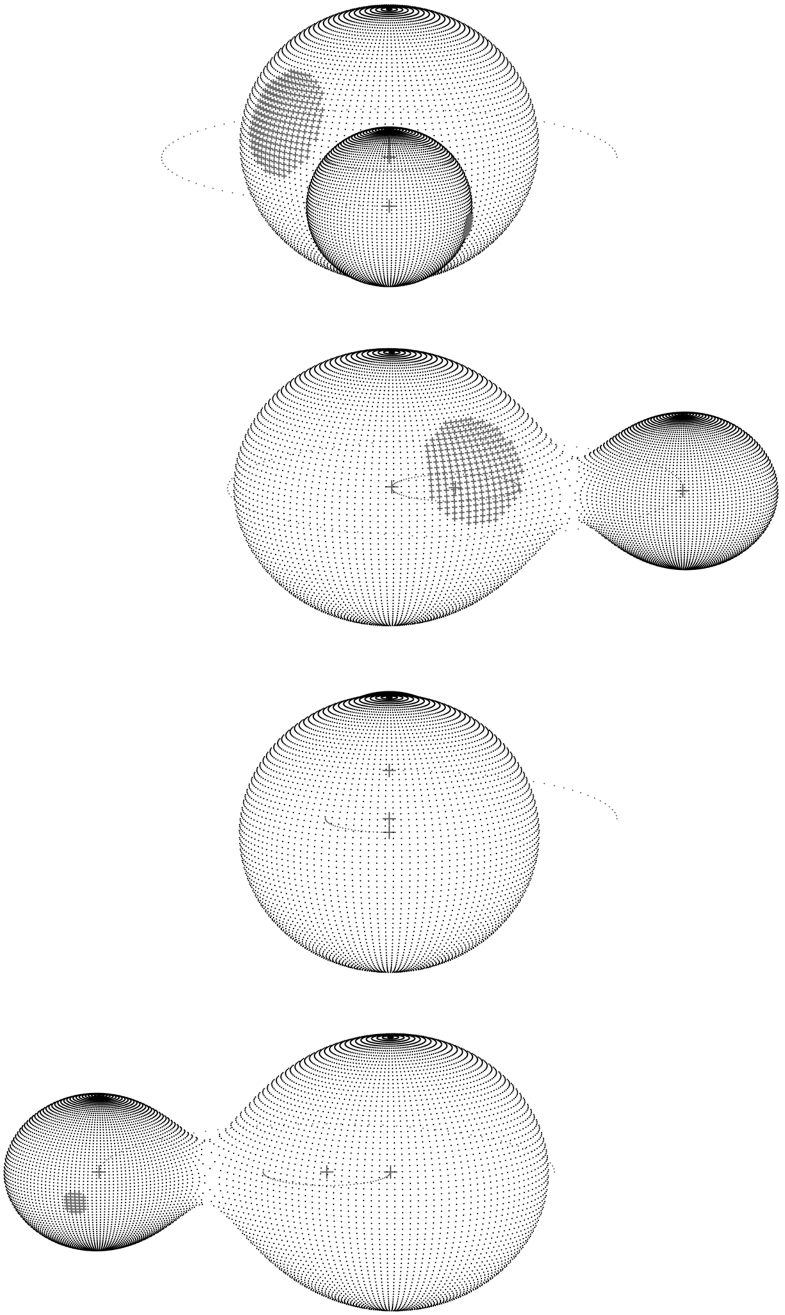

FIG. 6
The Roche-lobe surface of GSC 2751–1007 at phases 0·0, 0·25, 0·50, and 0·75.

Conclusions

GSC 2751–1007 is an active emission-line solar-type contact binary. It is almost certainly magnetically active, which is not unusual for a binary of this class. The exception is the erratic activity in the maxima and minima. The 31% fill-out shows that the system is in firm contact, suggesting that the period is decreasing, which is predicted by the theory of solar-type binaries through torques provided by stellar winds leaving the star along stiff, rotating magnetic-field lines (magnetic braking). It is expected to continue to coalesce until it finally becomes a fast-rotating A-type single star.

The star should be monitored for at least the next ten years to establish the long-term behaviour of the system. Radial-velocity curves are needed to obtain absolute (not relative) system parameters. A standard-magnitude study is also called for to decrease the estimated temperature uncertainty in the primary component given here.

Acknowledgements

An Arizona Space Grant supported this observing run. We wish to thank NURO and SARA for their allocation of observing time. We also wish to thank the American Astronomical Society–NASA-sponsored small research grant for support of our observing runs.

References

(1) R. F. Griffin & F. C. Fekel, *JAp&A*, **11**, 43, 1990.
(2) D. Montes *et al.*, in M. Manteiga & A. Ulla (eds.), *Lecture Notes and Essays in Astrophysics I* (see www.slac.stanford.edu/econf/C0307073/papers/DM.pdf)
(3) S. M. Rucinski, *MNRAS*, **215**, 615, 1985.
(4) G. Maciejewski, K. Czart & A. Niedzielski, *IBVS*, no. 5518, 2004.
(5) S. J. Gettel, M. T. Geske & T. A. McKay, *AJ*, **131**, 621, 2006.
(6) A. Paschke, *Open European Journal on Variable Stars*, **116**, 1, 2009.
(7) B. Gurol *et al.*, *IBVS*, no. 5791, 2007.
(8) A. N. Cox, ed., *Allen's Astrophysical Quantities, 4th Edition* (Springer, New York), 2000.
(9) D. H. Bradstreet & D. P. Steelman, *BAAS*, **34**, 1224, 2002.
(10) R. E. Wilson & E. J. Devinney, *ApJ*, **166**, 605, 1971.
(11) R. E. Wilson, *ApJ*, **356**, 613, 1990.
(12) R. E. Wilson, *PASP*, **106**, 921, 1994.
(13) W. Van Hamme & R. E. Wilson, *BAAS*, **30**, 1402, 1998.

CORRESPONDENCE

To the Editors of 'The Observatory'

Colour Resides in the Body or else Causes that Sensation

Roy Bishop nails his colours[1] to one mast of the two that drive the word "colour" onwards in the choppy seas of the English language and quotes Isaac Newton in support. The *OED* explains the two meanings well[2]: colour is "The quality or attribute by virtue of which something appears to have a colour, so that it may present different appearances to the observer regardless of shape, size, and texture; the sensation corresponding to this, now recognized as dependent on the wavelengths of the light reaching the eye. The colour of an object depends on the way it selectively absorbs light incident on it, and also on the nature of the incident light. Because sight is mediated by nerve impulses from the eye to the brain, a sensation of colour can also be produced by other means, such as pressure on the eyeball or stimulation of the neural pathways between the eye and the brain."

It illustrates this with a quotation from one of Newton's peers, Robert Boyle: "1663 R. Boyle *Exper. & Consider. Colours* ii. 10 Colour may be considered, either as it is a quality residing in the body that is said to be coloured, or to modifie the light after such or such a manner; or else as the Light it self, which so modifi'd, strikes upon the organ of sight, and so causes that Sensation, which we call Colour."

So the adjective "coloured" refers *both* to the sensation within the brain and the spectral-energy distribution of the external body.

And of course the photographs in *Treasures of the Southern Sky* are more kaleidoscopic than the Universe realistically appears. The point about image-reproduction technology is to reveal, exaggerate, render more pleasing, or illuminate what cannot ordinarily be seen by the eye or might be overlooked. Colour astrophotographs are intended to show things.

Yours faithfully,
PAUL MURDIN

Institute of Astronomy
Madingley Road
Cambridge CB3 0HA

Email: murdin@ast.cam.ac.uk

2012 November 1

References

(1) R. Bishop, *The Observatory*, **132**, 41, 2013.
(2) *Oxford English Dictionary* (Oxford University Press, on-line edition), 2012.

The Horned Moon, with One Bright Star: Transient Lunar Phenomena

It was interesting to read the article[1] by Gerald Smith & Andrew Smith detailing a completely new theory to account for some dark-side Transient Lunar Phenomena (TLP). Based upon the Cameron catalogues[2,3], and the archives of the ALPO and BAA Lunar sections, there are on record, 531 lunar night-side TLP observations out of a total of 2867 TLP, for which the date, UT, and lunar positions are known. Of these night-side TLP, 250 concern Aristarchus crater. However, it is suspected that many night-side TLP could be the result of observers working at the sensitivity limits of the human visual system, detecting lunar formations that were made temporarily bright enough to be seen by short-term — tens of minutes — changes in the Earth's albedo[4]. It is also worth noting that when observing the lunar surface in earthshine, we are seeing it close to zero phase angle, and it is at this stage that the lunar photometric function[5] has the steepest gradient and hence differences in porosity and scattering functions may affect the observed relative brightness of some surface features greatly, and over relatively short time-scales of perhaps an hour or two. In addition, the Moon's earthshine tends to be most frequently observed at small lunar phases when the Moon is closer to the horizon and more affected by variations in atmospheric transparency, turbulence, and scattered light from atmospheric aerosols. Hence the ability to notice true lunar-surface changes in earthshine can be easily impaired by these effects. Despite the above, it is possible that some earthshine TLP cannot be accounted for by the above explanations, and hence other theories need to be invoked. This is especially true when observers have reported seeing colour in earthshine, as this would infer that the TLP would have been bright enough to be seen with the colour-sensitive cones of their eyes.

With regard to the Smith & Smith dusty-lunar-exosphere theory[1], assuming that their model can be proven, namely strong forward Mie scattering of star light from mid-altitude 0·1–0·02-μm-radii dust particles, followed by isotropic Rayleigh scattering off a 'screen' of <0·02-μm-radii dust particles at higher altitudes, then surely it would be expected that the same would apply if the source of light was the Sun. For the Capella example given, this has a visual magnitude of +0·08, whereas the Sun has a magnitude of –26·7, or an apparent surface brightness of –10·7 magnitudes per $arcsec^2$. Given the 20 000 times difference in brightness between the Sun and Capella (per $arcsec^2$), would it not be expected to see, under similar conditions, overwhelmingly bright spots being produced on the lunar night side, even during times when there is relatively little dust loading of the Moon's exosphere? The size of the spots would of course depend upon the apparent solid angle of the proposed dust-particle clouds. Such phenomena should be detectable easily with time-lapse imaging of earthshine, especially with colour cameras, or alternating polarizing filters. However, amateur astronomers already monitor earthshine regularly for lunar occultations and impact flashes[6] by means of low-light-level CCTV cameras. Other research groups monitor earthshine too, with more sensitive and better-calibrated cameras[4,7]. In the many years that these have operated, no unusual bright spots in earthshine have been mentioned in the resulting publications; this would appear to be a major piece of evidence against the Smith & Smith theory for explaining bright spots seen in earthshine by astronomers of past centuries.

