THE

OBSERVATORY

A REVIEW OF ASTRONOMY

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Vol. 126 No. 1193

2006 AUGUST

THE OBSERVATORY

Vol. 126 | 2006 AUGUST | No. 1193

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2006 January 13th at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

K. A. Whaler, *President*
in the Chair

The President. First, I want to wish you all a happy New Year. I need to make the usual announcements concerning admissions in person: new Fellows, or long-serving Fellows who have not previously taken the opportunity to do so, are warmly invited to sign the membership book after the meeting, across in the Society's apartments in the less formal atmosphere of the drinks party, where I will be very pleased to welcome them to the Society.

We can now proceed to the advertised programme. It's my great pleasure to invite our first speaker, Dr. Sheila Rowan from Glasgow, to talk about 'The current and future status of gravitational-wave astronomy.' I'd like to mention that Sheila is one of the 2005 Philip Leverhulme Prize winners. The remaining five prize-winners will be giving talks at the monthly A&G meeting in March.

Dr. Sheila Rowan. For many years physicists have been rising to the challenge of searching for gravitational waves. Predicted by General Relativity (GR) to be produced by the acceleration of mass, they have remained an enigma since 1917. What are gravitational waves? They can be thought of as ripples in the curvature of space–time or as tiny fluctuations of the direction of g, the acceleration due to gravity, on Earth. Why are we interested in their detection? To some extent to verify the predictions of GR — although given the success of other GR predictions being verified it will be a major upset if gravitational waves do not exist. More importantly we want to use gravitational waves as a tool for looking into the heart of some of the most violent events in the Universe and so start a new branch of astronomy.

Einstein described the gravitational field in a geometrical way as the curvature of the space–time 'surface' caused by the presence of mass. Clearly, in this picture accelerations of any masses in the system are likely to cause propagating disturbances or ripples on this 'surface', and these disturbances are gravitational waves. All gravitational effects are tidal in nature and can be best thought of as fluctuating strains in space–time. Detailed analysis shows that there are two 'orthogonal' polarizations of gravitational waves at 45 degrees to each other, of amplitude h_+ and h_X, and each of these is equal in magnitude to twice the strain in space in the relevant direction.

The effect of the two polarizations on a ring of particles is to distort a circular ring into an ellipse, then back to a circle through an orthogonally orientated ellipse then back to a circle again, and from this the principle of current gravitational- wave detectors — looking for changes in the length of the arms of Michelson-type interferometers — can be clearly seen.

Gravitational-wave signals are expected over a wide range of frequencies: from 10^{-17} Hz in the case of ripples in the cosmological background to 10^3 Hz from the formation of neutron stars in supernova explosions. In an analogy with radio waves, which are generated by the acceleration of electric charge, gravitational waves are generated by the acceleration of mass. When a mass is accelerated conservation of momentum ensures that another part of the system recoils and because, unlike charge, mass has only one sign the radiation from the two 'halves' of the system essentially cancels out. Or in more scientific terms, there is no dipole radiation to be expected. However, if the accelerating system undergoes a change in shape where there is a changing quadrupole moment, then radiation of gravitational waves occurs.

Because of the very weak nature of gravity, signals produced by accelerating systems tend to be very weak. Indeed, the only sources of gravitational waves which are likely to be detected are astrophysical in origin, where there are potentially huge masses accelerating very strongly. The most predictable sources are binary star systems. However, there are many sources of much greater astrophysical interest associated with black-hole interactions and coalescences, neutron-star coalescences, low-mass X-ray binaries such as Sco-X1, stellar collapses to neutron stars and black holes (supernova explosions), rotating asymmetric neutron stars such as pulsars, and the physics of the early Universe. The signals from all these sources are at a level where detectors of very high strain sensitivity — of the order of 10^{-23} over relevant timescales — are required, and such detectors may be on the ground or in space.

There is currently in operation, or in the final stages of commissioning, a network of gravitational-wave detectors, each of which is based on using laser-interferometric sensing to detect the changes, induced by gravitational waves, in the relative arm lengths of large-scale variants of Michelson-type interferometers, where the arms are formed between freely-hung mirrors.

The American *LIGO* project comprises two detector systems with arms of 4-km length, one in Hanford, Washington State, and one in Livingston, Louisiana. One half-length (2-km) interferometer has also been built inside the same evacuated enclosure at Hanford. Construction of *LIGO* began in 1996 and progress has been outstanding with operation at instrumental design sensitivity now having been achieved. The French/Italian *VIRGO* detector of 3-km arm length, at Cascina near Pisa, is close to completing commissioning, and the Japanese *TAMA 300* detector, which has arms of length 300 m, is operating at the Tokyo Astronomical Observatory.

All these systems are designed to use resonant cavities in the arms of the detectors and use standard wire-sling techniques for suspending the test masses. However, the German/British detector, *GEO 600*, is somewhat different. It makes use of a four-pass delay-line system with advanced optical signal-enhancement techniques, utilizes very-low-loss fused-silica suspensions for the test masses, and is expected to reach a sensitivity at frequencies above a few hundred Hz close to those of *VIRGO* and *LIGO* when they are in initial operation. *GEO* is now fully built and its sensitivity is being continuously improved. Currently it is within a factor of five of design sensitivity over a significant fraction of its frequency range.

Four science runs have so far been completed with these new interferometric detectors. All have involved the *LIGO* detectors, and two have involved the *GEO* and *TAMA* detectors. New 'upper limits' have been set on the strength of gravitational waves from a range of sources: coalescing compact binaries, pulsars, burst sources, and a stochastic background of gravitational waves, with 14 major papers published or in press since 2004 resulting from the work of a collaboration of more than 400 scientists. The fifth science run of the *LIGO* detectors started on 2005 November 4 and is currently on-going with *GEO* having joined in 2006 January. This run will be the longest stretch of data-taking to date.

During the next few years we can expect to see searches for gravitational-wave signals at a sensitivity level of approximately 10^{-21} for millisecond pulses or close to 10^{-26} for pulsars, to take two examples. This latter level, equivalent to the neutron star having an ellipticity of $\sim 10^{-8}$, is at an astrophysically feasible level and thus the detection of gravitational waves from pulsars in the near term is a real possibility. Recent discoveries of additional compact binary systems have improved the statistics for the expected rate of binary coalescences detectable by the *LIGO* system by a significant factor, giving a plausible upper limit of approximately one per three years for binary-neutron-star coalescences and approximately one per year for binary-black-hole coalescences.

However, detection at the current level of sensitivity of the initial detectors is not guaranteed; thus improvement of the order of a factor of ten in sensitivity of the current interferometric detectors is needed to reach sensitivity levels where many signals are expected. Thus plans for an upgraded *LIGO*, *Advanced LIGO*, are already well formed, as are plans for an underground detector with cooled test masses to be built in Japan. *Advanced LIGO* will incorporate 40-kg fused-silica test-mass mirrors, suspended by fused-silica fibres or ribbons, along with an improved seismic-isolation system, and increased laser power of the order of close to 200 W. The upgrade is expected to commence in 2010, with full installation and initial operation of the upgraded system by 2013. At the same time, laboratory research is on-going on the concepts needed for future 'third-generation' detectors intended to be 100 times more sensitive than those currently in operation.

Perhaps the most interesting gravitational-wave signals (those resulting from the formation and coalescence of black holes in the range 10^3 to 10^6 solar masses) will lie in the region of 10^{-4} Hz to 10^{-1} Hz, and a detector whose strain sensitivity is approximately 10^{-23} over relevant timescales is required to search for these. The most promising way of looking for such signals is to fly a laser interferometer in space. *LISA* (*Laser Interferometer Space Antenna*) is being proposed by an American/European team; it consists of an array of three drag-free spacecraft at the vertices of an equilateral triangle of length of side 5×10^6 km. This cluster is placed in an Earth-like orbit at a distance of 1 AU from the Sun, and 20 degrees behind the Earth. Proof masses inside the spacecraft (two in each spacecraft) form the end points of three separate but not independent interferometers. *LISA* is expected to be launched around 2017 and to be producing data for up to ten years thereafter.

Some early relativists were sceptical about the existence of gravitational waves; however, the 1993 Nobel Prize in Physics was awarded to Hulse & Taylor for their experimental observations and subsequent interpretations of the evolution of the orbit of the binary pulsar PSR 1913 + 16, the decay of the binary orbit being consistent with angular momentum and energy being carried away from this system by gravitational waves. Thus it is now accepted that gravitational waves must exist unless there is something seriously wrong with General Relativity. The scientific community is poised now to herald their detection and the start of a new astronomy.

The President. Thanks very much, Sheila. We've got time for a couple of questions.

Mr. R. Barber. I haven't been to the Specialist Meeting, so this is probably something that everyone else already knows the answer to, but, unlike electromagnetic radiation, for which you can have a fairly good idea of spatial resolution, with gravity it's not as simple. What is the spatial resolution that you would expect to get with these detectors?

Dr. Rowan. Roughly about a degree is what we think we can achieve with a network of detectors. With more than one detector you can do triangulation, so we are able to do that with the network on Earth, and *LISA* also has an antenna pattern as it sweeps out.

The President. How long is a *GEO* run?

Dr. Rowan. Anything from a couple of weeks up to a few months. Ultimately the detectors will run continuously.

The President. And during that time are you sweeping out areas or just targetting a few specific sources?

Dr. Rowan. Well, it's not like a typical telescope, so essentially you see the whole sky. Any information about pointing has to be extracted from the data analysis, looking for modulations, say, due to the Earth's rotation.

The President. But you need that length of time to build up the signal-to-noise level?

Dr. Rowan. Yes.

The President. Well it's probably time we moved on. Congratulations once again on your prize and thanks for a very interesting talk. [Applause.]

A slight change of subject now! Our next speaker is Professor Mark Bailey from Armagh Observatory who is going to talk about 'The Armagh Observatory Human Orrery.'

Professor M. E. Bailey. These days, everyone is taught the principles of the Earth's place in the Universe: that our planet is one of nine traditional planets orbiting the Sun in the Solar System; that its nearly circular orbit lies in a plane (the 'ecliptic') that reflects the path of the Sun in the sky; that the orbits of the other planets lie very close to the same plane; and that the Earth takes a year of 365·25 days to revolve once about the Sun.

Contrast this with the results of casual observation: a planet that is very much at rest; stars and the Sun that appear to circle the Earth every day; and five classical planets that either stay close to the Sun in the sky (as with Mercury and Venus), or move slowly from west to east against the fixed stars, repeating their positions at intervals of several years or more.

The difficulty facing modern educators — one which resonates with one of the biggest paradigm shifts in science — may be described as the 'geocentric illusion'. Indeed, if one abandons the call to a higher authority or arguments by assertion, the points in question are among the hardest to explain in a simple way. As a result, there are many people, perhaps some among this audience, who really have *no idea* of the Earth's position and the positions of the other planets in 3-dimensional space.

The general problem can be illustrated by asking two very simple questions: (*i*) 'how far can you see on a clear day?'; and (*ii*) 'why do January mornings, as now, remain dark for so long after the winter solstice?' The answers depend on understanding the Earth's position and orientation in space and knowing a bit about its elliptical orbit around the Sun. Of course, a moment's thought will soon convince you that the Sun is the farthest object normally visible on a clear day, but people often argue whether the correct answer is a few miles — or even a few hundred miles — *i.e.*, to the most distant horizontal horizon. In turn, this is a lower limit to the radius of the celestial sphere. Similarly, the correct answer to the second question initially eludes most people, but once they start thinking they soon recall knowledge learned, but not understood, at school. In fact, most of us are natural Aristotelians, and we intuitively think of a geocentric model of the Universe, where the Earth is at rest and where the Sun, planets, and other Solar System objects move slowly against the fixed backdrop of a more distant 'celestial sphere'.

An orrery, which is a *dynamic* model of the Solar System, is designed to help us avoid this mistake, and to explain, in an informative and entertaining way, the heliocentric Solar System. The earliest such model was invented by the English clock-maker and inventor, George Graham (*c.* 1674–1751), around (or soon after) 1700. Graham gave a copy of his first model, or its design, to the celebrated London instrument maker John Rowley (1674–1728), later Master of Mechanics to George I. Rowley then made a copy for Prince Eugène of Savoy, and another for his patron, Charles Boyle, the fourth Earl of Cork and Orrery (1674–1731), which he presented around 1712 to Boyle's first son, John (1706/1707–1762), later the fifth Earl of Cork and Orrery. In this way, the device to illustrate the heliocentric model of the Solar System received the moniker 'orrery'. The idea was an immediate success, and many variants of the original model were soon under construction.

This brief history shows that there is much more to an orrery than meets the eye. Indeed, one of the more interesting parts of the story is the light that it sheds on the history of these islands and on the society of the day. The Boyle family, for example, has an extraordinarily rich heritage, with roots extending to the first, or 'Great' Earl of Cork (1566–1643). This remarkable individual, apparently a self-made man from Canterbury, Kent, rose from humble origins to become one of the richest men on the planet. Notwithstanding the orrery connection (and his many lifetime achievements), he is nowadays perhaps most widely known through the work of his seventh and youngest son, Robert 'the philosopher' Boyle (1626/1627–1691), the father of chemistry and one of the founding members of the Royal Society. Charles Boyle, although from a later generation, was himself a scholar, soldier, and statesman, and grandson of the Great Earl's third son, Roger Boyle (1621–1679), the first Earl of Orrery.

It is interesting to note that Charles Boyle's son, the fifth Earl of Cork and Orrery, subsequently married Henrietta (Harriet) Hamilton of Caledon, daughter of the first Earl of Orkney. He later acquired the Caledon Estate, in 1738, by marriage to the heiress Margaret Hamilton, following Henrietta's death in 1732. Any one of these names could be the point of departure for a piece of historical research in its own right. For those who collect coincidences, Caledon — where I lived for several years — is just a few miles from Armagh; and Henrietta Hamilton is buried near Taplow, Buckinghamshire, close to where I was born!

What then are the distinguishing features of the Armagh Human Orrery? In the first place, it is the first large-scale model of the Solar System to have been laid out with *precision*, so that 1 metre on the ground corresponds to 1 AU in space, *i.e.*, to a scale-factor 1:150 billion. This allows you to see at a glance not just the division of the classical planetary system into its two principal components, but also that the orbits are not quite circular, but elliptical. It also allows distances to be measured on the ground and converted accurately to distances in space. The enormous scale-factor reinforces another simple point about the Solar System — its size — and means that basic calculators simply run out of digits, forcing students to flex their mental muscles and practise the lost art of mental arithmetic.

Another feature of the Armagh Human Orrery is that the positions of the terrestrial planets are labelled on the ground every 16 days, starting from 2005 January 1. Those for the asteroid (1) Ceres are labelled every 80 days (*i.e.*, every five time-steps); and those for the gas giants, Jupiter and Saturn, every 160 days. The fundamental 16-day time unit was chosen so as to minimize the gradual accumulation of errors in a planet's position over many revolutions. The two comets, 1P/Halley and 2P/Encke, are also shown every 80 days, but with a 'zero' or start-tile corresponding to the time of their most recent perihelion passage.

Even with this optimized 16-day time-step, the positions of the planets on the ground, *i.e.*, as determined by moving from one tile to the next at regular 16-day time-steps, gradually get out of step with the corresponding ecliptic longitudes of the real objects in space. Such deviations can be accommodated by introducing occasional 'leap steps' (taking an extra step) or 'leap stops' (standing still for a step), analogous to the insertion of a leap day into the calendar every four years. With this device the Human Orrery is accurate for many decades either side of the present day. If required, much less frequent double leap steps or leap stops can be introduced for greater accuracy, analogous to the Gregorian reform of the original Julian calendar. However, if one requires the planetary positions at a time far removed from the present day, for example, to investigate the triple-conjunction theory of the Star of Bethlehem, it is simpler to compute the exact planetary longitudes for the time in question and convert these to a table of tile positions around the given date. These details provide great scope for advanced algebraic investigations of the orrery, while also introducing some of the intricacies of our modern calendar.

The fixed time-steps also lend themselves to the game of 'walking the orrery', designed to illustrate Kepler's third law. Here, members of a group stand on different planetary tiles, and move forward one tile at a time on the call of the group leader. Mercury whizzes round, while Venus, Earth, and Mars each move more slowly than the one before. In the outer Solar System, Jupiter and Saturn move hardly at all, there being 10 time-steps, or 160 days, between each tile on the ground. This entertaining activity brings home to people the speed with which Mercury moves compared to Earth, and shows how the planetary orbital periods vary with heliocentric distance.

The planetary tiles contain various pieces of information, not just the name of the object and the tile number (*i.e.*, the number of 16-day time-steps from the object's zero or start-tile), but the heliocentric distance (in AU), the ecliptic longitude (measured in degrees anticlockwise from the First Point of Aries), and the true anomaly (measured in degrees from the direction of the object's perihelion). This angle facilitates quantitative investigations to confirm the accuracy of Kepler's second law, *i.e.*, the law of equal areas.

Beyond the planetary tiles are two engraved stainless steel annuli. The first of these is marked with a scale of ecliptic longitude l, the direction of the First

Point of Aries ($l=0$), and the names and boundaries of the *thirteen* ecliptic constellations traversed by the Sun in the course of a year. From inspection, it is evident that the First Point of Aries currently lies in the constellation of Pisces and that the ecliptic constellations are of unequal length. This provides a jumping-off point to explain the concept of precession and why the twelve horoscopic constellations are invalid.

The outer ring provides direction pointers or 'signposts' to various objects lying close to the ecliptic in the wider Universe. These include the positions of Uranus, Neptune, Pluto, and Sedna on 2005 January 1, several bright stars, the direction of the galactic centre, galaxies such as M87, and a distant gravitational lens in Pisces. The outer ring can be used to describe which objects are potentially visible in the sky 'tonight', or at any other time, and to introduce the whole gamut of objects in the modern astronomical 'zoo'.

The wide variety of activities made possible with the Human Orrery include: investigations into which planets are visible in the sky at any time, for example whether Mercury and Venus are morning or evening 'stars', to the right or left of the Sun, respectively, as seen from the Earth's Northern Hemisphere; studies of planetary alignments or of planetary positions at the times of particular historical events; investigations into the ratios of the orbital periods of the different planets; calculations of the *speeds* of the planets in different parts of their orbits; and mathematical projects such as testing Kepler's laws, or investigating the properties of ellipses on paper and by direct measurement on the ground.

In short, the Human Orrery is an innovative educational tool with wide-ranging applications for explaining the positions and motions of the planets and other Solar System objects with respect to the Earth. 'Learning by doing' helps to instil in people's minds a picture of the heliocentric Solar System, and facilitates a deeper understanding of our changing position in space. It helps people to engage with subjects such as astronomy, space science, and mathematics, and encourages people to *observe* the sky in order to compare their observations with predictions made from the Human Orrery on the ground. Lastly, it opens the door to many interdisciplinary activities, is easy to make and use, and — like a sundial — can be realized in many different ways.

In conclusion, I should like to thank David Asher and Apostolos Christou for their contributions to bringing the Armagh Human Orrery concept to fruition; PPARC for seed funding to develop outreach materials for the exhibit; and the Northern Ireland Department of Culture, Arts and Leisure for their continuing support for astronomy at Armagh. More information on the Human Orrery is available at http://star.arm.ac.uk/orrery/.

The President. Thanks, Mark. Are there questions or comments?

Dr. G. Q. G. Stanley. With Mercury's orbit being run around so many times, have you done anything to make sure that the artwork doesn't get worn away?

Professor Bailey. Ah, that is a good point. The tiles are made from two stainless-steel discs, 3 mm thick, welded together, and the top one has the inscription water-jetted into it. Inside those gaps is very strong resin, bonded with adhesive so that it won't come out.

The President. I suppose it's not practical to include moons in a human orrery?

Professor Bailey. It would be very interesting to make the Moon and the Earth properly, because one of the difficulties with the Earth–Moon system, as some of you probably know, is that the Moon's orbit is always concave with respect to the Sun. Almost no model will show this, because that scale of one metre per astronomical unit would put the Moon a quarter of a centimetre, or something of that order, away from the Earth, so it's very difficult to show. On a big model — on a different scale — you could make a human orrery to show the lunar phases and the lunar orbit with greater precision; you could put the Sun half a mile away. That too would be interesting to do.

The President. So all those models are horrendously not to scale, then?

Professor Bailey. Yes, like that first one I showed of the Rowley model, which is far from being an accurate scale. All the books, all the pictures that you see, they're equally poor in that regard.

Professor D. Lynden-Bell. Do you make the man or woman representing Mercury turn around one-and-a-half times per revolution around the Sun? [Laughter.]

Professor Bailey. Well, you can do that, yes. It's the person representing the Earth that has the greatest difficulty. [Laughter.] You're right, that's an example of an extension of this model. Depending on the group that you've got, you can talk about that; you can also ask in which direction does the Sun rise on Venus, and of course it's different to what we're used to.

Mr. Barber. It's a fantastic idea. I wondered if you've thought about doing it commercially with other people, say going to Chatsworth and persuading them to have one of these as a crowd-puller?

Professor Bailey. I'd be delighted and we'd be very happy to collaborate with anybody who wanted to manufacture such an example, because, in some sense, we've now done the hard work: we've made a prototype. Having made this, there are lots of ways in which we could have improved it to take account of some of the points that have been raised even here. Even just in the manufacturing, we would improve things if we were to do it again, so if anyone wanted to make a long-lived exhibit we could advise them. If, on the other hand, all you want to do is have a bit of fun, all you need are the planetary coordinates, some paint, and an open space, say a car park, and you can do that too. So you can make it very cheaply at one level, or you can make it in a much more design-conscious way at another level. The more such orreries there are, the better it is for the public outreach of our subject.

Mr. Barber. So how much would it cost for one that was going to last for some time?

Professor Bailey. This one cost a lot of money. The real cost is in the manufacturing. Stainless steel doesn't come cheap — it's quite a large area — and also the top layer is expensive in order to give it a high-grade finish. This orrery set us back, in total, around about £80 000. But that's not a big sum in terms of public art, or even laying of car parks.

Professor J. Barrow. Are you able to superimpose some extrasolar planetary dynamics onto this?

Professor Bailey. Do you want to give a specific example?

Professor Barrow. I was thinking of shapes of orbits and objects being very close to their parent star, things like that.

Professor Bailey. Yes, you could have another orrery, if you had a big enough area, and say: "here's the Solar System, there's a gap, and here's another stellar system." Another thing that you can do easily with this model is to have rope to represent, as it were, an asteroid or a comet or even a spacecraft trajectory. You just mark on the rope the 16-day time-steps so you can see exactly how a spacecraft, *Rosetta*, shall we say, goes from launch to rendezvous with a particular comet.

Professor Barrow. You could have a way of logging on the ground all the new extrasolar planet discoveries as they come up. [Laughter.]

Professor Bailey. That would be good, yes! An example in our Solar System is Sedna. Standing on the orrery looking at the Sun, one can point out where Sedna would be. We tended to choose objects that are actually in the ecliptic so you could stand at a particular time of year and ask the questions: What can I see tonight? What could I see in the morning sky, the evening sky? What can't I see because it's daylight?

Dr. P. J. Message. Mark, do you have anybody asking why there isn't a transit of Venus at every inferior conjunction?

Professor Bailey. Only you! [Laughter.] Yes, that's a good question. Well, you know, it's not exact is it? But we did reproduce the transit of Venus of 2004 June 8.

The President. That's a good note on which to stop. Thanks again, Mark. [Applause.] Our next speaker is Professor Henny Lamers from Utrecht, with a very long title that I'll leave him to read!

Professor H. J. G. L. M. Lamers. My title is [speaking very rapidly] 'The most metal-poor stars in the Universe, interstellar depletion, λ Boötis stars, mass loss from Sirius, comets around β Pictoris, halo stars, and everything in between.' [Laughter.] I can speak that fast, but unfortunately only in Dutch! [Laughter.]

Extremely-metal-poor stars in our Galaxy might be the relics of the epoch of the first star formation. The study of their abundances can provide information about the early chemical enrichment of the Galaxy.

In 1986, the star HR 4049, in the galactic halo, was discovered to have an extremely low Fe abundance. This star turned out to be a post-AGB star with a number of peculiar characteristics: extremely low abundances of Fe, Ti, Cr (10^{-4} to 10^{-3} times the solar values), about normal C and S abundance, and a very strong infrared excess due to dust. Soon thereafter, the star was found to be a binary with a strongly elliptical orbit and an Hα line profile that varies with the orbital period of 430 days. The circumstellar matter is in a circum-binary ring that was formed during the previous evolutionary phase when HR 4049 was an expanding AGB star and transferred matter to its companion. The class of metal-poor post-AGB stars with similar characteristics now contains at least four more stars: HD 44179, HD 46703, HD 52961, and BD +39 4926.

The abundance pattern, *i.e.*, very low Fe, Cr, and Ti but normal C, S, and Zn, is qualitatively similar to that of the depleted interstellar gas. The depletion pattern of the interstellar gas is due to the fact that some elements (*e.g.*, Fe) stick more easily onto interstellar grains than others (*e.g.*, S, Zn). Mathis & Lamers and Waters *et al.* explained, in papers published in 1992, how the post-AGB stars can aquire this abundance pattern in their photosphere. They argued that the gas in the circum-binary ring is heavily depleted by the presence of dust. When the post-AGB star in its elliptical orbit approaches the circum-binary ring, it accretes matter from this ring. However, the radiation pressure from the accreting star removes the dust from the accretion flow and so the star accretes only the depleted gas onto its photosphere.

This mechanism also works for the last accretion phase of pre-main-sequence A-type stars, when the accretion rate is small and dust and gas can be separated by radiation pressure from the accreting star. There is indeed a group of young A-type stars with low metal abundance that shows the same abundance pattern as interstellar depletion: the λ Boo stars. The same mechanism will not work for accreting O and B stars, because they will destroy the dust, nor for the G and later-type stars, because they have convective outer layers that will mix the accreted matter with that of the convection zone.

Only ~ 1% of the A-stars are metal poor (including Vega). How does an A-type star lose its metal-poor outer layer? Gravitational settling or diffusion is not likely to work because the timescale is too short and most of the λ Boo stars are rapid rotators. Mass loss might remove the depleted outer layer. The mass-loss rate of only one A-type star is known: the mass-loss rate of Sirius from very-high-signal-to-noise spectra obtained with *HST–GHRS* has been found to be 10^{-13} to 10^{-12} $M_{\odot}$ yr^{-1}. Alternatively the metal-poor surface layer might be enriched by the bombardment of young A-stars by dusty comets. The multiple appearance of transient absorption components has been observed in the Ca II lines of β Pic. It is estimated that the star is bombarded by about 200 comets per year at an accretion rate of 10^{-18} to 10^{-14} $M_{\odot}$ yr^{-1} The high infall velocity prevents the separation of gas and dust, so the metals that were depleted onto the grains may still enter the photospheres of the A stars. The studies of the post-AGB stars and the λ Boo stars show that, although their spectrum is metal poor, they are not really metal-poor stars; only their photosphere is metal poor.

A new class of really metal-poor stars in the galactic halo was discovered recently. The very-metal-poor stars HE 0107–5240 and HE 1327–2326 both have a metal abundance of about 10^{-5} compared to the Sun. Both stars have a CNO abundance that is only 10^{-2} times as small as the Sun. In this case the absence of S and Zn lines suggests that the low metal abundance is not due to the accretion of depleted (dust-free) material. These may be really hyper-metal-poor stars. However, these stars still do not belong to the hypothetical first-generation Population III stars, because they contain considerable fractions of CNO. The two most likely explanations for the presence of these elements are: pre-enrichment of the interstellar gas by the products of low-energy supernovae or pollution from an AGB companion. (For a detailed description, see the review article by Beers & Christlieb in *Ann. Rev. Astr. & Astrophys.*, **43**, 531, 2005.)

The President. We have time for questions or comments.

Professor B. E. J. Pagel. What's the binary status of the λ Boötis stars? Are some of them binaries? None of them binaries?

Professor Lamers. None of them. But several of them have circumstellar dust, which is from their formation.

Dr. D. McNally. With such wonderfully clean spectra, do any of these stars show diffuse interstellar bands?

Professor Lamers. I don't know. We haven't seen them; we haven't looked for them, but they don't really stick out at all.

Professor I. W. Roxburgh. I would like to ask about the A stars. Do you dismiss the effect of diffusion in the surface layers?

Professor Lamers. Yes, I think that's probably not a solution. The reason is that some of these A stars are very young and almost all of these λ Boötis stars are rapid rotators, except Vega, and if a star is a very rapid rotator, that's not a good condition for diffusion.

The President. Any more questions or comments? Right, well thank you very much. [Applause.] Our last speaker this afternoon is Professor Gordon Bromage from the University of Central Lancashire, who is going to talk about '*SALT*: the *Southern African Large Telescope*.'

Professor G. Bromage. [The speaker described the history, development, and mission of the recently inaugurated *Southern African Large Telesope* (*SALT*), a 10-m-class telescope sited on the Sutherland plateau in the Northern Cape, South Africa, about 370 km NE of Cape Town. Its mission is two-fold: to provide a front-ranked, world-class large telescope facility in the Southern Hemisphere; and to be the focus for collateral benefits for Africa through industrial and educational empowerment of the previously disadvantaged communities, including public outreach and education.

The design concept incorporates a telescope with a spherical mirror, steerable in azimuth with a fixed elevation of 37 degrees. The *SALT* design was based on the *Hobby-Eberly Telescope* (*HET*) at McDonald Observatory, Texas, but every component has been redesigned for improved performance. The primary mirror, like that of *HET*, has 91 one-metre segments, all identical. The main alignment of the primary mirror is achieved using a tower (CCAS tower) whose apex coincides with the centre of curvature of the spherical mirror. Accurate alignment can be checked and maintained regularly during the night using capacitive sensors around the edge of each mirror segment. Correction for spherical aberration is done at prime focus, which also houses an atmospheric-dispersion corrector and the first-generation science instruments: *SALTICAM*, an imaging camera with an 8-arcminute field of view, and the *Robert Stobie Spectrograph* (*RSS*), an imaging spectrograph named after the late Director of the SAAO, who had been a leading figure in the development of *SALT* for some years. A fibre-fed high-resolution spectrograph will be installed within the next couple of years.

The speaker emphasized the efficient management of the building of the telescope, which had led to its completion only a few months late, with first light being achieved just five years after ground-breaking, and only 0·2% over the US$20-million construction budget. About one-third of the money for the project has come from the South African National Research Foundation (NRF), with the rest provided by other international partners, including a UK consortium of universities (Armagh, Central Lancashire, Keele, Nottingham, the OU, and Southampton). The construction of *SALT* was managed by a not-for-profit company set up for the purpose (SALT Foundation Limited) with its own Board of Directors and Science Working Group, and the partners own shares in the company and the assets. A ten-year agreement is in place with the SAAO for maintenance and running of the telescope.

The speaker also emphasized that a conventionally mounted telescope of *SALT*'s aperture could not have been afforded within the available budget. However, sky coverage is still good: the fixed-altitude design results in a sky coverage of about 70%, and maximum exposures of up to 2 hours, depending on the target declination. The telescope will operate mainly as a queue-scheduled instrument, chiefly for multi-object spectroscopy and polarimetry, and will also operate at high efficiency in the near UV, the mirror coatings yielding a total reflectivity of about 80% down to 320 nm.

The speaker noted the collateral benefits to southern Africa: the South African government had put in about one-third of the funding, but over 60% of the value of contracts was with South African companies. Educational benefits include schemes which have been set up for African PhD students to study in the USA and the UK, jointly funded by the South African NRF; visitor centres are also being set up. The South African government is encouraging African astronomers to use the allocation of South African telescope time, and collaborations are developing between countries within the consortium.

The speaker concluded the presentation by quoting directly from the speech given by President Thabo Mbeki at the formal inauguration of *SALT*, which took place on 2005 November 10: "This observatory is a place dedicated to the pursuit of knowledge. Its sole purpose is the discovery of the unknown, and therefore the further liberation of humanity from blind action informed by superstition that derives from failure to fathom the regularities and imperatives of the infinite natural world. ... Out of this place, enveloped by the quiet peace of the Karoo and its starlit skies, must and will come the message that thought is humanity's stepladder out of Hades — that ignorance is nothing but condemnation to live for eternity in the world inhabited by the souls of the dead. ... The great minds gathered here today to inaugurate the *Southern African Large Telescope* have the possibility to peer into ordinarily unimaginable vistas of time and space, to discover what the Universe was like when the first stars and galaxies were forming." The speaker noted that President Mbeki was also inspired by the fact that three million years ago, South Africa was home to a vulnerable new line of primates, the Australopithecines, which eventually gave rise to humans, and the oldest identifiable *Homo sapiens* fossils in the world have been found in South Africa: "... To us, as South Africans, it has seemed right that for us as human beings to continue the search for the origins of the infinite beginnings of the Universe, we should locate that inquiry, as represented by *SALT*, in the very geographic space that gave birth to *Homo sapiens*."]

The President. Thanks very much Gordon. We've got just a couple of minutes, if there are any questions or comments?

Dr. Stanley. I'm deeply impressed with what's been achieved in five years and with so accurate a budget estimation — that's the closest I've ever seen for anything; it's really quite amazing, a tribute to everyone involved in it. But with all these projects, one always comes out with something extra that one wishes one had known at the beginning. What was it that you learnt by the end of this project?

Professor Bromage. Well, the edge sensors are going to be absolutely crucial and they were delayed for quite a while. The prime contractor for that was Fogale in Paris and there was a lot of trouble with sub-contractors. So even if you've got as your project manager someone who's managed the military helicopters of the old South Africa, even if you've got an excellent management team, then of course things like that can still go wrong. The other aspect would have been to start work on the high-resolution spectrograph earlier, because a lot of us want to do high-resolution spectroscopy.

Professor Lynden-Bell. I'd just like to turn the clock back many, many years. One of the other contributions that the SAAO made in some respect was that it had the last South African government visit it. De Klerk, when he came, had been brought up within the confines of his church and the Afrikaner religion. He went away very worried by what he had learnt. Draw your own conclusions.

Professor Lamers. Is part of the focal-plane instrumentation moveable at all or is it completely fixed?

Professor Bromage. The prime focus? I didn't have time to go into this, but the tracker has to move to follow the object across the sky, essentially as it drifts across the mirror. So it has to move a couple of metres to an accuracy of 50 micrometres in three spatial dimensions.

Professor Lamers. How wide is the zone on the sky that can be observed?

Professor Bromage. Twelve degrees.

Mr. I. Ridpath. You say that the design was based on the original *Hobby-Eberly Telescope*. Comparisons are odious, but how does it compare with the original? You almost hinted that it's like the *Hobby-Eberly* done properly! [Laughter.]

Professor Bromage. Or, to put it another way, we benefited enormously from their successes and their failures. They were plagued by lack of funding; they didn't have any money for operations to start off with and, being completely innovative, there were lots of things they hadn't thought about or couldn't afford. So, even raising the telescope above ground-layer seeing — even dome seeing — they didn't properly deal with, but they're doing it now. They've virtually opened up the side of the dome, but *SALT* has automatically-controlled louvres that control the airflow. All sorts of things were not done properly, even the coating of the mirror, so the general perception about the *HET* is that it was a failure, I guess; however, it was trail-blazing and, although each *SALT* sub-system has been redesigned, each is still based on the same principle.