Yours faithfully,
ANTHONY C. COOK

Institute of Mathematics and Physics
University of Aberystwyth
Penglais, Aberystwyth
Ceridigion
SY23 3BZ

Email: atc@aber.ac.uk

2012 November 13

References

(1) G. J. Smith & A. J. Smith, *The Observatory*, **132**, 71, 2012.
(2) W. S. Cameron, *Lunar Transient Phenomena Catalog* (World Space Science Data Center, *Rep. 78–03 NSSDC, NASA-TM-79399*), 1978.

(3) W. S. Cameron, *Lunar Transient Phenomena Catalog Extension*, http://users.aber.ac.uk/atc/tlp/cameron2006.pdf, 2006.
(4) S.V. Langford *et al.*, *Astrobiology*, **9**, 305, 2009.
(5) B. Hapke, *AJ*, **71**, 333, 1966.
(6) B. Cudnik, *Lunar Meteoroid Impacts and How to Observe Them* (Springer, New York), 2009.
(7) R. M. Suggs *et al.*, *Earth Moon & Planets*, **102**, 293, 2009.

REVIEWS

The Cosmic Tourist, by B. May, P. Moore & C. Lintott (Carlton Books, London), 2012. Pp. 192, 28·5 × 23·5 cm. Price £25 (hardbound: ISBN 978 1 84732 619 5).

The trend for making lists of 100 things to encompass and summarize all knowledge has now reached the cosmos — how long before we have a book listing the 100 best books listing 100 things. With this book listing its top 100 cosmic destinations I suppose I was expecting the worst, and when I saw the comic-book cover my fears increased. An old metaphor says that you should not judge a book by its cover but in this case, correctly interpreted, the cover tells you all need to know about this book's content. On a black, star-speckled vista a physically unfeasible, *circa* 1950s comic-strip rocket is shown blasting off from planet Earth with our cosmic guides visible, in NASA spacesuits, through the large transparent cockpit cover. Patrick Moore's cat, Ptolemy, for whom the ship is named, sits with our three author heroes as they travel at the speed of thought to visit the 100 most awe-inspiring destinations in the Universe. The cover thus tells us this is a book to inspire and that the physics will be treated lightly — not flippantly or erroneously, just perfectly correctly but with a calm non-mathematical touch.

You will probably not be surprised that destination number 1 is the planet Earth nor that destination 100 is the cosmic microwave background, and the authors manage to sneak in as item 101 the evolution of humans at the end of that section. Although primarily an inspirational book on the wonders of the cosmos, it does need to be read sequentially rather than as a picture book. Explanations or little pieces of physics are given when they are first needed and not referred to again. By dipping in and out of the interesting objects you could miss some important explanations. The sequential fusion of hydrogen to helium, and subsequent heavier atoms is covered at number 15, 'The heart of the Sun', and then used again, without further explanation, for the supearnova at 'The heart of the Crab Nebula' (number 78). The term 'event horizon' is explained in number 82 dealing with the binary star SS 433, and again, but now as a known term, applied to the black hole at 'The centre of the Galaxy' in number 84. Most expressions are thus covered in the text and any that may seem unexplained are dealt with in the very useful five-page glossary in which astronomical and physical terms are clearly but briefly explained.

You may be surprised that, given the entire Universe to choose from, of the 100 selected destinations 53 are within the Solar System and eight of those are on the Moon. Each destination is given a page or double-page spread dominated by images. To cover the 100 objects or locations in 163 admittedly-large pages, the treatment of each must necessarily be brief, but I would say not superficial, and to some extent this brevity is compensated by the glorious images; they are indeed inspiring, interesting, and beautiful. The book is aimed at the older child, late pre-teens or early teens, and it is laudable that such an inspiring book exists for that age group. They have the ability and skills to look at other information sources and this book is the perfect stimulus.

So in spite of my prejudiced misgivings about a book of lists, in this case I find myself a convert. This is a very fine book; it is inspirational without dumbing down; there are no silly analogies, and everything is well explained — and I mean everything: I could not find any significant astrophysical destinations that were not covered — and it is bang up to date. There are a few gaps for things that are concepts rather than actual locations or destinations — gravitational waves, and the very early Universe, for example — but within the parameters laid out in the introduction this book more than achieves its aims. It is quite an astonishing *tour de force* that so much is covered so clearly and so beautifully illustrated. The images are wonderful, and the two pages of photo credits shows how well they have been researched, which together with the four-page detailed index and the already-mentioned glossary make this a wonderful introduction to the wonders of the Universe. At £25 for a large-format book it is also rather good value. — BARRY KENT.

Patrick Moore's Yearbook of Astronomy 2013, edited by P. Moore & J. Mason (Macmillan, London), 2012. Pp. 416, 22·5 × 14 cm. Price £20 (hardbound; ISBN 978 0 230 76750 8).

Patrick Moore's Yearbook for 2013 needs no justification, and almost no description. With 50 previous volumes as a testimony, the series has gained a steady and well-deserved reputation as a 'must' for all serious observers, particularly amateurs. Whenever Christmas comes round, the *Yearbook* sidles to the fore in the market of book purchases. What makes it so popular?

The book is printed on quite thick paper, so its fairly modest 400-plus pages make a book that would not conveniently fit into the pocket. In parallel with other 'Yearbooks', this one includes star charts, moon tables, and schedules of phenomena such as eclipses and occultations, plus descriptions or explanations of planets, comets, meteors, minor planets, and all the rest of the inhabitants of our local space. Again, as in other such compilations, the events are also summarized for each month. There's nothing special in those topics, and yet P.M.'s 'Monthly Notes' *are* different because each one includes some historical or anecodotal story that adds vital zest to the factual matter.

Arguably the most readable section of the book is its 'Articles' section. Each of the nine biographical histories, technical descriptions, or scientific stories is a well-researched expert account, yet their style is not cramped by the all-too-common need in journals to reduce the length; they seem able to take as much space as they need, and in consequence they are the more pleasant to read. Styles vary, of course; more than one author prefers to use semi-colons where commas are actually required, and it would have been superb to have some of the illustrations in colour, had that been an option. Selection was sometimes guided by an anniversary date, such as the 400th birthday of Hevelius; one chapter is a reprint of a past article that proved popular at the time. But whether the topic is digital meteor imaging, a space asteroid mission, Solar System science, the planning and development of *ALMA*, explaining the wonders of the aurorae, or reconstructing strategic events in the lives of historical figures, and however varied and vivid the contents, it's the personal touches that really bring them to life and give them the edge — the vicissitudes of a pioneer, meshed with the ups and downs of personal life, contribute equally to achievements and failures both in the past and in the present. Astronomers are, after all, only human.

It was while the book was still on my desk that its dust-jacket sadly became out of date: Sir Patrick Moore is no longer "the world's best-known living astronomer". Other obituaries will be written, but in a very real sense one can recall the epitaph in St. Paul's Cathedral, London, to Sir Christopher Wren: *If you want a memorial, look around you*. This book *is* Sir Patrick Moore, full of knowledge and information yet uniquely sprinkled with humour, wit, and inspiration. The *Yearbook* series is exemplary of public outreach. Long may it continue, and may its prime editor and originator rest in peace in the sound knowledge of a job very well done. — ELIZABETH GRIFFIN.

The Cambridge Photographic Moon Atlas, by Alan Chu, Wolfgang Paech & Mario Weigand, translated by Storm Dunlop (Cambridge University Press), 2012. Pp. 191, 34 × 25 cm. Price £35/$55 (hardbound; ISBN 978 1 107 01973 7).

From cover to cover, this book is full of the most amazing non-spacecraft images of the Moon you will have the privilege to look at for some time to come. A few images are from NASA, but it is hard to tell which are Earth-based and which are from a space-probe camera. This book definitely is not a collection of old blurry or pixellated CCD images of the Moon. It is the work of master astrophotographers Alan Chu from Hong Kong and Mario Weigand from Germany, and author and amateur astronomer Wolfgang Paech of Germany, and was translated from its original 2010 German publication by Storm Dunlop.

The book is divided into three main parts. The first part contains information about the structure of the Moon, and gives advice on how to use the book. The main part follows with 180 pages of lunar images and descriptive text divided into 68 sections on the nearside features, with the last section (number 69) covering the farside. The third part of the book consists of a brief glossary, an index to the features covered in the book, photo credits, and finally suggestions for further reading about the Moon.

The book begins by explaining the structure of the Moon. The authors cover the selenological ages and periods of the Moon and its chemical makeup. They compare the black basalts of the maria with the white anorthositic rocks of the highlands. They go on to give in one paragraph the theory of the megabasin impact that may be the cause of there being such a difference between the nearside and the farside. The nearside is covered with the dark maria areas and the farside lacks these lava-flooded areas. The different types of surface features with images showing these features, is discussed, as is the evolution of a crater from its initial impact to the modifications it goes through by the erosion caused by impacts of smaller bodies.

As part of this first section, the authors also cover the basics of observing the Moon, such as the selenographic coordinate system, the height of elevated features, colongitude, and librations. Then they briefly discuss telescopes to use for lunar observation. The best part of this section is the coverage that they give to imaging the Moon. They talk about the types of CCD sensors, and which colour of filters work best for digital images of the Moon. Since this book is mainly an atlas of electronic images, the authors devote over a full page with instructions on how to take and then process your lunar images to get as sharp a final version of the image as possible.