Mr. Ridpath. Really, your advances can feed back to them, can't they?

Professor Bromage. Yes, that is what's happening. They are now installing edge sensors and they've tackled the dome seeing and many other aspects they've learnt from *SALT*. We've been closely involved with them all the time; they have a 10% stake in *SALT*.

Professor I. D. Howarth. Why is it a Southern African telescope and not a South African telescope?

Professor Bromage. It's a political statement and also a factual statement, in that it's intended to include sub-Saharan African astronomers, as few as there are, to encourage development and the development of education. That's now taking place with the training of PhD students, for example, from a wider area. Now, there are relatively few astronomers, as you must know, outside of South Africa, but the South African government has said that they will give them free time on the money put in from South Africa to come and collaborate in using *SALT*. They are definitely attempting to make it a Southern African project.

Dr. R. C. Smith. I can't really get my head around the geometry. What fraction of the sky can you actually see?

Professor Bromage. At any one time?

Dr. Smith. No, in total.

Professor Bromage. Oh, you can see 70% of the southern sky if you wait for the appropriate time. You can't see the region around the southern Pole and you can't see north of + 10 degrees in declination. That was chosen, in a sense, by having the tilt at that angle. The particular altitude that was chosen was initially a compromise to get the maximum viewing angle, but then modified by needing, of course, to look at the Magellanic Clouds.

Dr. McNally. I've been intrigued to find out, all the time I've been seeing pictures of the *SALT* enterprise — what's the little dome on top of the industrial chimney?

Professor Bromage. That's the CCAS tower: the centre-of-curvature alignment system. There's a service lift that goes up there too, but its prime purpose is that it's the centre of curvature of the spherical mirror, so once a day (originally it was hoped it would be once a week), you move the main mirror around to point at that and do an initial alignment of the 91 segments individually from up there.

The President. Well that was a fascinating insight into an interesting new facility. Thank you very much again. [Applause.]

It's been my ambition for a while to finish one of these meetings on time and I've failed again, but not by much. [Laughter.] I invite you all to join us across the road for the usual drinks party. This meeting will now close and the next one will be held on Friday, February 10.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2006 February 10th at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

K. A. WHALER, *President*
in the Chair

The President. Welcome to the 186th anniversary meeting of the Society, the one which contains the Presidential Address. You may have noticed the camera at the back. We are trialling webcasting at both the A & G and Specialist RAS meetings for those who cannot attend in person. It will be available in retrospect on the website, and if you or anyone else who cannot get here finds it useful, we would be most interested in some feedback.

It's time to move on to the scientific part of the meeting. The first speaker is Professor Frank Close from Oxford University.

Professor F. Close. Eighteen months ago the RAS asked me to chair a small committee to investigate the question, "Will having people in space materially advance our knowledge, especially of astronomy and astrophysics, in ways that are otherwise impossible, or less certain?" Also on the panel were Professor Ken Pounds, and Dr. John Dudeney of the British Antarctic Survey, whose work is concerned with remote environments similar to those which we wished to consider.

It took us ten months to complete the work and we reported to Council on October 18 last year with a press conference scheduled for four days later. Unfortunately, October 22 coincided with breaking news about bird flu in the Greek islands and almost all the scientific media took off there. Those who did report the results of the enquiry seemed to think that we had recommended that the UK pay 150 million pounds per year for 20 years in order to send humans to the Moon and Mars and perhaps bring them back again! We did not do that! [Laughter.]

Most scientists, initially including ourselves, thought that sending people into space was a total waste of money, but remarkably, at the end of the report period, our conclusions had changed dramatically. There were three basic questions which we addressed. What scientific missions can be considered for the Moon and Mars anyway? Can they be achieved by robots or do they require humans on the spot? If they do require humans on the spot, what are the showstoppers — in other words what are the practical and financial limitations?

In answer to the first question, we found that there was certainly first-rate science which could be done. On the Moon, which has a pristine surface, the events of the last five billion years can be investigated, and if we were to drill below the surface we could trace the history of the solar wind and hence the Sun itself. And imagine the cultural impact if we were to find amino acids in 4·5-billion-year-old rocks which may have been seeded by cometary material. The cores of the Martian icecaps also require drilling projects and this is beyond the capability of simple robots.

Can any of these tasks be done by robots alone? Robotics experts say that you need to be very clear about the questions which need an answer. The critical parameters are: how much detail do you need, how much do you want to know the answer, and how much are you prepared to spend to get the answer? How long can you give a robot autonomy and how big a perturbation from the norm can you tolerate? It is only when you know that, that you can decide whether robots are needed or not. Robots are good at repetitive tasks but if the lifetime of the project is expected to be long then you will need humans to sort it out.

We are decades away from robots that can match humans even in the laboratory, and the working robots of twenty years hence would be those which are state-of-the-art in the laboratory today. At a recent meeting in Cambridge, Steve Squyres declared that "Man is a self-balancing 28-jointed adaptor-based biped and electromechanical reduction plant with segregated storage of special energy extract in storage batteries for subsequent activation of thousands of hydraulic and pneumatic pumps with motors attached; 62000 miles of capillaries, millions of warning signals, and a universally distributed telephone system, needing no service for 70 years if well managed". [Laughter.] Professor Squyres was also of the opinion that a geologist could do in 30 seconds what one of his rovers would struggle to do in a day. There is plenty of computer power available but the problem is turning it into asking the sort of questions that the human mind can. Drilling in Antarctica is a good analogue of what needs to be achieved but what happens if something unexpected is discovered and a change of strategy is required? Then you will need humans there. For the Moon and Mars we are not persuaded that a robotic approach can deliver the requirements either now or in the forseeable future. Clear scientific goals need to be defined for any Mars mission.

To address the final question posed at the beginning of this talk — trips to the Moon are fine and also to Mars, as long as there is no major solar flare. Beyond Mars the radiation is beyond human tolerance levels. One benefit could be significant biomedical research on Earth. The finances are a serious problem and require co-operation on a global level. The amount required is beyond the physics and astronomy budget in this country. How much value do you place on unquantifiables such as public outreach and education? In the wider scientific context we need to discover whether life is unique to our planet and consider what the impact of space travel on human beings will be. What are the commercial implications and economic benefits? We also need to assess the impacts on human health and well-being outside astronomy. In terms of commercial and industrial impact, space clearly yields economic benefits with multiple factors. We need to balance the income *versus* the out-goings. Public interest has traditionally been greatest when humans are involved. Our enquiries confirm that this is still the case.

We also need to look at the political and international aspects. If, in 10 to 15 years, all the major nations except the UK are involved in a Mars mission what would the impact be in the UK in terms of education, industry, and economy? This is raising another question and is not a statement.

The panel is grateful to the RAS for giving us the opportunity to take a look at these questions.

Mr. R. Dymock. We do not have a JFK to commit this nation, but isn't the bigger problem on Mars more to do with pieces of rock falling onto the surface than radiation?

Professor Close. Keep your head down! The radiation aspect is more to do with the journey there and back. As you get further from the Sun, the greater danger comes from galactic cosmic rays. It is easier to shield against solar flares.

Professor M. Rowan-Robinson. You presented some fascinating arguments but I am very concerned. You are talking about international science but not comparing it with the project — you are looking in isolation. In the real world we have finite budgets for science and the effect of this gung-ho report will be to attract the attention of George Bush. He will tell NASA that it is top priority and money will be diverted from other sciences. I think that *HST* shows fantastic human interest in robotic astronomy. It captures the imagination far more than the *International Space Station*, which is a complete waste of money. I believe that this proposal will be a waste of money and will divert resources.

Professor Close. I agree with almost everything you have said. We had that question before we started and came to the same conclusion, and that is why we answered it the other way round. Are there reasons why you want to do the science anyway; can you only answer these questions with humans being there? If the answer to these is "yes" and you regard them as worthwhile, then this is the price literally and metaphorically that you have to pay. For Mars you need to have the scientific case clearly spelled out before you start — on previous proposals the science had just been tacked on.

Professor R. Kennicutt. Have the financial figures of 150 million pounds been subject to a cost analysis?

Professor Close. That is just taking the total cost that people think the mission is going to be and splitting the cost between NASA and ESA.

Professor Monica Grady. The report is about the scientific case for space exploration. The Council agreed that there is a scientific case but it wasn't *the* case for space exploration. There might not be a financial or a political case — we must make the other cases as well. We can't take the money out of the science budget.

Dr. I. A. Crawford. The *Hubble Space Telescope* has now been serviced four times, so that emphasizes the advantages of human involvement there. The truth is that without it, *Hubble* would have failed a decade ago. It clearly emphasizes the advantages of human versatility.

Professor Close. Can I just say, with regard to Mike's point, that is where we were one or two years ago. No-one has really investigated this question and we now have to face the consequences of this. The conclusions that we came to are the conclusions that you saw.

The President. Thank you again for a very interesting review and also for undertaking the work on behalf of the Society. [Applause.] The next speaker is Professor Rob Kennicutt from the Institute of Astronomy, Cambridge.

Professor R. Kennicutt. The *SINGS* project (*Spitzer Infrared Nearby Galaxies Survey*) is one of the six original Legacy science surveys on the *Spitzer Space Telescope*. *SINGS* is a comprehensive, multi-wavelength Legacy study of 75 nearby galaxies (all within 30 Mpc) that span the range of types, luminosities, and infrared properties found in the local Universe. The main goals of our team's work are to quantify the nature and the distributions of star formation in galaxies, and to understand better the physical interplay between star-forming regions and the surrounding interstellar medium (ISM) across a much larger range of interstellar conditions than can be traced in the Milky Way alone. However, the project is also designed to maximize the archival value of the data for studies of galactic structure and evolution in general, and to serve as a foundation for studies of star-forming galaxies in the distant Universe.

Our project includes imaging of galaxies in the 3·5–160-micron region and spectroscopic mapping of the galaxies and infrared sources within them at 5–100 microns. This rich spectral territory was first exploited by the ESA *Infrared Space Observatory* a decade ago. The key capabilities that *Spitzer* has added are the ability to image galaxies in the infrared with spatial resolutions comparable to ground-based optical images, and sufficient sensitivity to study spectroscopically the entire suite of infrared line diagnostics in normal galactic centres and star-forming regions, not only the brightest sources. As with most of the other *Spitzer* Legacy projects we have supplemented the infrared data with observations at a wide range of other wavelengths including radio continuum, H I, CO, optical and near-infrared broadband, Hα, Paα, ultraviolet, and X-ray. This has made the *SINGS* sample the most comprehensive multi-wavelength dataset ever assembled for nearby galaxies.

Over the wavelength ranges covered by *Spitzer* we can trace several distinct emission components. At the shortest wavelengths (below 5 microns) we mainly trace the photospheric emission of red stars, and the images we have obtained at 3·5 and 4·5 microns are enabling us to map the distributions of stellar mass in the galaxies and, for example, to trace the underlying spiral density waves that have been been difficult to study in detail previously. At longer wavelengths the flux is dominated by emission from interstellar dust. In the *Spitzer* maps we see two distinct components. At mid-infrared wavelengths the emission consists mainly of molecular-band emission from so-called polycyclic aromatic hydrocarbon (PAH) species, while longward of 20 microns emission from larger grains, probably mixtures of silicates and ices, dominates. *Spitzer* images taken in these different spectral regions show a dramatic contrast in structures. The PAH emission is highly filamentary, consisting of a combination of bubble-like structures that trace photodissociation regions around star-forming clusters, and more diffuse emission of dust associated with the general cold interstellar medium. By contrast the far-infrared emission is strongly clumped in the star-forming regions themselves (dust mixed with ionized gas in H II regions), as well as a very extended 'cirrus' component of dust in the general interstellar medium being heated by a mix of stellar types and ages. These various dust components had been identified indirectly through modelling of the spectral-energy distributions in previous studies, but with *Spitzer* we resolve each component spatially as well. One of the unexpected revelations from our observations has been the stunning degree of organized structure in the ISM that is revealed by the dust images.

The most important application of the data is for understanding star formation on galactic scales. We have long known that extinction by dust obscures roughly half of the visible and ultraviolet light of young stars in a typical present-day galaxy, and this fraction increases dramatically in the most active star-forming galaxies, as well as in many of the galaxies we observe at high redshift. However, correcting for this extinction has proven to be problematic. With *Spitzer* we are now able to map the emission of this dust on the spatial scales over which the dust redistributes this light, and on the scales over which star-forming events are triggered. This has made it possible to construct star-formation-rate (SFR) indices that use a combination of visible (*e.g.*, Hα) or UV-plus-infrared fluxes to obtain robust, extinction-corrected SFRs. We are also using our data to test the reliability of other infrared indices (for example, the mid-infrared PAH emission) as alternative SFR tracers for high-redshift galaxies. The key to these applications is the strong synergy between observations of galaxies in the infrared with those taken at other wavelengths, in particular the visible, ultraviolet, and radio. These are but the first preliminary results, as we are still obtaining and processing the *Spitzer* data, so I expect a rich harvest of results to come over the next few years.

Mr. C. J. North. Looking at the image of M51 along the axis of the spiral arm

I seem to see a rotation. Is that an artefact?

Professor Kennicutt. The fact is that the whole structure is differentially rotating. The spiral shape is actually a wave pattern in a standing wave in the disc, which is itself rotating with a speed that is smaller than that of the stars. The other feature I should have mentioned is that what most people notice as spikes are connected to the spiral arms. There is a paper by Chakrabarti & McKee which suggests that they are higher-order gravitational resonance waves in the disc. There is another paper by Kim & Eve Ostriker suggesting that they arise from magnetohydrodynamic instabilities. There is a lot of physics needed to understand these features.

Mr. M. F. Osmaston. Can you say whether the spike features represent a rupture in the spiral arms or are they increments in density?

Professor Kennicutt. In the case of spurs, the smaller features are certainly density enhancements of gas and dust, although you can actually create that shock. What is probably happening is that the ordinary rotation speed of the gas and dust is 200 km s^{-1} in M51 over most of the disc but the speed of sound, even in the ionized gas, is only 10 km s^{-1} or so. If you can create one type of disturbance, which can cause perturbations to the flow of anything more than about 10–14 km s^{-1}, you can create collisions and hence there will be a supersonic shock formed which will produce those narrow features. In the case of the main spiral arm the driver for that is a much smoother underlying density wave.

The President. Thank you very much again. [Applause.] I will now hand over the Chair to Monica Grady.

Professor Monica Grady. It's traditional to have the Presidential Address at this time of year, so it gives me great pleasure to introduce my former house-mate Kathy Whaler to talk about 'Using magnetic-field observations to probe the deep Earth'.

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

Professor Grady. Thank you very much, Kathy. [Applause.] I think that we may have time for one or two quick questions.

Mr. Osmaston. I have two points to raise. You mentioned the problem, if I understood correctly, that the present field-decay rate is ten times faster than would be expected, based on predicted core properties, if the MHD dynamo were simply switched off. Would it be correct that this problem would diminish, the smaller the dimensions of the volume in which the MHD process dominates? I believe that the motions of quite a thick layer at the outside of the core may be dominated by core-mantle coupling effects, so this volume cannot strictly be regarded as part of the dynamo. Would this help?

This brings me to my second point — that of core–mantle dynamic coupling. I like your favour of electromagnetic coupling for length-of-day variation, but there is an important overall dynamical requirement which one must not lose sight of. This is that if the secular westward drift at low latitudes is coupled in any way to the mantle, and is long-term, then, to avoid the impossible continuous transfer of angular momentum from core to mantle or *vice versa*, there must be other regions in which there is compensatory eastwards coupling. In 1968 I spent half a morning at Madingley Road trying (unsuccessfully) to persuade Sir Edward Bullard that his (1950) inferred uniform westward drift at all latitudes was thereby most improbable. Electromagnetic coupling seems most likely at high latitudes, where the field cuts the boundary steeply, but it may be mechanical at low latitudes, the difference in these mechanisms providing a fertile basis for mismatch and length-of-day variation.

Professor Whaler. To answer your second question first, Bullard postulated differential rotation in the outer core, so that the outer part was slightly slower, and the inner part slightly faster, than the mean rotation speed. The inferred eastward drift in the lower part of the outer core is also a feature of numerical dynamo simulations, which is what prompted the seismologists to search for evidence for the super-rotation of the inner core. You're right that the free decay time for the field depends on the dimensions of the features being considered — although the dipole strength is decreasing much faster than if the outer-core flow stopped, smaller-scale components would decay more quickly without a flow to sustain them. Most estimates of boundary-layer thicknesses at the top of the core are small, so I don't think core–mantle coupling effects will reduce the effective dynamo volume. Also, the decay rate of a feature depends on its spherical-harmonic degree (*i.e.*, spherical wavenumber), not its radial dimensions.

Dr. G. Q. G. Stanley. Events of the magnitude of Chicxulub are a good probe into the Earth's core. With the technique and resolution that you have, could you pick up other impacts on the Earth?

The President. That's a very good question. If it's big enough you should certainly be able to see it, but we can see nothing smaller than 400 km from space. It is fair to say that we know more about ancient impacts on the Moon and Mars than we do on the Earth. The crust of the Earth has been recycled and most of the impacts have been obliterated.

Mrs. Hazel McGee. At the beginning of your talk you mentioned reversals of the Earth's magnetic field. Can you tell us when to expect the next one?

The President. The next one is overdue, but it is not a linear process; if it carries on at the current rate, it would be due in about 2000 years time.

I think that everyone is now thirsty, including me, so it's time to close the meeting and go across to the drinks party. The next A & G meeting of the Society will be on March 12.

Summary of the RAS Discussion Meeting

THE LIFE AND DEATH OF STAR CLUSTERS

A Specialist Discussion Meeting of the Royal Astronomical Society was held on Friday 2006 January 13, organized by Dr. Richard de Grijs (Sheffield).

Most stars are formed in star clusters, and star-cluster systems are essential benchmarks in galaxy formation and evolution. Thus the life cycle of star clusters brings together several central problems current in astrophysics. The aim of this meeting was to trace their life history through the results of observational and theoretical research. It was also experimental, as the meeting was the first of its kind to be recorded and placed on the RAS's website.

The entire topic was reviewed by Professor Henny Lamers (Utrecht), who summarized the basic facts about the destruction of star clusters, including the transformation from the young-cluster mass function, as observed in interacting galaxies, to that of the old globular clusters of the Milky Way. He then considered how we could understand the distribution of age and mass in external galaxies, in terms of their star-formation history and cluster destruction. He showed that the destruction time scale depends on environment, as expected theoretically. In detail, he reviewed the way in which the mass and age of a star cluster could be determined, in the face of age- and mass-dependent selection effects. Averaging over a variety of galaxies that he and his collaborators had studied, he found that the data required the time scale for disruption to depend on mass as M^{γ}, where $\gamma = 0 \cdot 62 \pm 0 \cdot 06$. He noted triumphantly that this agreed remarkably well with the independent modelling efforts of Baumgardt & Makino, who found $\gamma = 0 \cdot 62 \pm 0 \cdot 02$. Finally, he passed on to the absolute time scale (taken as the time scale for disruption of a cluster with initial mass 10^4 solar masses), which is much smaller for interacting galaxies (such as M51) than for undisturbed galaxies (*e.g.*, the Milky Way), and explored two possible explanations: destruction (*i*) by passing molecular clouds or (*ii*) by passing through high-density spiral arms. It is not yet clear which of these two effects, if either, is responsible for the fast destruction of clusters in interacting galaxies.

Studies of young, massive star clusters focus on extragalactic objects, but there is one local competitor, called Westerlund 1. Observations of this object, discovered in 1961, were summarized by Dr. Simon Clark (Open University). Its estimated distance is only 5 kpc, but the visual extinction of about 11 mag. makes it hard to observe. Though numerous X-ray sources are probably associated with invisible low-mass stars, estimates of the total mass of the cluster depend on the extrapolation of the mass function below the masses detectable in the visual and IR. Therefore the total estimated mass of 10^5 solar masses is very uncertain, but it is a factor of ten larger than any other young cluster in the Milky Way, and this places Westerlund 1 in a régime which may be dense and massive enough for formation of an intermediate-mass black hole. Optical studies were initiated only in 2001. Recent observations have revealed that the stellar mass function depends on position, and that the cluster is spatially much more extensive than once thought.

In the next talk, Richard de Grijs returned to the theme of the life cycle of star clusters. He noted that young, massive star clusters (YMCs) are the most notable and significant end products of violent star-forming episodes triggered by galaxy collisions, mergers, and close encounters. The question remains, however, whether or not at least a fraction of the compact YMCs seen in abundance in extragalactic starbursts are potentially the progenitors of globular-cluster-type objects. If we could settle this issue convincingly, one way or the other, such a result would have profound and far-reaching implications for a wide range of astrophysical questions, including our understanding of the process of galaxy formation and assembly, and the process and conditions required for star (cluster) formation. Because of the lack of a statistically significant sample of similar nearby objects, however, we need to resort to either statistical arguments or the painstaking approach of case-by-case studies of individual objects in more distant galaxies. In his talk, the speaker discussed the variety of methods employed to shed light on this fundamental question, but also pointed out the pitfalls associated with each of these. However, he concluded that, despite the difficulties involved in this field, an ever-increasing body of observational evidence lends support to the scenario that globular clusters, which were once thought to be the oldest building blocks of galaxies, are still forming today.

The morning session concluded with a talk by Professor Melvyn Davies (Lund Observatory), in which he took a closer look at the stellar components inside old star clusters, especially the production of so-called 'exotica'. He began by pointing out that the cores of stellar clusters, for example globular clusters, have number densities of stars about one million times larger than the solar neighbourhood. This is sufficiently crowded an environment that stellar collisions will occur for up to 10% of all stars within the cluster core. A larger fraction of stars will undergo close encounters. More massive, single stars will also change into binaries. He then considered three classes of object whose presence depends on such processes in rather different ways. (*i*) X-ray binaries are relatively common within globular clusters. The number of X-ray binaries observed within various globular clusters increases with encounter rate, showing that a large fraction of the X-ray population seen today is formed from recent tidal captures or exchanges of single stars into binaries. (*ii*) Millisecond pulsars have also been observed in large numbers within stellar clusters. They are believed to be formed within X-ray binaries when accretion of material onto the neutron star spins it up to millisecond periods. However, the current population of X-ray binaries is insufficient to explain completely the millisecond-pulsar populations. A solution is that the neutron stars were spun up in the past, when exchange interactions would have tended to create binaries containing a neutron star and a star of intermediate mass; between the time of formation and the present epoch, the companion star will have evolved, transferring mass onto the neutron star as it did so. (*iii*) Blue stragglers are main-sequence stars lying above the current turn-off mass for a globular cluster. They have been found in all globular clusters, and, surprisingly, in roughly equal numbers. This can be explained, however, by combining a population formed by collisions and dynamical encounters with a primordial population formed *via* mass transfer in binaries, providing the latter population is depleted today *via* encounters with other stars.

After lunch, the second review of the day was offered by Dr. Simon Portegies Zwart (Amsterdam), who gave a theoretician's (or modeller's) view of the issues addressed by Professor Lamers. The main parameters which characterize new-born star clusters are the total mass and size, followed by density distribution and mass function. Each of these parameters is crucial for the further dynamical and stellar evolution of the cluster. Including binaries (or higher-order systems) together with the single stars is still rarely done in detailed simulations of dense stellar clusters, but is a very crucial step in allowing a direct comparison between numerical simulations and observations. However, the global evolution of the cluster seems to suffer little from the presence (or absence) of binaries and higher-order systems. Therefore he suggested it may be time again to simulate star clusters in a hybridized way, in which the microscopic physics is solved differently from the macroscopic cluster evolution.

It seems likely that intermediate-mass black holes may form in dense, massive star clusters, and may contribute to the population in galactic nuclei. The possible implications of these were taken up by Dr. Holger Baumgardt (Bonn). He recalled that, in the late 1980s, Hills predicted that runaway stars could be accelerated to high velocities by dynamical encounters with the supermassive black hole (SMBH) in the galactic centre, and Dr. Baumgardt noted that the recently discovered hyper-velocity stars in the galactic halo could be the first examples of such objects. At present two mechanisms are considered capable of creating hyper-velocity stars: encounters of stellar binaries with an SMBH and the acceleration of single stars by an intermediate-mass black hole (IMBH) orbiting the SMBH. In order to test which scenario is operating in the Galaxy, he and his collaborators performed a series of *N*-body simulations modelling the encounter of single stars with an IMBH. Their runs consisted of 10^5 stars distributed in a stellar cusp around a central SMBH of $3 \times 10^6\, M_\odot$ and IMBHs of varying mass. Their main aim was to test if IMBH ejection leads to predictions which can be tested once enough hyper-velocity stars have been found. They found that although IMBHs sink towards the SMBH due to dynamical friction, the orbital plane of sufficiently massive IMBHs changes only slowly due to encounters with the cusp stars. This leads to an asymmetry in the velocity distribution of ejected hyper-velocity stars since ejected stars gain velocities mainly in the direction of the IMBH motion. With the astrometric information provided by *Gaia* it will become possible to trace the motion of ejected stars back to the galactic centre and thereby test the IMBH scenario.

The final speaker, Dr. Dougal Mackey (IoA, Cambridge), showed how the effects of stellar-mass black holes may be observable in nearby cluster systems. He reviewed the fact that observations of massive stellar clusters in the Large and Small Magellanic Clouds reveal a striking trend in cluster size with age. Young clusters appear exclusively compact, but the spread in size (parametrized by core radius, r_c) increases strongly with age so the oldest clusters cover a very wide range $\sim 0 \cdot 5 < r_c < 15$ pc. He and his collaborators have been using large-scale *N*-body simulations to try and uncover the origin of this trend. One possible explanation is that core size increases strongly with time for some LMC and SMC clusters. Their *N*-body simulations suggest that physical evolution such as this can be driven by the dynamical effects of a population of stellar-mass black holes (mass $\sim 10\, M_\odot$) if they are retained from the supernova explosions of the most massive cluster stars. The holes rapidly sink to the centre of the cluster *via* dynamical mass segregation. Here, the density of holes soon becomes sufficient to initiate strong multiple-hole interactions, which steadily eject holes from the cluster. This central mass loss drives expansion of the core, which is of the correct magnitude and occurs on the correct time scale to explain the observed radius–age trend. Future work will aim to constrain this physics more completely, and will have implications for star and cluster formation (how does initial cluster structure affect early evolution; do we require a variable initial stellar mass function from cluster to cluster?) as well as stellar evolution (are stellar-mass black holes formed without strong natal kicks?). — STEFAN DEITERS & DOUGLAS HEGGIE.

PHOTOMETRIC OBSERVATIONS AND ANALYSIS OF THE NEAR-CONTACT BINARY XZ CANIS MINORIS

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We present new observations of XZ CMi taken at the National Undergraduate Research Observatory (NURO). A light-curve analysis and an up-dated periodicity study is presented. The period is decreasing and a low-amplitude 23-year oscillation is apparent. Both of these phenomena could be associated with the presence of stellar magnetic activity. XZ CMi is a short-period, Algol-type, near-contact binary.

Introduction

XZ CMi [P 3077, AN 318·1934, BD+04 1850, GSC 185 1659, α(2000) = $07^h\ 54^m\ 07{\cdot}056^s$, δ(2000) = $+03^\circ\ 39'\ 20{\cdot}32''$] is an Algol-type variable discovered by Hoffmeister[1] for which high-precision observations were taken by Wilson[2] in *B* and *V*. Rafert[3] modelled the light-curves with the Wilson code, and found a substantial degree of third light, which prompted Terrell & Henden[4] to try to resolve the visual companion (~2·5″) photometrically. They performed PSF-fitting to determine the standard magnitudes of each star (Table I) and their results showed a third light of about 15% in all filters. They believe that variability in the out-of-eclipse portions is due to large spots on the less-massive secondary component. Due to irregularities in their light curves, they only included data from phases 0·95 to 0·55 in their solution, so no complete light-curve solution has been presented.

TABLE I

Standard magnitudes for XZ CMi, comparison, and check stars

XZ CMi	*V*	*U–B**	SP+	*B–V**	SP	*V–R**	SP	*R–I**	SP	*V–I**	SP
ϕ = 0·0	10·668	0·333	G8	0·489	F7	0·212	F2	0·309	G0	0·531	F5·7
	±0·008	±0·021		±0·032		±0·028		±0·022		±0·036	
ϕ = 0·25	10·031										
	±0·018										
T&H	10·122	−0·043	F5	0·371	F2·5	0·197	F1·5	0·259	F6	0·456	F3
Check	12·769	0·822	K3	0·972	K3	0·474	K0·5	0·477	K3	0·932	K2
	±0·018	±0·039		±0·021		±0·023		±0·023		±0·032	
Comp	12·076	0·892	K3	1·029	K3·5	0·483	K1	0·502	K4	0·975	K2
	±0·027	±0·023		±0·019		±0·028		±0·018		±0·014	

*Average of all data, T&H = Terrell & Henden[4]
+Spectral type: from A. Cox (ed.), *Allen's Astrophysical Quantities* (AIP Press, New York), 1999.

Observational materials, reductions, and standardized magnitudes

Our CCD observations were taken during 2005 March 8–12 by DRF and NCH with the Lowell 31-inch reflector and a liquid-nitrogen-cooled CCD camera with a metachrome-coated TEK 512 × 512 chip. Standard $UBVR_cI_c$ filters were used. Our images include 25 observations in *U*, 78 in each of *B*, *R*, and *I*, and 87 in *V*. Our observations are given in Table II. The stars GSC 185 1591 [$\alpha(2000) = 07^h\,53^m\,59{\cdot}62^s$, $\delta(2000) = 3°\,39'\,30{\cdot}5''$] and GSC 185 1493 [$\alpha(2000) = 07^h\,54^m\,00{\cdot}99^s$, $\delta(2000) = 3°\,37'\,37{\cdot}0''$] were used as comparison and check, respectively; the finding chart is given as Fig. 1. The photometry attained high precision as attested by the standard error of a single observation, which is less than 1% in BVR_cI_c. Principal extinction coefficients were determined from comparison-star measurements and transformation coefficients were calculated from Landolt standard stars on our two photometric evenings, 2005 March 8 and 12 (Table I). Both the comparison star and the check star were found to be early K-type dwarfs. Since the spectral type of XZ CMi was confused by the presence of the third light, we used F2 V as our spectral type, from Terrell & Henden[4].

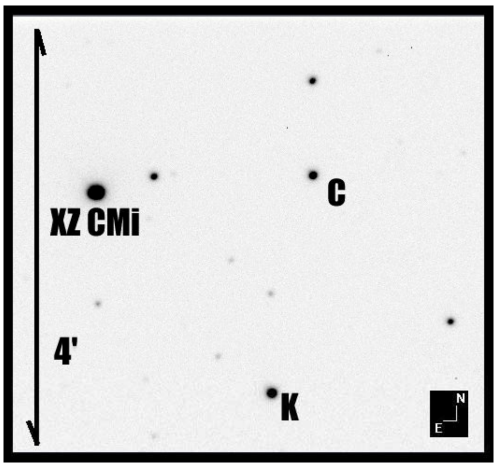

FIG. 1
Finding chart for XZ CMi.

TABLE II

Observed delta magnitudes (XZ CMi – comparison)
'HJD' = HJD – 2453400; DM = delta magnitudes

HJD	*UDM*	*HJD*	*UDM*	*HJD*	*UDM*	*HJD*	*UDM*	*HJD*	*UDM*
38·644	−3·0500	38·7756	−3·0930	40·6645	−3·006	40·766	−3·1490	41·7523	−2·5100
38·668	−3·0930	38·7983	−3·0870	40·7265	−3·109	40·783	−3·1630	42·6108	−3·0150
38·691	−3·1550	39·7645	−2·9850	40·6261	−2·479	41·699	−3·0420	42·6271	−3·0090
38·715	−3·1400	39·7884	−3·0170	40·6475	−2·781	41·717	−2·9400	42·6432	−2·9810
38·738	−3·1370	40·6097	−2·3330	40·7493	−3·126	41·735	−2·7520	42·6596	−2·9750

TABLE II (*continued*)

HJD	*BDM*	*HJD*	*BDM*	*HJD*	*BDM*	*HJD*	*BDM*	*HJD*	*BDM*
38·6300	−2·4610	38·7669	−2·5380	40·6193	−1·855	40·7757	−2·5540	41·7685	−1·8110
38·6368	−2·4680	38·7790	−2·5230	40·6296	−1·991	40·7861	−2·5470	41·7751	−1·8480
38·6469	−2·4810	38·7850	−2·5100	40·6361	−2·099	40·7939	−2·5510	41·7822	−1·9400
38·6538	−2·5030	38·7914	−2·5080	40·6509	−2·290	40·8000	−2·5320	42·6039	−2·4700
38·6598	−2·5150	38·8017	−2·4980	40·6573	−2·362	40·8072	−2·5160	42·6141	−2·4450
38·6712	−2·5320	38·8081	−2·4690	40·6680	−2·441	40·8141	−2·5240	42·6204	−2·4330
38·6777	−2·5230	38·8203	−2·4100	40·6744	−2·477	40·8210	−2·4980	42·6304	−2·4030
38·6842	−2·5330	38·8266	−2·3510	40·6851	−2·520	40·8273	−2·5020	42·6363	−2·4040
38·6943	−2·5480	39·7574	−2·3960	40·6919	−2·517	41·7020	−2·4950	42·6465	−2·4060
38·7010	−2·5440	39·7679	−2·4000	40·7025	−2·513	41·7097	−2·4600	42·6529	−2·4180
38·7074	−2·5630	39·7743	−2·4000	40·7197	−2·542	41·7199	−2·3850	42·6629	−2·4320
38·7181	−2·5660	39·7809	−2·4350	40·7299	−2·550	41·726	−2·3210	42·6729	−2·4520
38·7243	−2·5590	39·7918	−2·4510	40·7424	−2·550	41·738	−2·1820	42·6849	−2·4650
38·7309	−2·5670	39·7981	−2·4610	40·7528	−2·556	41·746	−2·0710	42·6908	−2·4800
38·7412	−2·5750	40·6030	−1·8630	40·7592	−2·555	41·756	−1·9110		
38·7608	−2·5600	40·6131	−1·8040	40·7696	−2·556	41·762	−1·8280		