The heart of this atlas is of course the 300-plus high-resolution images of the Moon. In most cases, they have used four images of the same area in order to show it under different lunation phases. This part of the book includes 68 areas plus the last section covering the far side. Some features are covered on two pages and some on four pages. The authors do a great job in clearly identifying lunar features with thin white lines for the placement of the feature names.

One minor thing that annoys me is when a certain incorrect phrase is repeated from one Moon guide to another. In this case, the authors have repeated the incorrect phrase that under a high Sun, the mare wrinkle ridges become "invisible". Saying that a wrinkle ridge is "invisible" would tend to indicate that you would see a strip of nothingness on the mare surface where the "invisible" wrinkle ridge runs. They do not become "invisible" — you can still see them — it's just that under a high Sun, they do not cast a shadow and are therefore not recognizable as an elevated feature.

The only problem that I see with this book is that they use gray dots with a white number in the dot to identify in the images the features covered in the text. This arrangement works fine for most of the features and keeps the images from being covered with feature names, but when they place the number/dot near a feature with a high albedo (bright), the dot almost disappears and can be a challenge to locate. Since a few of the sections are on four pages, the numbered feature may be discussed on a following page instead of the page with the dot. This can be confusing as you hunt around the first page only to discover that the descriptive text is on the following page.

Overall this photographic atlas of the Moon should be an addition to all lunar observers' libraries. The book is not designed to serve as an at-the-telescope guide, but for cloudy-night reference. I certainly would not want to take it out into the damp night air and watch the dew destroy it. — ROBERT GARFINKLE.

Total Addiction: The Life of an Eclipse Chaser, by K. Russo (Springer, Heidelberg), 2012. Pp. 193, 23·5 × 15·5 cm. Price £16·95/\$24·95/€24·95 (paperback; ISBN 978 3 642 30480 4).

When I was first asked to review this book, I quickly thumbed through and thought "Oh no, another book that makes eclipse chasers look like the most nerdy and eccentric beings on this planet", which is the impression conveyed by some television programmes. But I was pleasantly surprised as I started to read that this was not going to be the case.

In the first few chapters, the book covers the author's personal introduction to eclipse chasing and the excitement of sharing these events with others. There are contributions from other eclipse chasers and it is a very detailed account of what these eclipse chasers-experience, how they are motivated, and the different emotions and reactions they go through when observing under the shadow of totality. The book also briefly explains the science of how eclipses occur, although this was not the objective of the book. The author also carried out a survey of the eclipse-chasing fraternity, and she discusses the resulting breakdown and analysis of these results.

There are a number of detailed interviews that have been conducted, from beginners who didn't know what to expect from seeing a total eclipse to people who have spent a large part of their lives viewing eclipses all over the world. Having been to many total eclipses over the years, I found myself able to relate to their stories and can well understand how difficult it is to explain the magic of totality without appearing a little odd to the outside world. But the book does try to explain that if you are in a position to enjoy travelling to unusual places at unlikely times of the year then it can be very rewarding and can become addictive, like any other hobby.

I am not sure that this book makes light reading, since it goes into some depth about the psychological aspect of people's perspective on total eclipses and therefore can get a little repetitive; one can also get a little bogged down with the statistics of eclipses, which may not suit everyone. The interviews are very informative and perhaps give an insight to beginners as to what to expect when seeing totality, which should not be confused with seeing a partial eclipse. Totality is a far more enlightening experience. There is also a chapter on locations and helpful tips in getting started for future total eclipses up to 2020. — Jean Felles.

Stars: A Very Short Introduction, by A. King (Oxford University Press), 2012. Pp. 120, 17·5 × 11 cm. Price £7·99 (paperback; ISBN 978 0 19 960292 6).

According to the publisher, *Very Short Introductions*, which started in 1995, are for "anyone wanting a stimulating and accessible way into a new subject". It is perhaps a little surprising that a subject as popular as stellar astronomy has not already been featured, although 'Galaxies' and 'Cosmology' have [as has 'Planets' — see **131**, 256, 2010 — Ed.]. What we find in this new offering is not the regular presentation of popular astronomy but a serious, formula-free description of stellar structure and evolution. There is no mention of constellations or telescopes, but if the single word 'Stars' in the title was slightly misleading it was as much the publisher's fault as the author's; an *Introduction* to 'The night sky' (or some such) may still be to come.

King's presentation of the physics of stars is lucid and logical, its depth adequate for the intended readership. It is always tricky to avoid over-simplifying the style when simplifying the language in which a topic is couched, and he almost succeeds — though his sentences do tend to avoid complex structures as they search for neat ways to explain complex concepts in non-complex terms. His theme is the construction, evolution, and ultimate fates of stars, and he traces the mathematical physics non-mathematically with enviable skill and command. Commencing with the history of how astrophysics was born, and defining just the very basic concepts such as luminosity, Doppler shift, and parallax as needed, he manages to take the reader into the realms of neutron stars, black holes, and the very highest energies by logical arguments rather than hard mathematical proofs. Not until the end does he tackle star formation, but because of the associated ascending computational problems it fits rather well when done in that order. His account is clear, concise, and convincing.

He does not do a quite perfect job, however. As the subject matter gets more involved and enthusiasm mounts, the style degrades towards the characteristics of so much of today's scientific writing that pepper sentences with "this" and starts them with "So". A few Americanisms dot the pages, even though both author and publisher are British, and there is some confusion of commas in places. I noticed only one typo, though in striving to keep the language of the science at the level of speech rather than figures his explanation of 10^{16} is off in one place by a factor of 10, and crediting the first exoplanet discovery to Mayor & Queloz neglects the earlier confirmed work of the Canadians. I must, however, draw attention to a bad slip of a different kind, where Zwicky is referred to as "the cantankerous Swiss-American astronomer". Language of that nature is an absolute no-no in scholarly writing, and I was shocked that the publisher let it through, whatever the author's personal opinion. "Contentious" maybe, and that could describe a lot of the rest of us too, but anything stronger is heading towards libel and should be withdrawn. Use of that word was a serious blot in an otherwise very well-written and cleverly-crafted little book.

What King has produced is a 'must' for every aspiring astronomy student, and a powerful background exposition for any armchair astronomer. — ELIZABETH GRIFFIN.

The Star Book: How to Understand Astronomy, by P. Grego (David & Charles, Newton Abbot), 2012. Pp. 160, 16·5 × 24·5 cm. Price £12·99/$16·99 (paperback; ISBN 978 1 4463 0239 2).

There are many good books on popular astronomy but this one stands out for the high quality of its images and the clarity of the graphics. Nearly all the illustrations are in colour and many are the author's own work. The book falls naturally into three parts. The first is an introduction which covers the celestial sphere and the principles of star charting. During a sidereal day, stars follow different apparent trajectories depending on the observer's latitude, and this leads naturally to the latitude-independent definition of right ascension and declination. The annual motion of the Sun along the ecliptic causes the seasons, and each season has a different part of the sky where each constellation can be best seen. The colours and brightnesses of the stars are intimately linked to their life history. Different types of double and variable star are examples of different stages of stellar evolution. Together with star clusters and the Milky Way, they can be easily seen, even with simple equipment.

The second part describes the constellations visible from different latitudes at different times of year, maintaining strict parity between north and south. The charts are presented as coloured symbols on a black field. Each type of cluster and nebula has its own colour and symbol. The stars brighter than magnitude five are in white and the brighter ones are named. The most familiar stick figures, the constellation boundaries, and the ecliptic are clearly shown. There are two horizons on each chart, London and New York for northern latitudes and Canberra and Wellington for southern. All are faint, and London and Wellington are barely discernible by night. There are five charts of the northern sky and five of the southern. Each chart is supplemented by several pages listing and illustrating the most interesting objects. The captions are careful to point out with what equipment the picture was made, from the naked eye to a 250-mm-aperture telescope. The author has given a symbol to each constellation described. For the twelve zodiacal constellations these are the symbols of the corresponding signs, which refer to exact intervals of 30°. The confusion between the constellations and the signs is caused by the irregularity of the constellations, already known to Ptolemy, the precession of the equinoxes and the intrusion of Ophiuchus onto the ecliptic (see N. Kollerstrom, *The Observatory*, **115**, 261, 1995). The other constellations are given symbols from www.suberic.net/~dmm/astro/constellations.html.

The third section covers the Solar System and the Earth's interaction with it. The solar wind causes the aurora and noctilucent clouds in the upper atmosphere.

There they mingle with meteors which are persistent reminders of the multitude of small bodies in the Solar System. The Sun affects the Earth by its light and heat, and the Moon does through the tides. Most importantly the reader is shown what can be seen with inexpensive equipment and reminded of the stringent precautions necessary when observing the Sun. The Moon, its phases, eclipses, and surface features are particularly well covered. The book finishes with an account of light pollution, its cause and cure.

This book is recommended as an ideal present to anyone with a nascent interest in astronomy and also as a valuable supplement to a first course in astronomy for adults. — DEREK JONES.

New Eyes on the Universe, by Stephen Webb, (Springer, Heidelberg), 2012. Pp. 381, 24 × 16·5 cm. Price £40·99/$44·95/€44·95 (paperback; ISBN 978 1 4614 2193 1).

Present-day astronomical knowledge can revealingly be divided into two categories. One contains the things we know we know. But the other, more mysterious category, contains the things we know we don't know. (There is also a third category which contains unseen and unexplained unknowns we haven't even dreamt of yet, but that is being rather too Rumsfeldian*.)

Stephen Webb, head of Technology Enhanced Learning at the University of Portsmouth, concentrates on the second of the above categories. He revels in the fact that we are in a Universe which has an accelerating expansion, a mysterious origin, and not only consists mainly of material and energy the nature of which we are ignorant, but also is seemingly only enlivened by one inquisitive 'civilized' planet. His prose is accurately aimed at the non-technical reader — the book benefits from beautiful illustrations, cogent explanations, and a useful glossary — but his subject matter is right at the frontiers of our field. This is new, big astronomy at its most complex; in fact one could not get further away from a lonely astronomer with a pet project if one tried.