HJD	*VDM*	*HJD*	*VDM*	*HJD*	*VDM*	*HJD*	*VDM*	*HJD*	*VDM*
38·6225	−1·924	38·7689	−2·020	40·6212	−1·423	40·7715	−2·044	41·7704	−1·355
38·6318	−1·942	38·7809	−1·998	40·6315	−1·559	40·7777	−2·042	41·7770	−1·403
38·6387	−1·977	38·7869	−1·992	40·6380	−1·611	40·7880	−2·032	41·7851	−1·512
38·6489	−1·984	38·7933	−1·996	40·6528	−1·812	40·7958	−2·032	42·5987	−1·952
38·6557	−2·012	38·8037	−1·982	40·6592	−1·868	40·8030	−2·034	42·6056	−1·906
38·6617	−1·983	38·8100	−1·942	40·6699	−1·935	40·8091	−2·016	42·6159	−1·891
38·6731	−2·017	38·8223	−1·892	40·6764	−1·958	40·8160	−2·008	42·6221	−1·871
38·6797	−2·025	38·8285	−1·840	40·6870	−1·989	40·8229	−2·000	42·6321	−1·847
38·6861	−2·024	39·7518	−1·851	40·6939	−1·992	40·8293	−1·985	42·6380	−1·846
38·6963	−2·028	39·7593	−1·860	40·7044	−2·000	41·6931	−1·982	42·6482	−1·853
38·7029	−2·040	39·7699	−1·883	40·7217	−2·019	41·7039	−1·959	42·6546	−1·866
38·7093	−2·047	39·7762	−1·904	40·7318	−2·036	41·7116	−1·929	42·6646	−1·888
38·7200	−2·057	39·7828	−1·922	40·7340	−2·031	41·7218	−1·861	42·6746	−1·917
38·7262	−2·049	39·7937	−1·941	40·7349	−2·041	41·7283	−1·795	42·6867	−1·943
38·7329	−2·057	39·8001	−1·960	40·7358	−2·039	41·7402	−1·670	42·6926	−1·956
38·7431	−2·052	40·5985	−1·462	40·7444	−2·046	41·7475	−1·563		
38·7563	−2·040	40·6050	−1·395	40·7547	−2·038	41·7576	−1·436		
38·7627	−2·030	40·6151	−1·372	40·7611	−2·047	41·7639	−1·372		

HJD	*RDM*	*HJD*	*RDM*	*HJD*	*RDM*	*HJD*	*RDM*	*HJD*	*RDM*
38·6236	−1·665	38·7643	−1·761	40·6167	−1·176	40·773	−1·775	41·7659	−1·161
38·6275	−1·675	38·7725	−1·745	40·6230	−1·236	40·78	−1·777	41·7725	−1·161
38·6342	−1·708	38·7824	−1·746	40·6336	−1·361	40·791	−1·762	41·7796	−1·205
38·6512	−1·750	38·7888	−1·737	40·6444	−1·486	40·797	−1·758	42·6015	−1·686
38·6572	−1·755	38·7952	−1·716	40·6548	−1·591	40·805	−1·746	42·6077	−1·645
38·6647	−1·760	38·8055	−1·709	40·6614	−1·633	40·812	−1·733	42·6179	−1·623
38·6752	−1·753	38·8155	−1·681	40·6719	−1·689	40·818	−1·738	42·6240	−1·600
38·6816	−1·763	38·8240	−1·617	40·6786	−1·721	40·825	−1·723	42·6338	−1·575
38·6878	−1·770	39·7548	−1·581	40·6894	−1·733	41·695	−1·729	42·6401	−1·588
38·6984	−1·794	39·7614	−1·590	40·6999	−1·744	41·707	−1·681	42·6504	−1·590
38·7048	−1·791	39·7717	−1·625	40·7172	−1·758	41·713	−1·655	42·6565	−1·599
38·7116	−1·789	39·7783	−1·656	40·7234	−1·758	41·724	−1·602	42·6665	−1·631
38·7218	−1·792	39·7853	−1·674	40·7399	−1·773	41·7317	−1·523	42·6785	−1·671
38·7284	−1·781	39·7956	−1·687	40·7462	−1·781	41·7430	−1·402	42·6884	−1·699
38·7347	−1·797	40·6005	−1·230	40·7566	−1·784	41·7492	−1·321		
38·7582	−1·779	40·6067	−1·171	40·7631	−1·782	41·7594	−1·185		

TABLE II (*concluded*)

HJD	*IDM*	*HJD*	*IDM*	*HJD*	*IDM*	*HJD*	*IDM*	*HJD*	*IDM*
38·6244	−1·402	38·7651	−1·490	40·6174	−0·975	40·7739	−1·531	41·7667	−0·921
38·6283	−1·418	38·7732	−1·482	40·6238	−1·027	40·7803	−1·528	41·7732	−0·937
38·6350	−1·435	38·7831	−1·474	40·6343	−1·147	40·7920	−1·503	41·7804	−0·984
38·6412	−1·443	38·7896	−1·483	40·6451	−1·255	40·7982	−1·504	42·6022	−1·408
38·6520	−1·507	38·7959	−1·457	40·6555	−1·339	40·8054	−1·513	42·6085	−1·364
38·6580	−1·505	38·8062	−1·443	40·6622	−1·385	40·8123	−1·494	42·6187	−1·344
38·6655	−1·520	38·8164	−1·412	40·6726	−1·441	40·8191	−1·502	42·6247	−1·315
38·6759	−1·519	38·8248	−1·374	40·6793	−1·456	40·8255	−1·485	42·6346	−1·301
38·6824	−1·512	39·7556	−1·316	40·6901	−1·482	41·6962	−1·446	42·6408	−1·312
38·6886	−1·531	39·7622	−1·334	40·7007	−1·485	41·7079	−1·445	42·6512	−1·325
38·6991	−1·540	39·7724	−1·372	40·7179	−1·515	41·7141	−1·413	42·6572	−1·323
38·7056	−1·542	39·7790	−1·397	40·7241	−1·507	41·7245	−1·311	42·6672	−1·383
38·7123	−1·540	39·7860	−1·414	40·7406	−1·521	41·7325	−1·266	42·6793	−1·417
38·7225	−1·537	39·7963	−1·444	40·7470	−1·536	41·7437	−1·123	42·6891	−1·448
38·7291	−1·547	40·6012	−1·002	40·7573	−1·528	41·7499	−1·052		
38·7589	−1·518	40·6074	−0·959	40·7638	−1·534	41·7601	−0·940		

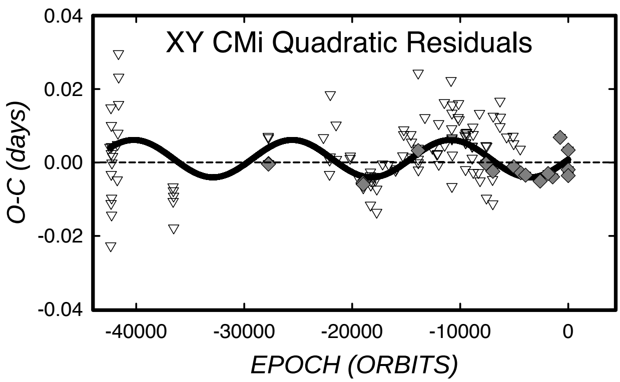

FIG. 2

Quadratic residuals of equation 2 and sinusoidal fit.

Periodicity

A thorough search of the literature reveals that some 127 times of minimum light have been determined[2–47]. However, photographic and visual timings show high scatter throughout the period diagram of XZ CMi (Fig. 2). Our new mean eclipse timings include HJD (Min I) = 2453440·6116 ± 0·0003, 2453441·7676 ± 0·0001, and HJD (Min II) = 2453442·6428 ± 0·0019. A linear fit to all available timings gives the following ephemeris, where standard errors are given in parentheses:

$$\mathrm{HJD}\ (T_{\mathrm{min\,I}}) = 2453441{\cdot}77769\ (\pm 0{\cdot}00075) + 0{\cdot}578809289\ (\pm 0{\cdot}000000044)\ E. \qquad (1)$$

The data show a parabolic trend so the following quadratic ephemeris was calculated:

$$\text{HJD}\ (T_{\min \text{I}}) = 2453441{\cdot}77121\ (\pm 0{\cdot}00075) + 0{\cdot}57880796\ (\pm 0{\cdot}00000010)\ E - 3{\cdot}5 \times 10^{-11}\ (\pm 0{\cdot}3 \times 10^{-11})\ E^2. \quad (2)$$

The *O–C* residuals for equations 1 and 2 are given in Table III. Such a negative quadratic term is not unusual for solar-type binaries. In addition, there appears to be a low-amplitude (0·0051 days, or a light-travel time of 0·9 AU) oscillation in the quadratic residuals:

$$\text{HJD}\ (T_{\min \text{I}}) = 2453441{\cdot}77225\ (\pm 0{\cdot}00125) + 0{\cdot}57880796\ (\pm 0{\cdot}00000010)\ E - 3{\cdot}5 \times 10^{-11}\ (\pm 0{\cdot}3 \times 10^{-11})\ E^2 + 0{\cdot}0051\ (\pm 0{\cdot}0007) \sin[4{\cdot}28 \times 10^{-4}\ (\pm 0{\cdot}1 \times 10^{-4})\ E + 6{\cdot}2\ (\pm 0{\cdot}2)]. \quad (3)$$

The standard error calculated from the residuals for the linear, the quadratic, and sinusoidal-quadratic ephemerides are 0·0113, 0·0089, and 0·0079d, respectively, *i.e.*, the fit steadily improves in each case. The sinusoidal fit to the quadratic residuals is shown in Fig. 2. The period of the oscillation is about 23 years. This cannot be due to a third body, not even a planet. However, one might expect a period of this order for a solar cycle. We should point out that the periodic fit is based largely on recent data covering less than a cycle. We believe that high-precision timings afforded by today's CCD detectors should be analyzed for the effect of magnetic cycles. From our *O–C* diagram we also note that timings from secondary minima may be less reliable.

The following linear ephemeris is from our observations only[49], which was used by the Wilson code to phase our observations:

$$\text{HJD}\ (T_{\min \text{I}}) = 2453441{\cdot}769097\ (\pm 0{\cdot}000166) + 0{\cdot}579166\ (\pm 0{\cdot}000081)\ E. \quad (4)$$

The new Wilson code calculates an ephemeris from the light curves as one of its adjustable output parameters. The light curves and the colour curves are shown in Fig. 3, calculated from differential magnitudes (XZ CMi – comparison) *versus* phase, and normalized at phase 0·25.

TABLE III

Quadratic and linear residuals of equations 1 and 2 for XZ CMi

	Epochs HJD-2400 000	*Cycles*	*Linear Residuals*	*Quadratic Residuals*	*Weighting*	*Reference*
1	28877·1020	−42440·00	−0·0095	0·0042	0·1	20
2	28923·3800	−42360·00	−0·0227	0·0028	0·1	19
3	28934·4150	−42341·00	0·0014	0·0149	0·1	19
4	28937·2830	−42336·00	−0·0246	−0·0112	0·1	19
5	28948·2940	−42317·00	−0·0110	0·0024	0·1	19
6	28952·3400	−42310·00	−0·0167	−0·0033	0·1	19
7	28956·4050	−42303·00	−0·0033	0·0101	0·1	19
8	28963·3450	−42291·00	−0·0090	0·0043	0·1	19
9	28966·2250	−42286·00	−0·0231	−0·0097	0·1	19

TABLE III (*continued*)

	Epochs HJD-2400 000	*Cycles*	*Linear Residuals*	*Quadratic Residuals*	*Weighting*	*Reference*
10	28967·3780	−42284·00	−0·0277	−0·0143	0·1	19
11	28989·3870	−42246·00	−0·0135	−0·0002	0·1	19
12	29022·3810	−42189·00	−0·0116	0·0016	0·1	19
13	29275·3150	−41752·00	−0·0172	−0·0048	0·1	20
14	29283·4280	−41738·00	−0·0076	0·0049	0·1	20
15	29311·2140	−41690·00	−0·0044	0·0080	0·1	20
16	29339·3080	−41641·50	0·0296	0·0021	0·1	20
17	29341·3200	−41638·00	0·0035	0·0158	0·1	20
18	29350·2990	−41622·50	0·0109	0·0232	0·1	20
19	32260·2400	−36595·00	−0·0118	−0·0067	0·1	46
20	32269·4970	−36579·00	−0·0157	−0·0106	0·1	46
21	32275·2880	−36569·00	−0·0128	−0·0077	0·1	46
22	32289·1780	−36545·00	−0·0142	−0·0092	0·1	46
23	32293·2210	−36538·00	−0·0229	−0·0179	0·1	46
24	37365·3600	−27775·00	0·0103	0·0071	0·1	15
25	37376·3570	−27756·00	0·0099	0·0067	0·1	15
26	40321·3410	−22668·00	0·0123	0·0068	0·1	9
27	40652·4100	−22096·00	0·0024	−0·0033	0·1	10
28	40655·3080	−22091·00	0·0063	0·0007	0·1	10
29	40688·3010	−22034·00	0·0072	0·0015	0·1	10
30	40692·6590	−22026·50	0·0241	0·0185	0·1	11
31	41000·2880	−21495·00	0·0160	0·0102	0·1	13
32	41023·4310	−21455·00	0·0066	0·0008	0·1	13
33	41753·3100	−20194·00	0·0071	0·0011	0·1	7
34	41764·3080	−20175·00	0·0077	0·0018	0·1	7
35	42139·3710	−19527·00	0·0023	−0·0037	0·1	8
36	42463·5010	−18967·00	−0·0009	−0·0069	0·1	17
37	42843·7740	−18310·00	−0·0056	−0·0116	0·1	5
38	42843·7820	−18310·00	0·0024	−0·0036	0·1	5
39	42843·7830	−18310·00	0·0034	−0·0026	0·1	5
40	42866·3530	−18271·00	−0·0002	−0·0062	0·1	12
41	42868·3800	−18267·50	0·0010	−0·0050	0·1	17
42	43079·9360	−17902·00	0·0022	−0·0038	0·1	5
43	43100·7720	−17866·00	0·0011	−0·0049	0·1	5
44	43180·6390	−17728·00	−0·0076	−0·0136	0·1	5
45	43184·6970	−17721·00	−0·0013	−0·0073	0·1	5
46	43496·6820	−17182·00	0·0055	−0·0004	0·1	14
47	43820·8150	−16622·00	0·0053	−0·0005	0·1	5
48	44191·8300	−15981·00	0·0036	−0·0022	0·1	5
49	44238·7140	−15900·00	0·0040	−0·0017	0·1	5
50	44576·7420	−15316·00	0·0074	0·0018	0·1	5
51	44627·6830	−15228·00	0·0132	0·0076	0·1	5
52	44634·6300	−15216·00	0·0145	0·0089	0·1	5
53	45012·5910	−14563·00	0·0130	0·0076	0·1	5
54	45042·6870	−14511·00	0·0109	0·0055	0·1	5
55	45060·6260	−14480·00	0·0068	0·0015	0·1	5
56	45405·6190	−13884·00	0·0295	0·0243	0·1	5
57	45407·3310	−13881·00	0·0051	−0·0001	0·1	3
58	45407·3320	−13881·00	0·0061	0·0009	0·1	3
59	45407·3350	−13881·00	0·0091	0·0039	0·1	3
60	45416·5900	−13865·00	0·0031	−0·0020	0·1	5
61	45762·7320	−13267·00	0·0171	0·0122	0·1	5
62	46164·4170	−12573·00	0·0085	0·0039	0·1	25
63	46413·8820	−12142·00	0·0067	0·0023	0·1	5
64	46441·6650	−12094·00	0·0069	0·0024	0·1	5
65	46496·6600	−11999·00	0·0150	0·0106	0·1	5
66	46505·3310	−11984·00	0·0038	−0·0005	0·1	26
67	46804·5920	−11467·00	0·0204	0·0163	0·1	5
68	46820·7870	−11439·00	0·0088	0·0047	0·1	5

TABLE III (*concluded*)

	Epochs HJD-2400 000	*Cycles*	*Linear Residuals*	*Quadratic Residuals*	*Weighting*	*Reference*
69	47161·7230	−10850·00	0·0261	0·0223	0·1	5
70	47197·5960	−10788·00	0·0129	0·0092	0·1	5
71	47207·4200	−10771·00	−0·0028	−0·0066	0·1	27
72	47207·4400	−10771·00	0·0172	0·0134	0·1	28
73	47210·3270	−10766·00	0·0101	0·0064	0·1	28
74	47214·3790	−10759·00	0·0105	0·0067	0·1	28
75	47232·3310	−10728·00	0·0194	0·0157	0·1	27
76	47233·4750	−10726·00	0·0057	0·0020	0·1	27
77	47539·6750	−10197·00	0·0156	0·0122	0·1	5
78	47566·3040	−10151·00	0·0194	0·0160	0·1	29
79	47592·3460	−10106·00	0·0150	0·0116	0·1	29
80	47912·4230	−9553·00	0·0104	0·0075	0·1	30
81	47941·3540	−9503·00	0·0010	−0·0020	0·1	30
82	47945·4130	−9496·00	0·0083	0·0054	0·1	4
83	47945·4130	−9496·00	0·0083	0·0054	0·1	30
84	47950·6240	−9487·00	0·0100	0·0071	0·1	5
85	47956·4130	−9477·00	0·0109	0·0080	0·1	30
86	47996·3510	−9408·00	0·0111	0·0082	0·1	31
87	48290·3820	−8900·00	0·0070	0·0044	0·1	34
88	48295·5880	−8891·00	0·0037	0·0012	0·1	5
89	48305·4310	−8874·00	0·0069	0·0044	0·1	50
90	48330·3250	−8831·00	0·0121	0·0096	0·1	34
91	48345·3720	−8805·00	0·0101	0·0076	0·1	34
92	48356·3590	−8786·00	−0·0003	−0·0027	0·1	34
93	48628·3990	−8316·00	−0·0006	−0·0028	0·1	35
94	48686·2960	−8216·00	0·0154	0·0134	0·1	36
95	48712·3240	−8171·00	−0·0030	−0·0050	0·1	36
96	49037·6240	−7609·00	0·0062	0·0046	0·1	5
97	49060·7620	−7569·00	−0·0082	−0·0097	0·1	5
98	49076·4040	−7542·00	0·0060	0·0044	0·1	37
99	49384·3210	−7010·00	−0·0036	−0·0047	0·1	38
100	49397·6270	−6987·00	−0·0102	−0·0113	0·1	5
101	49421·3820	−6946·00	0·0136	0·0126	0·1	38
102	49781·3980	−6324·00	0·0103	0·0097	0·1	39
103	49784·2990	−6319·00	0·0172	0·0167	0·1	39
104	49810·3410	−6274·00	0·0128	0·0123	0·1	40
105	50141·4140	−5702·00	0·0069	0·0069	0·1	41
106	50486·3840	−5106·00	0·0065	0·0072	0·1	42
107	50519·3740	−5049·00	0·0044	0·0051	0·1	42
108	50871·2880	−4441·00	0·0024	0·0036	0·1	44
109	37378·6652	−27752·00	0·0029	−0·0003	1·0	54
110	37375·7710	−27757·00	0·0027	−0·0005	1·0	54
111	42444·4014	−19000·00	0·0002	−0·0058	1·0	17
112	42444·4017	−19000·00	0·0005	−0·0055	1·0	16
113	42462·3443	−18969·00	0·0000	−0·0060	1·0	17
114	45404·4403	−13886·00	0·0084	0·0032	1·0	3
115	49016·7821	−7645·00	0·0014	−0·0002	1·0	47
116	49037·6191	−7609·00	0·0013	−0·0003	1·0	47
117	49401·6875	−6980·00	−0·0014	−0·0024	1·0	5
118	50515·3161	−5056·00	−0·0018	−0·0012	1·0	2
119	50897·3279	−4396·00	−0·0042	−0·0028	1·0	1
120	51159·5274	−3943·00	−0·0053	−0·0035	1·0	24
121	51936·8652	−2600·00	−0·0084	−0·0051	1·0	21
122	52605·9685	−1444·00	−0·0086	−0·0039	1·0	22
123	52362·2912	−1865·00	−0·0072	−0·0030	1·0	55
124	53010·8555	−744·50	0·0013	0·0068	1·0	23
125	53440·6116	−2·00	−0·0085	−0·0020	1·0	This paper
126	53441·7676	0·00	−0·0101	−0·0036	1·0	This paper
127	53442·6428	1·50	−0·0031	0·0034	1·0	This paper

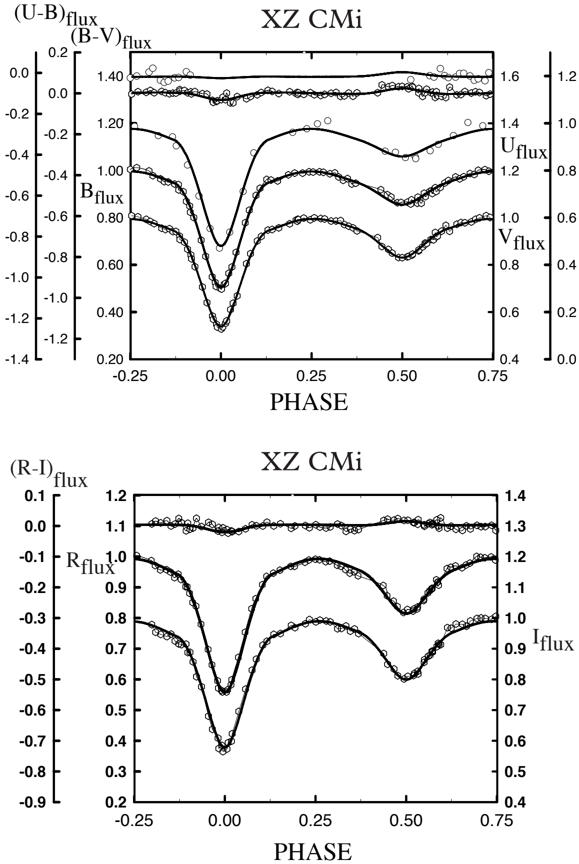

FIG. 3

UBVRI light curves overlaid with synthetic light-curve model predictions.

Modelling and light-curve solutions

We used the interactive modelling program BINARY MAKER 3·0[48] to determine our preliminary fits to each of the *BVRI* light curves, starting with the mass ratio from Terrell & Henden[4]. We also used a 15% third light in these fits. We began with the assumption of a semi-detached model due to the large difference in eclipse depths. Once a good fit was found for the *B* light curve (the other curves had similar parameters), the resulting averaged parameters were introduced into the Wilson program[49–52]. As is our usual practice, we input the third light as an adjustable parameter. The 2004 edition of the Wilson code includes full stellar atmospheres, rather than black bodies, and a detailed reflection treatment along with 2-D limb-darkening coefficients. Our solution parameters are given in Table IV, and synthetic light curves are shown in Fig. 3 overlying the actual data. Fig. 4 shows a Roche-lobe model for the binary.

TABLE IV

Synthetic light-curve parameters for XZ CMi

	Simultaneous solution
$\lambda_U, \lambda_B, \lambda_V, \lambda_R, \lambda_I$ (nm)	360, 440, 550, 640, 790
$x_{bol_{1,2}}, y_{bol_{1,2}}$	0·641, 0·647 0·253, 0·176
$x_{1I,2I}, y_{1I,2I}$	0·501, 0·605 0·275, 0·211
$x_{1R,2R}, y_{1R,2R}$	0·592, 0·701 0·291, 0·203
$x_{1V,2V}, y_{1V,2V}$	0·688, 0·790 0·290, 0·159
$x_{1B,2B}, y_{1B,2B}$	0·785, 0·851 0·283, 0·044
$x_{1U,2U}, y_{1U,2U}$	0·799, 0·870 0·325, 0·117
g_1, g_2	0·32
A_1, A_2	0·50
Inclination (°)	77·2 ± 0·1°
T_1, T_2 (K)	7000, 5036±12
Ω_1	3·755 ± 0·016
Ω_2	3·468 (fixed by mass ratio)
q (m_2/m_1)	0·830 ± 0·12
$L1/(L_1+L_2)_U$	0·736 ± 0·001
$L1/(L_1+L_2)_B$	0·776 ± 0·001
$L1/(L_1+L_2)_V$	0·819 ± 0·001
$L1/(L_1+L_2)_R$	0·886 ± 0·001
$L1/(L_1+L_2)_I$	0·928 ± 0·006
JD_o (*days*)	2453441·76910 ± 0·00017
Period (*days*)	0·579166 ± 0·000081
r_1, r_2 (*pole*)	0·337 ± 0·005, 0·341 ± 0·099
r_1, r_2 (*point*)	0·387 ± 0·011 –
r_1, r_2 (*side*)	0·357 ± 0·003, 0·357 ± 0·108
r_1, r_2 (*back*)	0·389 ± 0·002, 0·3 ± 0·007

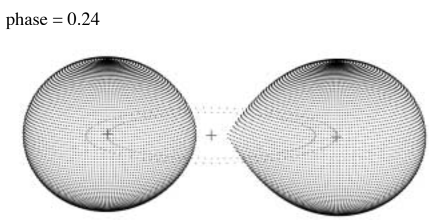

FIG. 4
3-D Roche-lobe model.

Discussion

The solution was of Algol-type, with the secondary, less-massive component filling its Roche lobe and the primary under-filling. The spots we introduced to fit apparent irregularities in the light curve were eliminated in the Wilson-code iterations. There are still slight irregularities, but the fits, once visualized, were very close to the data. (No major spot regions were needed.) The difference in component temperatures was found to be about 2000 K, so the secondary component is approximately K1 V, thus we expect magnetic activity to arise mostly from this component. However, the F2·5 type of the primary component allows for weak magnetic activity.

The Wilson code iterated our mass ratio to about 0·8 as compared to Terrell & Henden's[4] 0·64. Had we fixed the mass ratio at the lower value we cannot say that we would not have arrived at a solution with a similar residual. A q-search may shed some light here, but what is needed is a set of high-precision radial-velocity curves. We do not claim that we have calculated a correct mass ratio. Our third-light values varied from 17–18%, remarkably close to Terrell & Henden's PSF determinations. The same values (17–18%) were found with our BINARY MAKER 'hand fits'. The fill-out of the primary component was 92%, so we would classify XZ CMi as a near-contact binary.

The quadratic term of our ephemeris, from our period study, shows a decaying orbital period. The magnitude of the decay is consistent with angular-momentum loss due to stellar winds escaping along stiff but rotating magnetic-field lines. The low-amplitude (and somewhat noisy) 23-year sinusoidal oscillation would be expected from solar-type magnetic cycles. We suggest that high-energy observations from spacecraft be undertaken to verify this.

Acknowledgements

This research was partially supported by a grant from NASA administered by the American Astronomical Society.

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Note:
BAVSM = Berliner Arbeitsgemeinschaft fuer Veraenderliche Sterne-Mitteilungen
BBSAG = Bulletin der Bedeckungsveraenderlichen-Beobachter der Schweizerischen Astronomischen Gesellschaft

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 189: HD 14415, HR 3112, AND HR 4454

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Cambridge Observatories

The stars discussed here are all shown by their radial velocities to be members of multiple systems. HD 14415 appears to be a mid-G star possibly somewhat above normal-giant luminosity, the literature suggests that HR 3112 is a giant in or near the Hertzsprung Gap, while HR 4454 is considered to be an Am star. As far as published evidence goes, they all appear spectroscopically single; it is their radial-velocity behaviour that has demonstrated their multiplicity. At first sight the systems seemed to be simple binaries, with orbital periods of about 700, 97, and 9 days, respectively. For the first two the orbital eccentricity is just above 0·5, whereas the inner orbit of HR 4454 is of low eccentricity. For all three stars, however, continued observation has shown that the γ-velocities are not constant. In the first two cases, all that has so far been properly documented is a drift in the γ-velocity, adequately approximated by the assumption of a linear trend, which is quantified by a specially modified version of the normal orbit-solving program. A few radial velocities measured long ago, however, provide indications of parts of the outer orbits in each case. For HR 3112 there are enough to suggest that the period may be about 90 years.

Although the spectrum of HR 3112 has never until now been recognized as composite, there is good reason to think that the HR 3112 system consists of a primary star that is really a *late*-G giant, an unseen lower-main-sequence companion in the 97-day orbit, and a bright companion with a type close to A2V sharing the outer orbit. Indeed, *Hipparcos* resolved a companion answering closely to the expected brightness and separation. Spectra kindly taken by Bohlender at the DAO after this paper was initially drafted confirm positively that HR 3112 is indeed a newly discovered bright composite-spectrum system.

For HR 4454 a complete 11-year cycle of the outer orbit has been documented — an orbit of high eccentricity with an amplitude (9·5 km s^{-1}) almost as great as that of the 9-day variation. Still another hierarchy of duplicity is represented by the *Hipparcos* discovery of a faint 'visual' companion almost one second of arc from the principal star — much too distant to be the long-period spectroscopic companion — so HR 4454 is at least quadruple.

Introduction

It is increasingly recognized that an appreciable proportion of binary stars is actually of higher multiplicity. Many of the objects that have been discussed in this series of papers are visual as well as spectroscopic binaries. In some cases easily-resolved visual companions to the spectroscopic systems have themselves proved to be spectroscopic binaries: for example, the companion to HD 6645 was found[1] to be a short-period double-lined system, and the companion to HR 2879 proved[2] to be a hierarchical triple, making that system at least quintuple. Quite apart from the stars that possess both visual and spectroscopic companions, several objects already treated here have shown velocity variations having more than one periodicity, often manifested merely as a steady drift in the γ-velocity of a binary system of more or less short period. Thus HD 7426[3] and HR 965[4] are single-lined systems whose γ-velocities showed drifts which, incidentally, are still being followed at Cambridge. V455 Aur[5] is a double-lined example with a drifting γ-velocity. 1 Gem[6,7], which gives a radial-velocity trace exhibiting two dips, consists of a secondary star in a short-period large-amplitude orbit which itself has a γ-velocity that varies on a leisurely time-scale in a manner complementary to that of the primary star. 24 Aqr[8] is another double-lined object somewhat analogous to 1 Gem, in which a short-period sub-system (the primary in 24 Aqr's case) was found to be in a long-period orbit that it shares with the other observed component; HD 158209 is another, whose outer orbit proved to be of a short enough period (about 8 years) to be documented[9] at the same time as the inner one. HR 2236[10] and HD 141690[11] gave radial-velocity traces that included, in each case, one component whose velocity was sensibly constant over the duration of the observations but which was clearly the signature of a distant companion to the short-period binary. The present paper, therefore, is far from breaking new ground in relation to the characters of the systems discussed, but it is of interest, all the same, to draw attention to three newly discovered multiple systems, two of which are bright enough to feature in the *Bright Star Catalogue*.

HD 14415

HD 14415 is an eighth-magnitude star just a degree or so north of the Double Cluster in Perseus. There is only a very modest literature on it, and most of the references in which it does feature mention it only as a photometric comparison star to the interesting variable S Per that lies about 9′ following. On that account Skiff[12] gave a measurement of its V magnitude, $8^{m}\cdot302 \pm 0^{m}\cdot002$; the only other photometry of it appears to be that from *Tycho*, which transforms to $V = 8^{m}\cdot32$, $(B-V) = 0^{m}\cdot99$. Spectral classifications resolutely place it at G5, which is the type in the *Henry Draper Catalogue*; Rydström[13] gave it as gG5, and a representative[14] of the French objective-prism group called it G5 II as well as giving a mean radial velocity of +10 km s^{-1} from seven measurements. De Medeiros & Mayor, who made a large investigation[15] of rotational velocities of evolved stars, seized upon HD 14415 as an addition to their programme despite its being fainter than most of their objects, owing to its classification[14] in a luminosity class that was otherwise under-represented. They[15] reported just two observations, which showed an almost indeterminately small rotational velocity but demonstrated that the radial velocity was variable: a mean of +4·90 km s^{-1}, together with information that could be interpreted (see Paper 188[16], section on HD 14544) to show that the two measurements differed by 6·0 km s^{-1}, was listed. Later, the individual measurements, with their dates, were filed with the *Centre de Données Stellaires* (*CDS*); the two velocities are given there as +9·2 and +3·0 km s^{-1}, and are seen to have been obtained in 1986 and 1987. In addition, four extra data, obtained in 1997/8, appeared in the file.

The immediately previous paper[16] in this series explained how, upon the appearance at the *CDS* in late 2001 of the listing of the individual de Medeiros & Mayor[15] velocities, certain stars that had shown velocity discordances were selected for observation from Cambridge. HD 14415 was such a star, and 24 measurements have been made of its radial velocity. They are listed in Table I, preceded by the six observations retrieved from the *CDS*.

The star has proved to have an orbital period inconveniently close to two years, such that the phase coverage exhibits gaps that will take a long time to repair. Although it is now nearing the completion of only the second cycle of its variation since the systematic observations began in 2002, it has become clear that the velocities in the two cycles do not accord with one another, but have drifted upwards. Furthermore, there is no way in which the de Medeiros & Mayor velocities can be fitted to an orbit that is straightforwardly derived from the Cambridge observations. Clearly there is an additional slow variation superimposed upon the two-year orbital cycle.

Previously[2–4], variations of γ-velocities were illustrated, and where necessary quantified, graphically, but quite recently (in the case of HD 112445 in Paper

TABLE I

Radial-velocity observations of HD 14415

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

Date (UT)	*MJD*	*Observed Velocity* $km\ s^{-1}$	*Phase*	*Computed Velocity* γ $km\ s^{-1}$	*Computed Velocity Orbital* $km\ s^{-1}$	$(O-C)$ $km\ s^{-1}$
1986 Nov. 23·80*	46757·80	+10·0	$\overline{8}$·498	(+4·0)	1·3	0·0
1987 Sept. 17·09*	47055·09	+3·8	$\overline{8}$·920	(+4·4)	−5·0	0·0
1997 Aug. 31·01*	50691·01	+11·4	$\overline{2}$·085	(+8·6)	+1·6	+0·5
Sept. 3·97*	694·97	+11·2	·091	(+8·6)	+1·8	+0·1
Dec. 14·83*	796·83	+11·9	·235	(+8·7)	+2·8	−0·3
1998 Jan. 7·79*	50820·79	+11·9	$\overline{2}$·269	(+8·7)	+2·7	−0·2
2002 Sept. 2·08	52519·08	+10·1	0·682	+10·7	−0·4	−0·2
Oct. 28·06	575·06	+9·4	·761	+10·8	−1·4	+0·1
2003 Jan. 7·02	52646·02	+7·4	0·862	+10·9	−3·4	0·0
Feb. 18·89	688·89	+6·3	·923	+10·9	−5·1	+0·5
Mar. 15·83	713·83	+5·1	·958	+10·9	−5·7	−0·1
Aug. 15·12	866·12	+13·7	1·175	+11·1	+2·8	−0·2
Sept. 16·04	898·04	+14·1	·220	+11·2	+2·8	+0·1
Oct. 18·04	930·04	+13·8	·265	+11·2	+2·7	−0·1
Nov. 13·00	956·00	+14·0	·302	+11·2	+2·5	+0·3
Dec. 11·98	984·98	+13·4	·343	+11·3	+2·3	−0·2
2004 Jan. 24·89	53028·89	+13·2	1·406	+11·3	+1·9	−0·1
Mar. 1·79	065·79	+13·1	·458	+11·4	+1·6	+0·1
Sept. 2·10	250·10	+10·7	·720	+11·6	−0·9	0·0
Oct. 7·10	285·10	+10·4	·770	+11·6	−1·6	+0·4
Nov. 14·02	323·02	+8·8	·824	+11·7	−2·6	−0·3
Dec. 17·89	356·89	+7·9	·872	+11·7	−3·7	−0·1
2005 Jan. 12·86	53382·86	+6·9	1·909	+11·7	−4·7	−0·1
Mar. 18·80	447·80	+7·7	2·001	+11·8	−4·1	0·0
24·80	453·80	+8·3	·009	+11·8	−3·4	−0·1
Apr. 6·82	466·82	+10·2	·028	+11·8	−1·7	+0·1
Aug. 7·08	589·08	+14·7	·201	+12·0	+2·8	−0·1
Sept. 17·10	630·10	+14·8	·260	+12·0	+2·7	+0·1
Dec. 8·92	712·92	+14·2	·377	+12·1	+2·1	0·0
2006 Jan. 28·83	53763·83	+13·9	2·450	+12·2	+1·7	+0·1

*Observation by de Medeiros & Mayor[15]; not used in solution of inner orbit, but contributes to Fig. 3. See text.