We are treated to the excitement of the *Large Synoptic Survey Telescope* which will scan the sky from its cloud-free mountain eyrie generating a petabyte of data every month or so. We descend into mines and dive into the sea hunting for neutrinos and dark-matter candidates. Hectares of land are covered with detectors tuning into low-frequency radio waves or peeping at Čerenkov radiation. We zoom into space with bigger, better, and more sensitive satellites probing the whole gamut of the electromagnetic spectrum. World-wide teams of astronomers come together in the hope of detecting gravitational waves and gamma-ray bursts. The pages zing with terms like polarized cosmic microwave backgrounds, dark flow, dark energy, inflation, gravitational lensing, mid-mass black holes, baryon acoustic oscillations, wimpzillas, spongy universes, Sloan Great Walls, planet-formation probabilities, and extraterrestrial messages in the water hole.

This book is exciting, pacey, and accessible. It continuously underlines the fact that there is a great deal out there that we know far too little about. The future is bright. Fortunately the tax payers of the world are still happy to pump money into the long-term, expensive, big-science projects that are needed. The job of the astronomer is far, far from over. This is really encouraging. — DAVID W. HUGHES.

*After Donald Henry Rumsfeld (born 1932) the much-quoted United States 13th and 21st Secretary of Defense.

L'Observatoire de Paris: 350 ans de science, edited by L. Bobis & J. Lequeux (Observatoire de Paris/Gallimard, Paris), 2012. Pp. 176, 23 × 18·5 cm. Price €26 (about £21) (paperback; ISBN 978 2 0701 3806 7).

In reading this account of the Observatoire de Paris from its founding in 1667 to the current activities of today, the reader is reminded of the curious similarity between Paris and Greenwich (founded just eight years later in 1675). Sadly the latter is no longer with us as an active research and instrument-building facility, but at several stages during the last 350 years the activities of the two institutions were comparable — the discipline of time-keeping is one which stands out. One is also reminded that the more authoritarian leaders of both observatories, U. J. J. Leverrier and G. B. Airy, were in charge at the same time, adding to the parallels.

James Lequeux has been on something of a mission in the last few years, authoring biographies of Arago and Leverrier and translating a book on Foucault into French. These individuals, of course, are all intimately connected with Paris Observatory but in this volume, along with his co-editor Laurence Bobis and six other contributors, he has also tackled the lesser-known directors such as Mouchez, Tisserand, Loewy, and Baillaud, most of whom had a track record in observational astronomy of some kind. It is noticeable that in the list of directors after Andre Danjon (1945–1963), with the sole exception of Daniel Egret (2003–2011), this reviewer did not recognize any of the incumbent names. Since 1990 the head of the Paris Observatory has been called the President, perhaps emphasizing that the post is now strictly administrative. Although the number of departments which come under the aegis of the Observatory has recently been reduced, the number of staff, engineers, and doctoral students numbered almost 800 in 2010 and it would be interesting to know at what level the annual budget of the Observatory is set.

This is an enjoyable book — informative, profusely illustrated, and lightly written to appeal to the many visitors who pass through the gates every year. Perhaps it will trigger a more comprehensive and deeper history of a leading scientific institution. It charts the progress of the Paris Observatory through a long and sometimes very turbulent history, including the French Revolution, and the beginnings of mutual cooperation with the *Carte du Ciel* project in the 1880s, and onwards to today where the immense cost of astronomical instruments and research necessitates inter-governmental cooperation, *i.e.*, funding.

The index consists only of an alphabetical list of the names mentioned in the history of the Observatory but I was surprised not to see that of Paul Baize here. Although a paediatrician in normal life Baize was one of the greatest amateur double-star observers and made significant contributions to both the observational catalogues and the orbital catalogues in a long career using the 31-cm refractor in the West Tower and latterly the 38-cm refractor in the East Tower. — ROBERT ARGYLE.

We Are the Martians: Connecting Cosmology with Biology, by G. F. Bignami, (Springer, Heidelberg), 2012. Pp. 128, 23·5 × 15·5 cm. Price £26·99/$29·95/€29·95 (paperback; ISBN 978 88 470 2465 6).

This book is ideal for general readers who would like a simplified overview of some of the hot topics and issues in cosmology and 'contact astronomy'. In Sagan-like style, it offers facts and theories, as well as open-to-thought ideas on origins. Bignami's outline of what happened before the Big Bang, or the possibility of other universes, or the work of God, limits itself to the honest response "we simply do not know". He does not delve into the issue of exo-theology, or astro-theology, one of the considerations put forward by Steven Dick[1] for reconciliation of science with religion.

Within the ambit of ancient philosophical assumptions, Bignami refers to Epicurus, who subscribed to the atomistic theories of Leucippus and Democritus (worlds with suns, moons, and earths figure in the conjectures attributed to Democritus, 'the laughing philosopher'). The author also refers to Plato and Aristotle, labelling them as the forefathers of anthropocentrism, regardless of the fact that Aristotle considered the Pythagorean concept of fire and not the Earth at the centre of the cosmos; in that concept the Earth revolves around fire.

A large slice of the book reiterates pivotal theories as to what happened after the beginning of the Universe. By way of different topics, which include the light spectrum, nucleosynthesis, expansion of the Universe, generations of stars, innumerable galaxies, supernova explosions, interstellar molecular clouds, and exo-planetary systems, the reader is led to the key issue of whether the Earth is the only place with life. As to the possibility of extraterrestrial life in the Solar System, the author points to conditions on Titan and Enceladus as potentially compatible with the development of simple forms of life. Similarly, he refers to the possible development of life forms on Europa and Ganymede.

From the vantage point of Mars, in the context of the possibility of past or present forms of life, Bignami dreams a little and heightens the issue of whether an elementary form of life on rocks of Martian meteorites landed in Antarctica — so the title of his book. In the frame of meteorite Yamaha 593, as well as important ifs and buts, Bignami keeps this teaser alive. He also considers the presence of pristine organic material on comets passing close to the Earth.

A further topic of this book is the possibility of developed forms of life and technological civilizations beyond the Solar System. Keeping in mind the large numbers of extrasolar planetary systems, potential habitable zones, and the possibility of finding an exo-Earth in the future, this topic is of central importance for the detection of technological alien civilizations and how to contact them. As Bignami emphasizes, it is not clear whether one exists and what signal to expect. Maybe this is due to incompatibility of means of contact, or the longevity of alien technological societies, or that culturally as well as technologically we are alone. — P. Chapman-Rietschi.

Reference

(1) S. J. Dick, *Many Worlds* (Templeton Foundation Press, Philadelphia), 2000.

The Story of Helium and the Birth of Astrophysics, by Biman B. Nath (Springer, Heidelberg), 2013. Pp. 274, 23·5 × 15·5, Price £22·95/$39·95/€45·75 (paperback; ISBN 978 1 4614 5362 8).

Biman Nath clearly loves helium, and you very probably will too after reading this book. It is not possible to tell the whole story in a single volume, thus the *Hindenburg*, which burned, and the *Shenandoah*, which did not, appear only in the introductory chapter. And the US selling off its helium stockpile is relegated to a footnote.

Instead, the author has chosen to focus on the development of spectroscopy, especially solar spectroscopy, to the point where a chromospheric emission line at 587·6 nm could be cleanly separated from the sodium *D* lines and attributed to another element, confirmed by Ramsay with laboratory techniques in 1895, for which he received a Nobel Prize. Nath particularly wants to bust a myth that the discovery was made separately but simultaneously by Norman Lockyer and Jules Janssen in 1868, in connection with an Indian solar eclipse that year. The myth is not universal: I checked two elementary textbooks, two solar-physics books, and two histories of astronomy, and only one credits anybody by name except Ramsay, and that is John North's *Cosmos* (University of Chicago Press, 2008) which says "Lockyer", with which Nath would essentially concur.

The heroes along the way are Fraunhofer, Foucault, Bunsen and Kirchhoff, William and Margaret Huggins (I can accept her as a "hero" but draw the line at calling Marilyn Monroe "an actor"), then Janssen and Lockyer, Father Secchi, James F. Tennant, and Norman Pogson, those last two probably the least-well-known even to those of us who dabble in astronomical history. What Janssen and Lockyer did both do nearly simultaneously and independently was to show that you can see prominences without an eclipse, and get their spectra, by first dispersing sunlight and then putting the slit of a second spectrometer on a prominence. Their reports of this by chance reached the French Academy in Paris on the same day, hence perhaps, suggests Nath, the myth, which appears in at least one edition of the *Encyclopaedia Brittanica*.

I read a draft rather than the final volume, and so some of the charming glitches will probably not be waiting for you: a star named Zeta Puppies (well, there are dog stars); some slight confusion of 'our' Henry Draper of the *Catalogue* with his father, who was the 1879 founding president of the American Chemical Society; the claim that Doppler shifts change the colours of binary companion stars discernibly; and (my favourite) a statement about Tennant being offered the directorship at Madras: "He accepted the offer. Perhaps he was looking for a change of place, because his first wife had died that year. A replacement was eventually found, and Norman Pogson came to India as the Government Astronomer in 1861." Tennant indeed soon left Madras, but he did not remarry until 1867. Tennant urged Pogson to send a Madras expedition to observe the 1868 eclipse whose path crossed India, but it was Tennant himself who led the English expedition.

The volume describes the roles of a number of other folk in the process, several named Herschel, Pogson's son, and Mr. Ladd of London (maker of prisms). And George Airy rises to the opportunity of the eclipse with much the same expertise as he showed in the discovery of Neptune.

Do I have a conflict of interest concerning this book? At least three or four. The author and I crossed paths at the University of Maryland; I encouraged him when he thought of writing the book; read a draft copy with a flea comb (remember those Puppies) in hand; and borrowed some of his ideas in the process of assembling a paper (just freed from the limbo of refereeing) on the blurring boundaries among astronomy, chemistry, and physics associated with Moseley's 1913 paper on atomic number as more fundamental than atomic weight — with his* permission, let it be said. Still, I think typical ageing astronomers will enjoy the book, far more than the one by Schultz reviewed earlier in these pages (see **132**, 390). — VIRGINIA TRIMBLE.