178[17]) our procedures were modernized a bit by the use of a new orbit-solving program, in which a normal single-lined solution is modified by the incorporation of a single extra unknown — a linear trend, which may be held to represent sufficiently accurately the variation of the γ-velocity of the short-period ('inner') orbit over what is clearly only a small segment of the long-period ('outer') one. The γ-velocity has then to refer to some arbitrarily designated epoch, and the slope or gradient of the trend can conveniently be specified in units of km s^{-1} per thousand days. In actuality the improvement of the computational method over the graphical one may often be more or less illusory, because the uncertainty in the slope may well arise as much from an interdependence between it and certain other elements of the orbit as from any lack of precision in subjective estimation from a graph, but superficially at least the appearance of mathematical rigour may be thought to invest even a rather prosaic discussion with an enhanced level of pedagogical sophistication!

Application of the modified program to the Cambridge observations alone produced for HD 14415 an inner orbit with a period of 692 ± 6 days and a slope or trend of the γ-velocity of +1·42 ± 0·18 km s^{-1} per thousand days. A preview of how the Haute-Provence data[15] might fit that solution led, however, to a conviction that the period would need modification. The 1997/8 velocities all fall within a small range of phase practically at the maximum of the two-year orbital variation, but the two older data fall at very different phases and velocities and can be accommodated simultaneously only if the period is held at a value very close to 704 days (within about 1 day). Accordingly, that period has been imposed upon all subsequent efforts to discuss the data. The solution of the Cambridge observations, under that constraint, is illustrated in Figs. 1 and 2 and yields the elements that follow.

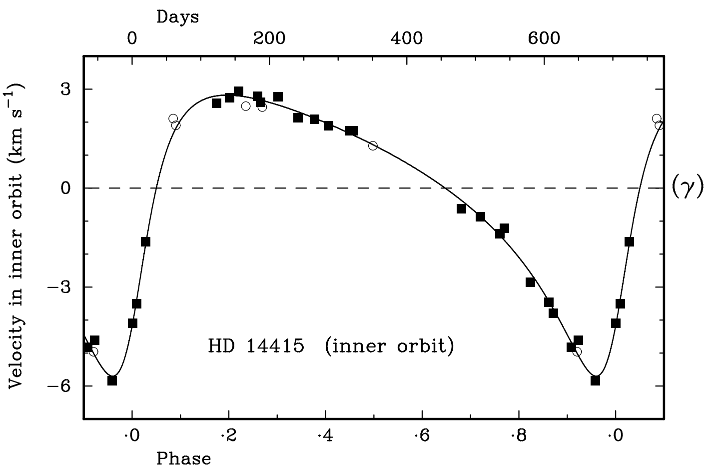

FIG. 1

Cambridge radial-velocity measurements of HD 14415 (filled squares) plotted as a function of phase in the inner orbit, with the velocity curve corresponding to the adopted orbital elements drawn through them. The velocities are not plotted 'as observed', but have been corrected for a linear variation of the γ-velocity with time, as explained in the text and plotted in Fig. 2. The γ-velocity of the inner orbit is treated as zero; its actual value is specified as a linear function of time in the table of orbital elements and is plotted in Fig. 2.

Open circles represent observations made available through the *Centre de Données Stellaires* by de Medeiros & Mayor[15]. They do not contribute to the orbital solution, but have been brought into line with it by the application of corrections that were specifically adopted to achieve that end — the only purpose in plotting them is to illustrate the phases at which they fall. The necessary corrections constitute the information that allows the corresponding observations to be plotted in Fig. 3, where they offer some indications of the variation of the γ-velocity at times before the Cambridge observations started.

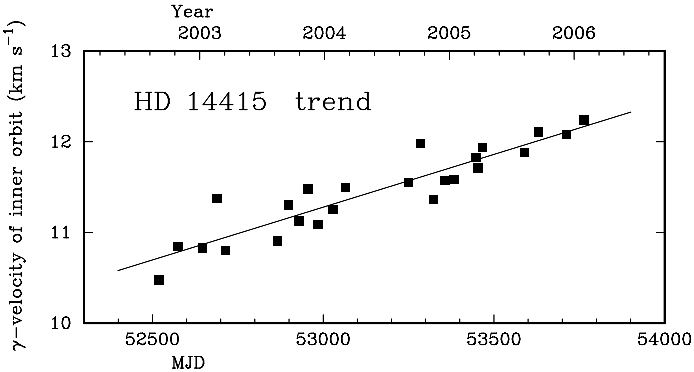

FIG. 2

Graph showing the adopted variation of the γ-velocity of HD 14415, plotted directly against time. The line is a linear fit to the points, and is to be regarded as an approximation to a small part of the outer orbit; the points themselves represent the Cambridge radial velocities after the variation attributed to the inner orbit has been subtracted from them.

P	= 704 days (fixed)	$(T)_2$	= MJD 53447·3 ± 2·2
γ*	= +11·71 ± 0·05 km s^{-1}	$a_1 \sin i$	= 35·1 ± 0·9 Gm
Trend	= +1·16 ± 0·13 km s^{-1} (1000 d)$^{-1}$	$f(m)$	= 0·00348 ± 0·00026 $M_\odot$
K	= 4·26 ± 0·09 km s^{-1}		
e	= 0·525 ± 0·017		
ω	= 229·9 ± 2·4 degrees	R.m.s. residual	= 0·18 km s^{-1}

*At 2005 January 1·0

Fig. 2 is thought to be visually compelling as evidence of the reality of the trend, as is the fact that the numerical value is nine times its own standard deviation. As a final demonstration of that reality we could, however, appeal also to the improvement obtained by the introduction of the extra unknown into the fit of the model to the observations. When the orbit is computed as a straightforward single-lined one, the period being fixed at 704 days, the sum of the squares of the deviations of the 24 observations is 4·50 (km s^{-1})^2; since five orbital elements have been fitted the number of degrees of freedom is 19. The solution which includes the trend and whose elements are given above has the sum of squares reduced to 0·79 (km s^{-1})^2, with 18 degrees of freedom. Those 18 degrees therefore cost about 0·044 (km s^{-1})^2 each, whereas the single degree represented by the trend accounts for all the rest, *viz.*, 3·71 (km s^{-1})^2, thus leading to a variance ratio, $F_{1,18}$, of about 84. The 1%-significance point of $F_{1,18}$ is reached at $F_{1,18}$ = 8·29 and the 0·1% point at 15·38, so the significance of a value of 84 must truly be beyond any possible cavil!

The availability of observations, however few, at epochs about 10 and 20 years ago must in principle provide a couple of valuable points contributing towards the delineation of the outer orbit, which is otherwise characterized only by Fig. 2. Only the *Coravel* observations listed by de Medeiros & Mayor[15] are of utility in that connection, the objective-prism ones[14] being of unsatisfactory accuracy and in any case not listed individually. The inclusion of the early measurements is not an entirely straightforward matter, because the two-year orbit can be properly represented only by a solution that includes the trend, which then necessarily gets applied to the early observations too. Not surprisingly, it transpires that the trend has not been maintained at the same slope for the past 20 years, so each of the two groups of early observations proves to be offset from the velocity curve defined for the two-year variation by the recent observations — they all fall too high. They are therefore brought into line by the application of empirical corrections. For purposes of illustration Fig. 1 has been plotted with the 'corrected' Haute-Provence measures already included. The corrections applied (nett of the adjustment of $+0 \cdot 8$ km s^{-1} that is commonly made in this series of papers to velocities from the Haute-Provence *Coravel* in the interest of systematic homogeneity with Cambridge velocities) are $-4 \cdot 7$, $-4 \cdot 4$, and $-0 \cdot 7$ km s^{-1} for the 1986, 1987, and 1997/8 measurements, respectively. They represent the corrections needed to those data to bring them down onto the velocity curve drawn in Fig. 1 and (equivalently) onto the trend line seen in Fig. 2 extrapolated backwards in time. To produce a diagram showing the implied variation attributable to the outer orbit, therefore — a diagram analogous to Fig. 2 but covering the whole time span of the data — the points corresponding to the early observations have to be plotted with their corrections annulled, so they appear *above* the extrapolated trend line by the same amounts of $4 \cdot 7$, $4 \cdot 4$, and $0 \cdot 7$ km s^{-1}. By that means Fig. 3 has been drawn to represent the variation that is to be attributed to the outer orbit; the trend line itself has been omitted, since its validity is obviously restricted just to recent times. There is clearly insufficient information for anything much to be said about the outer orbit except that its period is probably a lot longer than the 20-year time-span of the data.

In the cases of straightforward binary systems, there is no need for journals of observations such as Table I here to include a column giving the calculated velocity at each epoch, since that quantity is implicit, being the difference between the observed velocity and the residual. Although of course the same relationship holds in the present case, the calculated velocity here is the sum of two contributions — the steadily changing γ-velocity and the periodic variation — which cannot be identified separately in the absence of explicit tabulation, which is therefore provided in Table I. The sum of the two velocities calculated from the computed model, plus the residual, should equal the observed velocity, but in a few instances there is an apparent discrepancy of $\pm 0 \cdot 1$ km s^{-1} arising from rounding errors. Whichever source of variation is plotted — the orbital velocity in Fig. 1 or the γ-velocity in Fig. 2 — the residuals quantify the offsets from the computed variations (the full line in either figure) of the points corresponding to each observation. The entries for the computed γ-velocities of the early observations in Table I are printed in brackets because they are the values obtained by direct extrapolation of the trend that is calculated from the recent Cambridge data. To obtain agreement with the orbital velocity curve the early observations need the empirical corrections noted in the previous paragraph. The corrections are the inverse of the residuals that the observations would otherwise exhibit; it is useful to see those residuals not as errors but as helping to delineate how far above a linear extrapolation of the recent trend the true γ-velocity variation should be drawn in Fig. 3.

The mass function of the two-year orbit is small, and the same promises to be true of the outer orbit too. There is no reason to think that the two companions are other than low-mass stars, and especially since the colour index

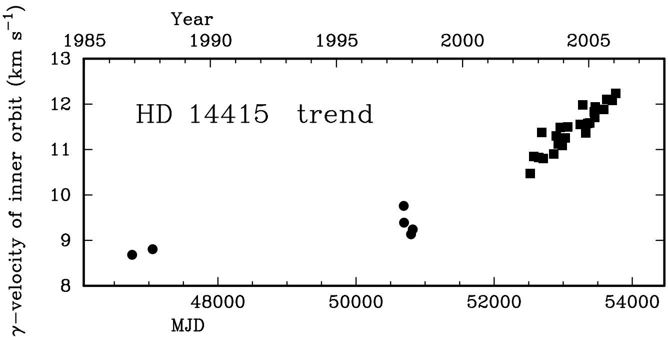

FIG. 3

Variation of the γ-velocity of the 700-day inner orbit of HD 14415, over the whole time-span of the available radial-velocity data. The right-hand portion of the diagram repeats Fig. 2 on a much reduced scale; the filled circles plot the positions that the radial velocities provided by de Medeiros & Mayor[15] occupy after the computed contributions from the variation attributable to the inner orbit have been subtracted from them.

of HD 14415 is plenty red enough for the spectral type it seems likely that both of them are lower-main-sequence stars, although the possibility that the long-period one might be a white dwarf cannot be ruled out — indeed, a cynic might recall that it is not unknown for stars to be assigned to luminosity class II when they are really normal giants with 'barium' characteristics attributable to the evolutionary activities of what are now white-dwarf companions. The closer companion is not likely to be a white dwarf, since in that case tidal effects during its giant-branch evolution could have been expected to reduce the eccentricity of the orbit to well below its observed value of slightly above 0·5.

HR 3112

HR 3112 is a 6^m G giant at a high declination in Camelopardus, very close to the boundary of Ursa Major; it is to be found about 4′ north-preceding the third-magnitude star o UMa, and is marked in *Norton*[18] as a double star directly north of the object labelled AX Cam. There seems to have been only one ground-based measurement of its *UBV* magnitudes, by Imagawa[19], who obtained $V = 6^m{\cdot}42$, $(B-V) = 0^m{\cdot}58$, $(U-B) = 0^m{\cdot}33$. The validity of the V magnitude, particularly, seems very doubtful, since *Hipparcos* obtained a value of $6^m{\cdot}09$ that is supported by the *Tycho* measures, which lead to that same V and to $(B-V) = 0^m{\cdot}64$. The spectral type is given in the *Bright Star Catalogue*[20] as G1 III, but the writer has not been able to discover any such classification in the literature; it seems likely that it is a somewhat reprehensible 'MK-ization' of the gG1 that was listed in the previous edition[21] and was itself probably copied from that type that was listed by Wilson & Joy[22], which may in turn have come from the classification of G1 by Adams *et al.*[23] and the listing by them of a spectroscopically estimated absolute magnitude of $+1{\cdot}2$. There is, in fact, a direct MK classification of HR 3112, as G2 II–III, by Bouw[24], who in a Case Western PhD thesis estimated types from infrared spectrograms taken on I-N emulsion, which has very coarse grain, at the very low dispersion of 385 Å mm^{-1}. Gray[25] estimated the types of G-giant stars to 1/100 of a spectral class by measurements of the relative depths of the V I and Fe I lines at 6151 and 6152 Å, respectively, in high-resolution spectra; notwithstanding that HR 3112 had the bluest colour index of all the 66 giants that he surveyed, his method assigned it one of the latest types, G9·2. Taxed with that matter recently, Gray (private communication 2006) has drawn attention to a later paper[26] of his, in which the relative line-strengths were found not to be such a unique function of temperature as the earlier work assumed. At the same time, however, he has confirmed that the line-depth ratio does indicate the star to be much cooler than its colour index would lead one to expect. In his recent correspondence he also comments that "the absolute line depths are about 25% shallower than other stars of similar line-depth ratio. This probably implies a composite spectrum. I would guess this giant has a hot main-sequence companion." — and that was before I had mentioned anything about finding the object to be multiple.

Little other interest seems to have been taken in HR 3112, apart from three investigations[27–29] of its lithium abundance, which have concluded that that abundance is moderate. The *Hipparcos* parallax shows the object to have an absolute magnitude very close to zero, within an uncertainty of about a quarter of a magnitude.

Young[30] was the first to publish a radial velocity for HR 3112 when he gave a mean, +18·2 km s^{-1}, of four measurements obtained at 33 Å mm^{-1} with a Cassegrain spectrograph at the DDO 74-inch reflector. There is an asterisk against the entry for HR 3112, leading to a note that indicates that the velocity is more than usually uncertain, and "We judge in these cases that the variation is somewhat greater than would be expected from the character of the lines." The range of the four velocities is given as 13 km s^{-1}; Young gave the individual plate velocities for certain stars whose spectroscopic-binary nature was almost certain, but he evidently did not regard HR 3112 as being in that category. Wilson & Joy[22] published a mean value from three velocities, obtained at the Mount Wilson 60-inch Cassegrain, that were subsequently given individually by Abt[31]. Two measures, obtained in 1986 and 1987, were obtained by de Medeiros & Mayor[15] with the Haute-Provence *Coravel* and their details were later made available through the *CDS* in the same way as those of HD 14415. One velocity was given by Marrese, Boschi & Munari[32] as a by-product of their simulation of the type of data that might be expected from the proposed spacecraft *Gaia*. All of the published measurements, so far as they were given with individual dates and velocities, are listed in chronological order at the head of Table II.