*Nath that is, not Moseley, who died in 1915 at Gallipoli, while the referee of my second Crab Nebula paper was languishing in the trenches on the German side of the eastern frontier. The usual prize of a glass of wine is offered to the first reader who can persuasively claim to have known someone who knew someone who knew Moseley; better wine if you knew someone who knew Moseley!

Annual Review of Astronomy and Astrophysics, Volume 50, 2012, edited by S. M. Faber, E. van Dishoeck & J. Kormendy (Annual Reviews, Palo Alto), 2012. Pp. 652, 24 × 19·5 cm. Price $227 (print only for institutions; about £142), $89 (print and on-line for individuals; about £56) (hardbound; ISBN 978 0 8243 0950 2).

Well, *Annual Review of Astronomy and Astrophysics* has reached its half-century (which, as I write this — on 2012 November 18 — is somewhat better than most of the England cricket team have done in the first Test Match against India! [Things improved dramatically in the later matches! — Ed.]), and this certainly deserves a round of enthusiastic applause. Charting the progress of astronomy for 50 years with reviews of very high quality is indeed a valuable and laudable service, and I trust that *ARA&A* will go on to score their century.

As we have come to expect, this volume starts with a reflective article by one of the grandees of our science, and it is Jim Peebles' turn this year to outline the development of cosmology during the same lifetime as *ARA&A*. This well-referenced piece is thus a useful background that students starting in this arena would do well to read. The remainder of the volume spans the range from the very small (nuclear reactions) to the very large (galaxy clusters), and along the way I found three diagrams of special interest — at least to a retired star enthusiast!

But to start at the beginning, both of the book and of the formation processes that are considered later in the book, we have a review of magnetic fields in molecular clouds, by Crutcher, one result of which shows that star formation is influenced more by gravity than magnetism. Once things do start forming, at the small end of the size range we have planets, and their 'interaction' with discs around stars is discussed by Kley & Nelson; we also have exoplanets which can be found in the micro-lensing surveys outlined by Gaudi; next we come to low-mass stars and brown dwarfs, whose formation and early evolution is considered by Lubman, and it is here that I found my first special diagram: (Fig. 9, p. 95) an H–R diagram for the spectral types M6 to T2; there are not too many points on the 'cool' side yet but it will be interesting to see this fill as time goes on. Moving on to massive stars and their evolution towards supernovae, Langer has produced my second special diagram (Fig. 10, p. 141), neatly encapsulating the evolution of stars from around 10 to 100 $M_{\odot}$. Of course, stellar evolution requires nuclear reactions, and an update on reaction rates is presented by Wiescher *et al*. And while on the topic of nuclear reactions, you can read Watt's studies of nuclear bursts on the surfaces of accreting neutron stars, which can be manifest by their X-ray-burst emission.

Now on to the grander scale of galaxies, where we get a synthesis by Ivezić *et al*. of results, post-SDSS and other surveys, on the stellar populations of the Galaxy, and it all seems to be rather more complex than might hitherto have been thought, particularly as a result of mergers with nearby small galaxies. This work should be studied alongside the complementary paper by Kennicutt & Evans on star formation in the local group, based on observational and theoretical work of the last decade. Another, related component of galaxies is treated in this volume by Putman *et al.*, who describe the gas to be found in galactic haloes and its influence on star formation and thus galactic evolution. Closer to the centre of galaxies may be found black holes, and Fabian considers the effect of their jets and other emissions on the environment, in a discussion of feedback in AGN.

Before returning to the opening theme of cosmology (which I take to represent the grandest of scales), we have to examine the distribution of matter (dark and not-so-dark) revealed by the way galaxies cluster, and a fully referenced account is presented by Kravstov & Borgani.

But where, I hear you ask, is the third figure to have impressed your reviewer? It comes from an instrumentally-based paper by Davies & Kasper on adaptive optics, showing just how far this remarkable technology has come. And the picture in question shows the very centre of the Milky Way together with the 'visual' orbit of star 'S2' around Sgr A* (Fig. 9, p. 324), using data secured by the *NTT*, *VLT*, and the *Keck* telescope.

Volume 50 of *ARA&A* is a must for the serious astronomy library. — DAVID STICKLAND.

Comparative Magnetic Minima: Characterizing Quiet Times in the Sun and Stars (IAU Symposium No. 286), edited by C. H. Mandrini & D. F. Webb (Cambridge University Press), 2012, Pp. 460, 25·5 × 18 cm. Price £76/$125 (hardbound; ISBN 978 1 107 01986 7).

This 460-page hardbound volume is the proceedings of an IAU symposium held in Argentina in 2011. The meeting was centred around solar and stellar magnetic-activity cycles, and on the possibility of a trend in the Sun's magnetic cycle towards another grand minimum and what effect that may have on the Earth's climate. It is an excellent read.

Solar variability over hundreds of years can be detected through proxies in tree rings and polar ice sheets. Understanding the origin of solar magnetic activity requires a detailed description of how dynamo action arises through the interaction of magnetic fields with rotation, convection, shear flows, *etc.* Looking at our sunspot records and various proxies, two extended periods of solar minimum stand out: the Maunder Minimum in the mid-1600s and the Dalton Minimum in the early 1800s. An analysis of the cosmogenic isotope data provides a standard proxy for solar activity in the past. Such data show that phenomena comparable with the Maunder Minimum have occurred several times during the history of solar activity.

The recent solar minimum (between cycles 23 and 24) was the longest and deepest minimum in the past 100 years, which some authors suggest is the beginning of a new grand minimum. Of course, successive solar cycles differ slightly from one another, in amplitude, length, and other characteristics, so what was special about the last cycle? There are many questions that we need to address, *e.g.*, what is it about the solar dynamo that causes a grand minimum and what governs the length of the minimum and how does the Sun recover?

The proceedings from this meeting contain a wealth of interesting and thought-provoking papers. The first one to catch my attention was a paper by Leif Svalgaard, 'How well do we know the sunspot number?', which has major implications for predictions regarding Earth's climate, *e.g.*, with the new reconstruction, the modern grand maximum disappears. Many presentations following this talk showed plots of a steady rise in spot numbers over the past three hundred years instead of a plot which does not show any such trend. Rather disturbing. Although, the recent minimum between cycles 23 and 24 may have been different from others in the Space Age, a quick look at sunspot records clearly indicate other similarly deep minima.

Other papers discuss whether there exists a minimum state of activity even when sunspots are absent. The paper by Cliver suggested that the ground-state magnetic-field strength at the Earth is around 2·8 nT and that during periods of Maunder-type minima the Earth is embedded in just the slow solar wind.

The book contains a wealth of papers based on modelling the solar dynamo. An interesting conclusion is that a simple dynamo model based on differential rotation with random fluctuations of dynamo-governing parameters is able to reproduce some basic features of the solar magnetic-activity evolution, although much more work is needed. However, what can cause such variations leading to a chaotic modulation?

The second part of the meeting discussed solar-like and other late-type stars and what we can learn from those objects that would help us to understand the Sun better. The existence of star-spots is well established; in fact the first suggestion of star spots dates back to 1667, although in this particular instance it was not the correct interpretation. Solar-like dynamo and magneto-convective processes occur in more distant objects. Many late-type stars are known to exhibit cyclic magnetic activity. The proceedings contain several papers on this and on grand minima observed on other stars. With regard to the stellar grand minima, most of the work in this area has centred around Ca II *H&K* surveys, although with the presence of various satellites, X-ray data are now available. However, with limited satellite time coupled with cross-calibration problems, the ground-based surveys are still the best way forward, although as noted by Saar & Testa, more work is needed. Such data can be used to extend solar-dynamo models in different directions, *e.g.*, rotation rate, activity amplitude *versus* period relationships, *etc*. Overall, this is an excellent book for the library, containing a rich source of references. — GERRY DOYLE.

Stellar Structure and Evolution, Second Edition, by Rudolf Kippenhahn, Alfred Weigert (d. 1992) & Achim Weiss (Springer, Heidelberg), 2013. Pp. 604, 23 × 15 cm. Price £81/$119/€96·25 (hardbound; ISBN 978 3 642 30304 3).

The first edition (Kippenhahn & Weigert, 1980) was definitely the book to beat if you were planning to write a volume on stellar physics. This is somewhat less true of the second edition because the authors have chosen to continue to restrict their discussion to entities with nearly spherical symmetry. This excludes binary stars, rapid rotators, star formation with discs and jets, stellar seismology, and three-dimensional calculations for ejection of material by core-collapse supernovae. References to other texts on most of these subjects are provided, though other all-purpose stellar physics books (apart from one by Weiss *et al.*) go unmentioned. On the historical side, Chandrasekhar (1939), Clayton (1968) Eddington (1926), Jeans (1928), and Schwarzschild (1958) are cited.

The authors have chosen to put all of what they call "eternal truths" (basic physics, the *U–V* plane, Eulerian and Lagrangian coordinates ...) up front, without changing much from the first edition. "Mutable" truths follow, so that "The onset of star formation" does not appear until Chapter 26 and page 299, focussing largely on the Jeans criterion, with white dwarfs, neutron stars, and black holes treated rather briefly near the end.

Unquestionably, there is an enormous amount of physics and astronomy in this second edition, more, I suspect, than a typical first-year-graduate class, or instructor, can master in a semester. Some of the material cannot easily be found in other books, for instance, how a star gets through the helium flash (in the H–R diagram, Fig. 33.5 and in luminosity *versus* time, Fig. 33.9). The answer, not surprisingly, is "very quickly" but surprisingly, at least to me, with peak core luminosity in excess of $10^{10}\ L_{\odot}$, for a year or so.

Certainly, anyone planning to teach the subject should have the book, and a good use for it might be to pick out specialized items, like the helium-flash time-scale, the use of white-dwarf cooling to set a limit on the age of the Universe, and meridional circulation, to supplement some other text. The units are mostly cgs, with no tables of constants or equivalents. Having to figure out conversion factors is probably good for students and undoubtedly for instructors. — VIRGINIA TRIMBLE.

Space–Time Reference Systems, by Michael Soffel & Ralf Langhans (Springer, Heidelberg), 2013. Pp. 314, 23 × 14·5 cm. Price £67·99/\$99/€80·20 (hardbound; ISBN 978 3 642 30225 1).

The authors describe this volume as "an introduction to the problem of astronomical–geodetical space–time reference systems." It begins with classical concepts, moves on to relativistic time and space, and includes both worked exercises and MAPLE files. A successful reader will need both strong background and strong effort, but there are charming insights even for dabblers. The acronyms range from AC (Astrographic Catalogue) to VSOP (no, not the brandy, *Variations Seculaire des Orbites Planetaires*). If your goal is to get from an observed position in the sky at time T to a catalogue place at time T_0 with respect to mean equator and equinox of time T_0, you will need to correct for diurnal aberration and geocentric parallax, nutation, precession for the time interval ($T - T_0$), annual aberration and annual parallax, and proper motion for the time interval ($T - T_0$). At least the words might ring distant bells if you survived a lecture course on positional astronomy as good as that taught by Maud Makemson at UCLA in 1962.

Some of the pictures are marvellous — time-measuring devices from Harrison's marine chronometer to the Caesium-fountain clock in Paris; a cross-section of the Earth showing 14 things that affect its rotation (from viscous and electromagnetic torques at the core–mantle boundary to ocean loading and luni-solar tides); a very nice map of the tectonic plates and their motions as currently understood. Californians are likely to have heard of the Cocos, Nazca, and Juan de Fuca, but perhaps not the Rivera, and the map makes clear that, while the South Pole lives on the Antarctic Plate, the North Pole lives on the North American Plate. The actual purpose of the map is to illustrate "differences between VLBI drift velocities and NUVEL-1A plate model velocities". The units on the map (and the following one of differences between NUVEL-1A and APKIM2005) are cm/y, but the accompanying table shows angular-velocity vectors in degrees per million years (for geographic coordinates) and milli-radians per million years (for cartographic coordinates). Again, though the authors speak of an introduction, this is, I think, a book to which the reader must bring both lots of knowledge and lots of hard work, for everything interacts with everything else — plate motions also affect Earth rotation, and clock accuracy only exceeded irregularities in rotation rate from about the mid-1930s with quartz crystal clocks. — VIRGINIA TRIMBLE.

Modern Statistical Methods for Astronomy: With R Applications, by E. D. Feigelson & G. J. Babu (Cambridge University Press), 2012. Pp. 476, 25·5 × 18 cm. Price £55/\$90 (hardbound; ISBN 978 0 521 76727 9).

Statistics is a subject which can be confusing, as there are many quantities, procedures, and tests which might be computed, followed, or applied. For the astronomer who has data and who wants to know what could be done with them, this book is an excellent resource, as the possibilities are brought here under one roof in a text which conveys the enthusiasm of the authors for their subject. To go into detail of every technique would lead to an unmanageably large book, so the authors have adopted a heterogeneous coverage, with the underpinning ideas presented for some, and the rationale for a subset being explained, but generally it is not a book where theoretical development is presented in detail. Where they are included, the deeper discussions are rewarding and valuable. For the rest there are ample references to further reading. There are also occasional recommendations on which methods are to be preferred, and some useful comments on where common practice may be incorrect. A great strength of the book is the set of statistics programs in the freely-available R programming language which accompany each chapter, including analysis of simulated datasets. These complement the text extremely well and could certainly serve as useful starting points for readers in developing their own software, and it is commendable that all the data and programs are available for download from Penn State, as are thousands of R routines in the CRAN archives. Although there is a little discussion of Bayesian techniques, the approach is not one which Bayesians would necessarily follow, but this is a book which would grace anyone's shelves. — ALAN HEAVENS.

Advances in Machine Learning and Data Mining for Astronomy, edited by M. J. Way, J. D. Scargle, K. M. Ali & A. N. Srivastava (CRC Press, Boca Raton), 2012. Pp. 698, 26 × 18·5 cm. Price £63·99 (hardbound; ISBN 978 1 4398 4173 0).

The editors of this volume — three NASA researchers and a computer scientist — have done a good job in gathering knowledgeable contributors, but the resultant book does suffer from the heterogeneity of style, level, and notation that tends to afflict such multi-author volumes. Its stated aim is to foster the interdisciplinary collaborations between astronomers and computer scientists needed to see modern machine-learning techniques applied to solve 'big data' problems in astronomy, and it approaches that laudable and necessary task through a three-part structure: 'Foundational issues', followed by 'Astronomical applications', and, finally, 'Machine-learning methods'.

I am tempted to say that the first of these is superfluous, the second would be better replaced by a reading list of journal papers, and that there exist several good introductory machine-learning books that serve the purpose of the third better than it does; but that would be to ignore the quality of some of the individual contributions, especially in the second part, which provides about two-thirds of this book's almost-700 pages. Notable amongst these are two substantial reviews, by Jean-Luc Starck and collaborators on weak gravitational lensing and on cosmic-microwave-background data analysis, that are sufficiently comprehensive and well provided with appropriate references that they would nicely serve the proverbial new graduate student, while the chapters by Tamas Budavari on catalogue cross-matching and by Joshua Bloom and Joseph Richards on source detection and classification in time-series data are valuable summaries by the leaders in these domains.

Other chapters vary greatly in level, from the too superficial to the too specific, and, while the selection of topics for chapters does illustrate the range of astrophysical applications of machine-learning techniques, it does so in a somewhat random way that somehow fails to capture the nature of astronomical research in a manner that could help a computer scientist wanting to see how their data-mining expertise could be put to good use in astronomy. A similar heterogeneity is displayed in the third part, where some authors have made a great effort to introduce their topic to interested astronomers, and others appear oblivious to that intended readership.

I am sorry that the value of the chapters of this book varies so greatly, since I think its editors are correct to identify the training of astronomers in machine-learning techniques as a pressing need for our community, but this is not the book to make the breakthrough there, even if several of its contributors could possibly write such a book. — BOB MANN.

OTHER BOOKS RECEIVED

A New Perspective on Relativity: An Odyssey in Non-Euclidian Geometries, by B. H. Lavenda (World Scientific, Singapore), 2012. Pp. 668, 23·5 × 16 cm. Price £123/$187 (hardbound; ISBN 978 981 4340 48 9).

Through the use of non-Euclidian geometry, and without Einstein's equations, Levanda derives a new formalism for gravity and diffraction. This text for the mathematically inclined presents a novel outlook on General Relativity for the open-minded theoretician.

Introduction to the Anisotropic Geometrodynamics, by S. Siparov (World Scientific, Singapore), 2012. Pp. 302, 23·5 × 15·5 cm. Price £73/$110 (hardbound; ISBN 978 981 4340 83 0).

For those unconvinced by the need for dark matter to explain current observations of spiral-galaxy rotation curves and gravitational lensing, this book, by a researcher from Russia's State University of Aviation, offers an unorthodox approach which also impacts on the detection of gravitational waves.

THESIS ABSTRACTS

THE DYNAMICS OF PLANETS AND DISCS

By Alexander James Mustill

Recent years have seen the fulfilment of the long-held dream of discovering planets around stars other than our own Sun. These planets exhibit a dazzling variety of properties, and are in many cases accompanied by dusty debris discs similar to our own Asteroid and Kuiper Belts. With hundreds of examples of extra-solar planets and debris discs now known, the study of the interactions between them is of paramount importance. In this thesis, I investigate a few of the many types of planet–disc interactions.

First I investigate the ability of a planet to excite relative velocities in a debris disc by long-term secular perturbations. Such excitation may play a crucial role in the transition from a planet-forming disc in which relative velocities are low and collisions between particles result in growth, to a debris disc in which collisions are destructive. Hence, it has important implications for planet formation in the outer reaches of planetary systems and the production of the dust which is our only way of observing extra-solar debris discs. I find that massive planets can be effective at exciting the velocities even when very distant from a disc, for example, in the ε Eridani system where the semi-major axes differ by an order of magnitude. Hence, the collisional evolution of a debris disc cannot be treated in isolation from any planets in the same system.

Then I turn to investigate the process of capture into mean-motion resonances. These resonances are a common feature of both our own system and many observed extra-solar systems. The most effective means of populating them is by the convergent migration of two bodies. This migration may occur for many reasons, for example, through Poynting–Robertson drag on dust grains or through the tidal interactions of planets with protoplanetary gas discs. The outcome of an encounter with a mean-motion resonance depends on the migration rate and the particle's eccentricity, and hence observing resonant configurations in mature systems can tell us a good deal about the migration processes at work in protoplanetary discs. Resonant trapping is also likely to be responsible for the observed asymmetries in many debris discs, and these asymmetries provide clues to the presence of planets in those systems, and their possible migration histories. Using a Hamiltonian model I determine the outcome of a resonant encounter, and discuss applications to solar and extra-solar systems.

Finally I investigate the nature of orbits of bodies very close to perturbing planets. Such bodies are on unstable chaotic orbits, whose instability is driven by the overlap of mean-motion resonances close to the planet. I extend previous numerical and analytical studies of this chaotic zone to include the dependence of its extent on the particles' eccentricity, finding that the width of the chaotic zone grows with eccentricity. The extent of the chaotic zone determines the effect of the planet's sculpting of the inner edge of a debris disc, as well as the ability of a planet to feed material into the inner system. — *University of Cambridge; accepted 2012 April.*

A full copy of this thesis can be requested from: alex.mustill@uam.es

Radio Emission From Ultra-Cool Dwarfs and the Relevant Radiation Mechanisms

By Shenghua Yu

In this thesis, I discuss the radio emission from ultra-cool dwarfs (UCDs) and the radiation mechanisms, focussing on the causes and processes for the radio emission, as well as the consequences.

Radio observations since 2000 July indicate that cool objects (temperature < 2500 K) can emit intense energy radiation at radio frequencies with very high brightness temperature and high degree of polarization. Statistically the quiescent radio emission has been detected from only ~9% of UCDs with spectral type later than M7 in a total sample number of ~193. TVLM 513–46546, a long-term monitored M8·5 dwarf, not only shows rotation-modulated radio emission, but also presents a complex function of detected energy flux density, time, and frequency.

A coherent radiation process can interpret the high brightness temperature and high degree of polarization, with the electron-cyclotron maser being the best candidate to fit the observed relationships between the energy flux density, time, and frequency. Based on the electron-cyclotron maser emission and the rotation of the dwarf, I introduce an active-region model for TVLM 513–46546 in this thesis. In this model, given the physical properties of a plasma source and magnetic field on the dwarf, the properties of the active region are determined and discussed. The generation and propagation of X-ray emission is also discussed.

Numerical simulations have also been done for understanding the generation and evolution of the radio emission. After setting up a grid for the initial parameters of plasma and magnetic field and running several series of simulations, I present the evolution of the radiated electromagnetic fields and their energy, the kinetic energy of particles, the growth rate and polarization of the radiated waves, and the spectrum of the radiated fields. The results of the simulations and their physical implication are shown in the thesis. — *Armagh Observatory/Queens University Belfast; accepted, 2012 January*.

A full copy of the thesis is available at: http://star.arm.ac.uk/PhD-Thesis/thesis.html

OBITUARIES

Edwin Darnley Clements (*1923–2012*)

E. D. Clements, who died on 2012 October 23, was known universally as Clem. He was born in Farnborough on 1923 March 15 and as a boy took an early interest in engineering, constructing some large and complex Meccano models for which he won a number of prizes. One of these models was a transit circle complete with wheeled observer carriage. He remembered being shown the total solar eclipse of 1927 *via* reflection from the water in a bucket. In 1936, his father bought him a copy of *Norton's Star Atlas* as he had started to take an interest in the night sky from Aberdovey, where his family often went on holiday. A little later he was given a 2·5-inch telescope, but shortly after the outbreak of World War II he moved with his family to Aberdovey. Whilst there he found a 1-inch scale map of Aberystwyth on the beach, which fired him up to climb his first hill and which was to become a lifelong passion. He went up to Cambridge in 1942, to St Catherine's College, and emerged in 1945 with a BA in engineering. In 1946 he was employed at the Royal Aircraft Establishment in Farnborough; in 1948 April he was working as a surveyor for Great Western Railways at Paddington; but his last job commenced when he began work in the Meridian Department in the newly relocated Royal Greenwich Observatory at Herstmonceux in the Spring of 1956.

He became an observer on the *Cooke Transit Circle* and later moved to the Astrometry Department under the direction of C. A. Murray. At this time the 26-inch and 13-inch refractors were being used regularly and he became responsible for the practical aspects of this work including preparing the cards needed to help observers point the telescopes, find suitable guide stars, and details of filters required and exposure times. Early on, this project included plates for parallax determination and increasingly deeper plates to image newly found radio sources for which accurate optical positions were needed. Although several members of the Astrometry Department were employed in measuring plates, the vast majority was done by Clem using a Zeiss Comess measuring machine, later followed by a Zeiss Ascorecord. In the area of visual measurement, he had no equal. During the 1960s and 1970s he measured several thousand plates. He had a remarkable tolerance for doing repetitive work and doing it very well. The results appear in *Monthly Notices* — see, for instance, ref. 1.

At that time the computer that was used to reduce the plates required punched cards as input, and Clem would enter each x and y coordinate and star number onto a separate card using a hand punch. He also used that method to enter the details of all the plates taken at Greenwich and Herstmonceux, and that catalogue is now a unique resource for researchers of the future. Despite all that work, his diffident and unassuming character meant that he simply did not want to be interviewed for a higher post; he was happy doing what he knew best, which was observing and measuring photographic plates.

Clem's dislike of modern technology, despite his qualifications, lasted throughout his life. Each week, at the beginning of his appointment at Herstmonceux, he would commute from his home in Southampton by bicycle to his digs in Hailsham, a distance of 85 miles. He would have no truck with observing on the *Isaac Newton Telescope* because it had a computer. He never learned to drive and his bicycling holidays have passed into local legend. On one occasion having arrived back from a European trip, he explained that he cycled to the south of France instead of Switzerland as previously planned, because, as he pointed out, "The wind had changed"! In his lifetime, by his own calculation, he had covered at least 230 000 miles on two wheels. He retired on 1982 October 31 and moved to Guildford with his family where his new abode was sited yards from St Martha's Hill. No day passed when he did not make an ascent and descent (3720 in all according to Clem himself) except when he was off on one of his badger forays.

His two main interests in life were climbing hills and criss-crossing the country working on the ecology of badgers. He is on record as the 271st person to bag all the Munros — mountains in Scotland over 3000 feet — there were 276 of them when he achieved the feat in 1969. In fact he was about the 100th to ascend them all, having delayed notifying the relevant authorities. He was also the second-known person to complete ascents of the English and Welsh 2000-foot mountains, having completed this as early as 1953. By the time he was 83 the hill climbing came to a stop but he then started to compile extensive lists of the lower hills in the UK and in Europe as well. His badger diaries record that by 2000 he had visited 6000 setts, and had compiled a catalogue of 24 000 setts countrywide. What he did in each of these activities, let alone his achievements at Herstmonceux, would have meant a lifetime's work for anyone else.

In 1956 April, having just moved into digs in Hailsham, he met Sybil Goffe Cave, a friend of his landlady. They were married in 1960 June in Hailsham. They had a daughter, Mary Irene Goffe Clements, who was born on 1972 March 29. Both predeceased him. — R. W. ARGYLE.

Reference

(1) E. D. Clements, *MNRAS*, **197**, 829, 1981.

Colin Andrew Murray (1926–2012)

Andrew Murray died in Eastbourne on 2012 November 7. The son of a prominent Eastbourne architect, Andrew was born on 1926 January 7 and after attending Westminster School he won an Exhibition to Christ Church, Oxford, graduating in mathematics in 1947. He did his National Service in the army, serving in the Suez Canal Zone, and on his return to Eastbourne applied for a job at the newly-formed Royal Greenwich Observatory at Herstmonceux, obtaining a temporary Assistant Experimental Officer post, which was based at Greenwich.

His appointment began on 1950 February 10 working in the Meridian Department which, at that time, was under the supervision of R. T. Cullen who had been at Greenwich since the beginning of the century. Cullen was soon succeeded by L. S. T. Symms whose practical problem-solving ability was a great influence. At that time the work of the Meridian Department was two-fold: the reduction and publication of observations made with the *Airy Transit Circle* (*ATC*), and Andrew was allocated the task of reducing the transits.

Eventually he became a regular observer with the *ATC* and during that time he met Mary Nason, daughter of the Vicar of St. Alphege at Park Vista. They were married at St Alphege's Church on 1954 February 27. They moved from Greenwich in 1954 August and lived with Andrew's parents in Eastbourne until the marital home was ready — Peckwater Cottage in Chapel Row, close to Herstmonceux village.

He continued in the Meridian Department at Herstmonceux, observing with the *Cooke Transit Circle* and helping to produce reduction procedures for the newly-installed *Photographic Zenith Tube* which would be the main instrument for the determination of time and latitude variation. In 1960 July he moved to the Astrometry Department, then led by Alan Hunter, later to become RGO Director. In 1961, he accompanied the Astronomer Royal, Dr. Richard Woolley, to Mount Wilson to take photographs of open clusters at the 80-ft focus of the 60-inch. The night assistants respected him because he could point the telescope at the Moon, using only the Nautical Almanac. Previously they were used to searching around in the general neighbourhood until they hit it. He used the plates to measure the proper motions in M 67 and identify the stars which were not members of the cluster. He also measured the proper motion of ω Centauri but the observations were not accurate enough to identify individual members.

In 1962 he succeeded Dr. Hunter as head of the Astrometry Department, a post in which he would remain until his retirement in 1986. Andrew's work in astrometry covered an unrivalled range of activity, from being an observer with the *ATC* at Greenwich (a video, still shown daily at the RO Greenwich, shows him demonstrating how to observe with the telescope), to the development and scientific use of an automatic plate-measuring machine, *GALAXY* (*General Automated Luminosity and XY*), to scan Schmidt-plates in about 12 hours, and eventually to the space-based *Hipparcos* mission which was launched in 1989 (Andrew attended the launch). He played a crucial role in the early stages of the *Hipparcos* mission, ensuring a UK involvement in the data-processing at the Royal Greenwich Observatory through the Northern Data Analysis Consortium. It is fair to say that several of the principal scientists currently working on the *Gaia* mission would probably not be involved without the early initiatives of Andrew concerning UK involvement in space astrometry.

During his tenure there was an active observational component to the department. The 13-inch and 26-inch refractors were used to measure the positions of quasars and active galaxies in collaboration with Cambridge radio astronomers. When pulsars were discovered in 1967 the positions of the first four (called LGM 1–4) were sent to Herstmonceux with a request for deep photographic exposures on the fields with the 26-inch but with no explanation as to why. There was also an on-going parallax programme with the larger refractor which Andrew extended to the 98-inch *Isaac Newton Telescope* when it came into operation in 1967, occasionally riding in the prime-focus cage himself to take the plates. It was on one such occasion with the writer operating the telescope in the control room that Andrew said "In twenty years' time you will be reducing these plates", but by the mid-nineties astrometry (and the *INT*) had moved on.

The work with *GALAXY* concentrated on two large projects. The first was re-measurement of the second *Cape Photographic Catalogue* stars — a total of 5280 plates covering the southern sky in a four-fold overlapping corner-to-centre pattern in which he co-operated with Christian de Vegt at Hamburg. The second was a survey of about 6000 stars in an area of sky around the South Galactic Pole using a series of 70 plates taken with the *UK Schmidt Telescope* at Siding Spring. One objective was to test the proposition that a large number of plates taken over a short time base would give proper motions of equivalent accuracy to those obtained with a few plates taken over a long time base, but the main idea was to produce an unbiassed sample of astrometric and photometric data from which motions parallel to the Galactic plane, and the general density of stellar populations, could be studied.

In 1975, he and F. Graham Smith visited Brorfelde Observatory in Denmark for discussions about involving the astronomers there with the newly-emerging Northern Hemisphere Observatory on La Palma. The negotiations led to the installation of the *Carlsberg Automatic Meridian Circle* (*CAMC*) on La Palma and, with the subsequent collaboration of the Spanish Navy at San Fernando, led to a very successful and long-lasting project.

His book *Vectorial Astrometry*, published in 1983, was the first to use vector methods throughout and to offer a systematic discussion of General Relativity in astrometry. In 1988 he gave the Halley Lecture in Oxford with the title 'The distances to the stars'[1].

In 1967 the family moved to Quyddleswell Mount, a larger house near the village of Hooe, and on retirement he remained there and continued to work on the *Hipparcos* and *CAMC* projects in a consultative capacity. In his spare time he was a keen bell-ringer. On one occasion, when new ropes were required for the church bells, and it was important that they had any elasticity removed before they could be used, he asked Peter Willmoth to hang them in the *INT* dome with heavy weights attached. Later, he moved to Eastbourne where he was a member of the local Astronomical Society and attended its meetings from time to time. He also dedicated quite a lot of his spare time to music. He was Treasurer of the Eastbourne Symphony Orchestra and sang as a bass in a chamber choir associated with that orchestra called the Tudor Singers. They performed mainly sacred music and also madrigals and secular anthems.

He was a liveryman of the Worshipful Company of Clockmakers. Elected a Fellow of the RAS on 1952 January 11, he served as Foreign Correspondent (1975–1977), and was a regular attender at the RAS Club dinners. He was an Editor of this *Magazine* from 1961 until the end of 1966. Between 1976 and 1979 he was President of IAU Commission 24 — Photographic Astrometry. He was appointed Visiting Lecturer at the University of Sussex in 1972 and gave several series of lectures to the MSc course on Galactic astronomy jointly with Derek Jones. From 1978 until his retirement he was a Visiting Reader.

He had a wry sense of humour. Once at the RAS, Fred Hoyle was giving a lecture on cosmology with the aid of an overhead projector where the acetate sheet could be moved along on rollers. Fred gave a violent turn on the handle and the acetate roll broke from one end and smartly rolled itself up. Andrew promptly remarked "He's reached a singularity!"

His wife Mary and children Simon, Jane, and Richard survive him. — R. W. ARGYLE.

Reference

(1) C. A. Murray, *The Observatory*, **108**, 199, 1988.

Sir Patrick Alfred Caldwell-Moore (1923–2012)

Patrick Moore was a true giant of the astronomical world. With his infectious enthusiasm, boundless energy, and unparalleled communication skills, he inspired generations of astronomers — both amateur and professional — and raised the public awareness of the science of astronomy to heights that had never before been attained.

Born on 1923 March 4, in Pinner, Middlesex, he was brought up in East Grinstead, Sussex. Between the ages of 6 and 16, he was frequently ill because of a heart condition and so was educated mainly at home. When he was six years old, his mother presented him with a copy of *The Story of the Solar System* by George F. Chambers, published in 1898; that was the book that sparked his lifelong interest in astronomy. He applied himself assiduously to the task of getting to know his way around the sky, and by 1934 had scraped together sufficient funds to buy the 3-inch refractor which enabled him to begin to study in detail the Moon and planets. He joined the British Astronomical Association in 1934 at the age of 11, and presented his first paper, 'Small craters in the Mare Crisium', in 1936.

He served in the Royal Air Force during the Second World War, flying as a navigator on bombing missions; one way or another, he had what he described as "an interesting war". After leaving the RAF he declined to take up a place at Cambridge because he could not bring himself to apply for a government grant. Instead, he worked for a time as a prep-school teacher. Following the publication of his first book, *Guide to the Moon* (which subsequently ran to eight editions) in 1953, he resigned from his teaching post and devoted himself to a career as a freelance writer. *Guide to the Moon* was soon followed by further books, notably *Guide to the Planets* and *The Amateur Astronomer*, an indispensable 'bible' for budding (and established) amateur observers. With his writing career firmly on track, he continued to be an assiduous, painstaking, and accurate observer. He paid special attention to the areas around the lunar limb, which were revealed by librations. His charts of those areas were consulted by Soviet space scientists during the *Luna* programme. Always active within the British Astronomical Association, he served as Director of the Mercury and Venus Section, Director of the Lunar Section (twice), and as President (from 1982 to 1984).

His big breakthrough came in 1957 when he was invited by BBC producer Paul Johnstone to present a series of programmes, to be broadcast once every four weeks, entitled *The Sky at Night*. The first programme, which came out on 1957 April 24, featured the appearance in the evening sky of a bright comet — Arend-Roland. One of the early highlights of his television career came on

1959 October 24, when the Russians provided copies of the first grainy images of the far side of the Moon, obtained by the *Luna 3* spacecraft, just in time to be shown for the first time live on that evening's *The Sky at Night*. Among other pioneering ventures were his successful television coverage of a total solar eclipse from the top of a Yugoslavian mountain in 1961 February, and a first attempt later that year — though badly frustrated by clouds — to broadcast direct images of Jupiter and Saturn viewed through a 24-inch telescope.

In 1965, he accepted an invitation to become the first Director of the fledgling Armagh Planetarium in Northern Ireland, but resigned from that post in 1968 and returned to his home county of Sussex, moving into the delightful thatched house in Selsey, which was to be his home for the rest of his life. Very soon afterwards, he became a key member of the BBC team that covered the Apollo missions, from the first circumlunar flight of *Apollo 8* in 1968 December to the final landing mission of *Apollo 17* in December 1972.

Patrick Moore remained at the helm of *The Sky at Night* right up to the time of his death, having missed (due to a severe bout of food poisoning) only one of the more than 700 programmes that had been broadcast up to that time. Over the course of those 55 years he proved himself to be a truly exceptional guide to the world of astronomy. He explained the basics and new discoveries alike with clarity, enthusiasm, and gusto, drew the best out of the many guests who graced his programme, enchanted millions of viewers and enticed many of them to get out and see for themselves the delights that the night sky holds. *The Sky at Night* is without doubt the longest-running regular television programme with the same presenter — a record that is unlikely to be broken any time soon, if ever, and a testament to Patrick Moore's unique flair and broadcasting style.

He was a co-founder, and a former President, of the Society for Popular Astronomy (which originally was called The Junior Astronomical Society), which celebrates its 60th anniversary in 2013. He edited, or co-edited, the annual *Yearbook of Astronomy* for over fifty years from 1962, was the driving force behind the founding, in 1987, of the monthly magazine *Astronomy Now*, and was its first editor. He also played a major role in founding the BBC's *Sky at Night* magazine in 2005. Another of his achievements was his compilation of the Caldwell Catalogue — a list of 109 deep-sky objects accessible to modest telescopes, but which do not feature in the Messier catalogue.

His contributions to astronomy, broadcasting, and the public understanding of science have been recognized by numerous awards and honorary degrees. He was appointed OBE in 1968, CBE in 1989, and was knighted in 2001. He was awarded a BAFTA in 2002 (presented, to his great delight, by his good friend, *Apollo 11* astronaut Buzz Aldrin) for services to television. Of all his awards, perhaps the one he prized most dearly was his election in 2001 as an Honorary Fellow of the Royal Society — as an amateur astronomer he felt that to be recognized in this way by the pre-eminent scientific body in the land was an honour beyond compare.

He was a true polymath, with interests and abilities that ranged far beyond the world of astronomy. A talented self-taught musician who composed haunting piano pieces, rousing marches, waltzes, and three comic operas, he was an accomplished pianist and an excellent xylophone player whose on-stage credits include a solo performance at a Royal Command Performance and a duet with renowned percussionist Evelyn Glennie. A dedicated cricket enthusiast, he was a highly effective, if unconventional, leg-spin bowler who played regularly for his local team in Selsey and, on occasion, for The Lord's Taverners. Among other things, he was a county-standard chess player and a remarkably effective table-tennis player. Eccentric, opinionated, and certainly not politically correct (with firmly-held views that he was not in the least afraid to express forcibly — sometimes getting himself into hot water as a result), kind, generous to a fault, and intensely loyal, he had a tremendous sense of fun and a propensity for playing pranks, promulgating spoofs, berating authority, and for sending himself up.

Throughout his long career he endeavoured to reply personally to every letter that landed on his desk, and gave freely and willingly of his time, energy, enthusiasm, and resources to societies, organizations, and individuals who sought his advice or help. 'Farthings', his home for the last 44 years, was a welcoming place, where his hospitality was legendary. As his physical problems mounted in later life and his lack of mobility and dexterity became acute, he became intensely frustrated that he could no longer play the piano or xylophone, participate in cricket, nor eventually use his telescopes or the idiosyncratic 1908 Woodstock typewriter on which the great majority of his books had been written. But his brain remained as active and focussed as ever, and his work-rate nothing short of phenomenal. Until late 2012 November, when he was hospitalized for a couple of weeks, he was still working on book projects and revisions, having just completed a set of updates for the forthcoming paperback edition of his monumental *Data Book of Astronomy*.

He passed away peacefully at home on 2012 December 9, with close friends and carers around him, and with his beloved cat, Ptolemy, by his side. How best to sum up his life and influence? I can do no better than to quote words penned by his close friend — astrophysicist and legendary guitarist, Brian May: "Patrick is irreplaceable. There will never be another Patrick Moore. But we were lucky enough to get one." — IAIN NICOLSON.

Here and There

A PARADOX AT THE EDGE OF THE SOLAR SYSTEM

Voyager 1 is almost 18 billion kilometres from the earth, while its companion Voyager 2 is almost 15 billion years away. — *A&G*, **53**, no. 4, 4.9.

REPLAY FOR THOSE WHO MISSED IT?

The Perseid meteor shower takes place on the nights of the 10th and 12th. — *Daily Telegraph*, 2012 August 6.

OLD UNCLE TOM COBLEY AND ALL

Maraston C., Stromback G., Portsmouth I.-U.O., Kingdom U., 2011, *MNRAS*, 418, 2785 — reference in *MNRAS*, **421**, 314, 2011.

A NEW SOURCE OF FUNDING: ADOPT A MIRROR

. . . adoptive optics helps to recover a sharp image. — *Nature*, **491**, 291, 2012.