As in the case of HD 14415, HR 3112 was selected from the listing of individual velocities by de Medeiros & Mayor for observation at Cambridge, and the observations were begun in 2002. The Cambridge observations number 34; they are set out in Table II. The star was very soon discovered to be a short-period binary; the period derived from the Cambridge measurements alone is 97·566 ± 0·016 days. It was also quickly recognized that the velocity curve did not repeat accurately but exhibited a continually increasing positive displacement, intimating the presence of a second companion in an orbit of relatively long period. We can treat the data for HR 3112 in exactly the same way as those for HD 14415. First, it is noticed that in order to make the Haute-Provence velocities fit the 97-day velocity curve, it is necessary to make not only an arbitrary offset (carrying information about the long-term trend) but also to

TABLE II

Radial-velocity observations of HR 3112

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

Date (UT)	*MJD*	*Observed Velocity km s*$^{-1}$	*Phase*	*Computed Velocity* γ *km s*$^{-1}$	*Orbital km s*$^{-1}$	*(O−C) km s*$^{-1}$
1933 Dec. 5·44*	27411·44	+16·5	$\overline{258}$·622	(−35·1)	−5·1	−0·3
1945 Apr. 1·23*	31546·23	+28·1	$\overline{215}$·016	(−26·5)	+10·8	−1·2
1946 Apr. 22·18*	31932·18	+21·9	$\overline{212}$·973	(−25·7)	+2·0	+0·6
1986 Nov. 24·16†	46758·16	+16·9	$\overline{60}$·983	(+5·3)	+4·1	0·0
1987 May 13·90†	46928·90	+6·0	$\overline{58}$·734	(+5·7)	−7·1	0·0
2000 Apr. 20·90‡	51654·90	+23·4	$\overline{9}$·189	(+15·5)	+7·1	0·0
2002 Sept. 30·21	52547·21	+18·5	0·338	+17·4	+1·6	−0·5
Dec. 11·20	619·20	+30·5	1·076	+17·6	12·9	+0·1
2003 Jan. 5·15	52644·15	+19·4	1·332	+17·6	+1·7	0·0
27·08	666·08	+14·0	·557	+17·7	−3·8	+0·1
Feb. 15·06	685·06	+10·5	·751	+17·7	−7·3	+0·1
Mar. 2·99	700·99	+11·9	·915	+17·7	−6·0	+0·2
14·95	712·95	+30·5	2·037	+17·8	+12·9	−0·1
23·91	721·91	+28·0	·129	+17·8	+10·2	0·0
27·91	725·91	+25·8	·170	+17·8	+8·0	0·0
30·88	728·88	+24·2	·201	+17·8	+6·6	−0·2
Apr. 8·86	737·86	+21·0	·293	+17·8	+3·0	+0·2
21·86	750·86	+16·7	·426	+17·8	−0·8	−0·3
May 6·92	765·92	+13·6	·580	+17·9	−4·3	0·0
Oct. 18·23	930·23	+22·0	4·265	+18·2	+4·0	−0·2
Nov. 3·17	946·17	+17·5	·428	+18·2	−0·9	+0·2
28·14	971·14	+12·0	·684	+18·3	−6·3	0·0
Dec. 15·21	988·21	+10·2	·859	+18·3	−7·9	−0·2
27·15	53000·15	+22·5	·982	+18·4	+3·9	+0·3
29·16	002·16	+26·8	5·002	+18·4	+8·4	+0·1
2004 Feb. 26·03	53061·03	+13·8	5·606	+18·5	−4·8	+0·1
Mar. 1·03	065·03	+13·0	·647	+18·5	−5·6	+0·1
29·94	093·94	+15·3	·944	+18·6	−3·2	0·0
Apr. 21·90	116·90	+26·7	6·179	+18·6	+7·6	+0·5
Oct. 19·23	297·23	+31·3	8·028	+19·0	+12·2	+0·1
26·25	304·25	+30·6	·100	+19·0	+11·8	−0·2
2005 Jan. 5·06	53375·06	+11·2	8·826	+19·1	−8·0	+0·1
13·09	383·09	+12·6	·908	+19·2	−6·5	−0·1
19·16	389·16	+20·3	·970	+19·2	+1·4	−0·3
22·10	392·10	+27·1	9·001	+19·2	+8·0	0·0
23·16	393·16	+29·2	·011	+19·2	+10·0	0·0
Nov. 14·17	688·17	+32·4	12·036	+19·8	+12·8	−0·2
19·17	693·17	+32·4	·087	+19·8	+12·4	+0·2
Dec. 17·18	721·18	+20·4	·375	+19·9	+0·5	0·0
2006 Jan. 26·05	53761·05	+12·1	12·783	+19·9	−7·7	−0·1

*‡†Not used in solution of the inner orbit, but contributes to Fig. 6. See text.
*Mount Wilson photographic observation[22, 31].
†Haute-Provence *Coravel* observation[15].
‡Observed by Marrese *et al.*[32].

refine the period slightly, to 97·533 days, a value whose uncertainty is probably no greater than 0·003 days. Then a solution of the orbit with the 'trend' program, from the Cambridge observations alone but with the period kept fixed, produces the results that are illustrated in Figs. 4 and 5 and are encapsulated in the orbital elements that follow:

P	$= 97{\cdot}533$ days (fixed)	$(T)_5$	= MJD $53001{\cdot}92 \pm 0{\cdot}10$
γ*	$= +19{\cdot}13 \pm 0{\cdot}06$ km s^{-1}	$a_1 \sin i$	$= 12{\cdot}37 \pm 0{\cdot}07$ Gm
Trend	$= +2{\cdot}09 \pm 0{\cdot}11$ km s^{-1} (1000 d)$^{-1}$	$f(m)$	$= 0{\cdot}00796 \pm 0{\cdot}00013\ M_{\odot}$
K	$= 10{\cdot}69 \pm 0{\cdot}05$ km s^{-1}		
e	$= 0{\cdot}505 \pm 0{\cdot}004$		
ω	$= 299{\cdot}2 \pm 0{\cdot}7$ degrees	R.m.s. residual	$= 0{\cdot}19$ km s^{-1}

*At 2005 January 1·0

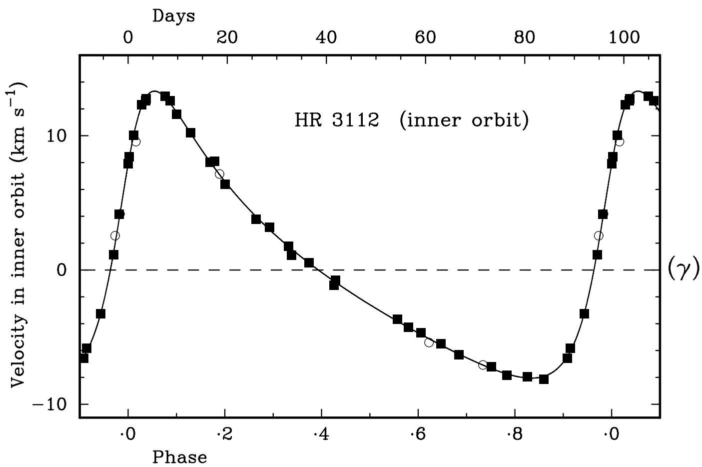

FIG. 4

The inner orbit of HR 3112, exactly analogous to Fig. 1.

The trend is nearly twice as steep as in the case of HD 14415 and is seen to be nearly twenty times its standard deviation, so its reality requires no further justification. We can try to obtain an idea of the variation of γ in the time before the Cambridge observations started, by the same procedure as was used for HD 14415 above. What that procedure amounts to is that each observation, or set of observations if fairly close together in time, is assigned an empirical offset such that the corresponding data point(s) is/are brought into agreement with the short-period velocity curve, and then the 'trend' figure is plotted with the offsets effectively removed again by being applied with reversed sign to the plotted points. It may be appreciated that the trend shown in Fig. 5, amounting to nearly 1 km s^{-1} per annum, is altogether unsustainable over the long term, so observations made long ago necessarily fall far above the extrapolated trend line. We quantify *how far* above it they fall by seeing how much must be subtracted from them to make them match the short-period orbit, and thus determine how far above the extrapolated trend line they must be plotted in order to represent the true variation of velocity in the outer orbit.

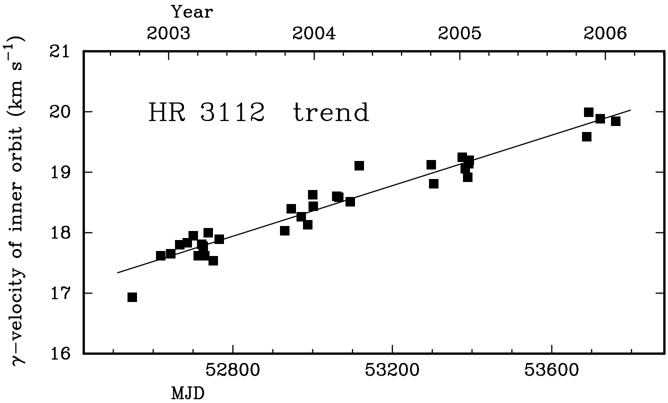

FIG. 5

Variation of the γ-velocity of HR 3112, analogous to Fig. 2.

The procedure is applicable with confidence to the velocities obtained with the Haute-Provence *Coravel*; in relation to the other published measurements, which may well have much larger accidental and systematic deviations, the validity of the *procedure* is not impaired, but we need to recognize that such validity as the *result* may possess is wholly dependent upon the reliability of the data that we are putting into it. The actual offsets (km s^{-1}) that were applied to the published observations of the various past years to place them on the velocity curve of the inner orbit (where they have been plotted in Fig. 4, as open circles) were as follows: 2000[32] −0·7; 1986/7[15] −7·4; 1945/6 and 1933[22,31] −45 and −57, respectively. When those offsets are applied with reversed sign to the positions of the corresponding data points in a figure analogous to Fig. 5 but with the trend line extrapolated far back into the past, the result is Fig. 6. Although that figure must be viewed in the light of the *caveat* given above concerning the possible errors of the early observations, it certainly does give the impression of portraying an orbit most of which has been traversed in the 72 years spanned by the observations. A plausible orbit with a period of about 90 years could readily be fitted to the points, but the writer (though quite capable of carrying it out himself) prefers to leave his successors to perform that simple task when they have accumulated good measurements for long enough to derive a *reliable* orbit.

Gray has provided important evidence, referred to above, that even in the red the spectrum of HR 3112 includes a substantial contribution from a hot companion. Not only are the late-type lines apparently filled in to a significant extent (about a quarter) by what may be supposed to be the quasi-continuous spectrum of a hot star, but the existence of such an object would provide a natural explanation for the remarkably blue colour index for a star of the type (G9) assigned by Gray. It would not, however, explain the G1 and G2 types[22–24] given on the basis of direct classification of the spectrum. Experiments with photometric models show that a combination of G9III and A2V, with a ΔM_V of $0^m \cdot 8$, reproduces the colour indices of HR 3112 excellently, and moreover has an intensity ratio of 3 at λ 6200 Å, just as observed by Gray. Such a combination ought to appear conspicuously composite in the violet and to be

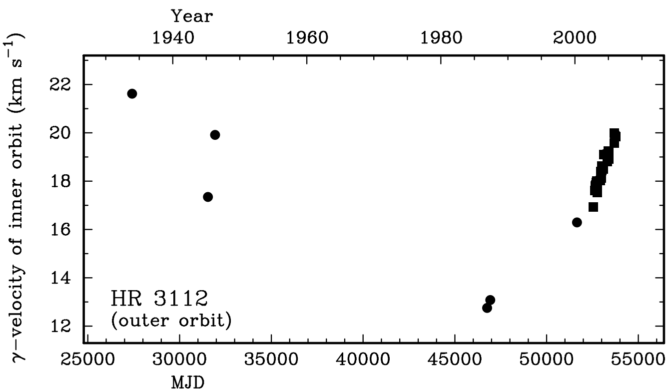

FIG. 6

Variation of the γ-velocity of HR 3112 over the whole time-span of the available radial-velocity data. The right-hand portion of the diagram repeats Fig. 5 on a much reduced scale; the filled circles plot the positions that the radial velocities provided by Wilson & Joy[22,31] (1933, 1945/6), de Medeiros & Mayor[15] (1986/7), and Marrese *et al.*[32] (2000) occupy after the computed contributions from the variation attributable to the inner orbit have been subtracted from them.

dominated by the hot component in even the 'ground-based' part of the ultraviolet.

It is easy to decide whether the putative hot companion should be considered to be the one in the 97-day orbit or the distant one. The mass function of the inner orbit is only 0·008 $M_\odot$, a value that could be achieved by a companion with a mass of only 0·5 $M_\odot$ if the primary is supposed to be not much more than 2 $M_\odot$. The mass function of the outer orbit which we have refrained from calculating is, however, about 0·3 $M_\odot$ and requires a secondary nearly as massive as the principal star even if the orbital inclination is high. Thus we favour a model of the system in which there is an invisible companion, probably a K or M dwarf, in the 97-day orbit, and a hot main-sequence star (which, remarkably, has never been explicitly noticed in the spectrum), with a type close to A2 V, in the long-period outer orbit. The mean separation of the components in that orbit should be about 30 AU; it should be about 20 AU at the moment, because it is obvious from Fig. 6 that we are close to periastron. The characteristic angular separation should therefore be about 20 times the parallax, *viz.*, 0″·12.

Having reached such conclusions purely from a study of the new radial velocities and a few historical ones, plus the discrepancy between the colour index and the temperature type and Gray's recent comments on the apparent dilution of the spectrum in the red, one was greatly encouraged by noticing that *Hipparcos* saw HR 3112 as a double star with a ΔHp of $0^m·51 \pm 0^m·12$ and an angular separation of 0″·159. It seemed so remarkable that what ought to be a very conspicuous example of a composite spectrum had completely escaped attention until now that direct confirmation was very desirable. Through the good offices of Dr. R. E. M. Griffin, Dr. D. Bohlender very kindly observed HR 3112 on 2006 February 10 with the Dominion Astrophysical Observatory's 72-inch reflector. He obtained 10-Å mm^{-1} spectra (resolving power about 10 000) at Hα and in the λ 3700-Å region in the near-ultraviolet. The spectra fully confirm expectations.

In a late-type giant Hα is[33] a strong line about 2 Å wide, with a steep-sided profile and very little in the way of extended wings, whereas in early-type stars the line has not only a deep core but also a very broad wing profile extending over something like 50 Å. What is seen in HR 3112 is a combination of both: Hα has a deep and rather box-like core, which no doubt largely represents the late-type spectrum although it must include a contribution from the core of the early-type profile, but superimposed upon it is the wide profile of the early-type component. It is hard to estimate just how far towards the centre of the profile the broad component should be deemed to extend, but conservatively one could estimate that the absorption at the point of inflexion amounts to about 12% of the height of the continuous spectrum. If Vega could be taken as a fair example of an early-type spectrum, the true depth of the early-type Hα line at that point is[34] something like 40%; that would yield an estimate of 12/40, *i.e.* 30%, for the contribution of the hot star at that wavelength. Dr. Bohlender's ultraviolet spectrum extends between limiting wavelengths of 3610 and 3880 Å. It shows very strong Balmer lines from H9 to H14, which thereafter rapidly tail off and become lost in the forest of late-type lines. Those Balmer lines are not visible at all in the spectrum[33] of a late-type giant and must be ascribed wholly to the early-type star. The late-type lines cut the spectrum up to such an extent that it is not possible to say confidently, without a proper analysis based on either an apportioning or a synthesis of the composite spectrum, what proportion of the light comes from each component in that part of the spectrum, but it is safe to conclude that the hot star contributes more than 50%. There is, accordingly, no reason to modify the component classifications estimated above, *viz.*, G9 III and A2 V, of which the former is due to Gray and the latter from photometric modelling of the colour indices of the combination.

HR 3112 is the primary of a wide visual double star, OΣ (App.) 90 (that arcane nomenclature was carefully explained in Paper 42[35] of this series). The system is listed in Burnham's 1906 catalogue[36], where it is also called "Ursae Majoris 2", as BDS 4359 and is noted as being relatively fixed, at a separation and position angle of about 48″ and 82°. The secondary star is not far from that same position now: neither component has a large proper motion, but the separation has increased slightly to about 51″. The secondary is HD 65447 and is quite a bright star in its own right, having *Tycho*-derived magnitudes of $V = 7^{m}\cdot52$, $(B-V) = 0^{m}\cdot93$. The *HD* type is F8, but that is much too early to accord with either its colour or the nature of the radial-velocity traces that it gives. Its velocity has been measured at Cambridge four times. On the second, third and fourth occasions that the primary was observed (*cf.* Table II) it gave velocities of $-13\cdot0$, $-12\cdot6$, and $-12\cdot4$ km s^{-1}, respectively, and on 2004 March 1·03 it was $-12\cdot0$ km s^{-1}. It could well be a single star.

HR 4454

HR 4454 (HD 100518) is a $6^{1}/_{2}{}^{m}$ Am star to be found about 5° south-preceding Denebola (β Leo). It is the preceding member of a triangle of stars, about 20′ on a side, of almost identical brightness, the other members being HR 4464 at the south vertex and HD 100717 at the north. Its *V* magnitude has usually been found[37–42] to be very close to $6^{m}\cdot55$, so it is only by the grace of a little luck that the star features in the *Bright Star Catalogue*, whose ostensible cut-off is at $6^{m}\cdot5$; Osawa[43] gave a seemingly discordant magnitude of $6^{m}\cdot46$, but that was not a new measurement but was simply copied (*via* the second edition of the *Bright Star Catalogue*) from the *Henry Draper Catalogue*. The colour indices have been given by both Osawa[43] and Feinstein[38] as $(B-V) = 0^{m}\cdot18$, $(U-B) = 0^{m}\cdot10$, and by Eggen[39] as $0^{m}\cdot20$ and $0^{m}\cdot085$, respectively.

The *HD* type of HR 4454 is A2. Osawa considered its spectral type to be A5 V, but noted that the metallic lines would indicate A8. Anne Cowley[44] more explicitly recognized it as an Am star, putting it at A2m and noting that the same discovery had been made independently (but not published) by Bidelman. Gray & Garrison[45] gave a complete metallic-line classification, kA2hA7mA7 (IV+) where the + was intended to indicate that the luminosity is somewhat *brighter* than would correspond to class IV. Abt & Morrell[46] classified the star as A2A5IIIA6. It is the present writer's belief that the convention in specifying the sub-type in a (non-detailed) Am classification is that it is *hydrogen* (Balmer-line) type that counts, so an averaged type for HR 4454 would be about A5m and not the A2m that is often given, for example, in the *Bright Star Catalogue*[20].

There have been several estimates of the star's luminosity, in addition to those implicit in the spectral classifications. Young & Harper[47] separately and independently obtained $M_V = 2^{m}\cdot0$: and $2^{m}\cdot4$:, respectively, from classical comparisons of luminosity-sensitive line-pairs seen on DAO Cassegrain spectra. They gave the results from each line-pair separately, and it is of interest that the reason why their final results were both listed with colons to indicate uncertainty was because the ratio 4071/4077, involving the Sr II line λ 4077 Å, was discrepant, giving 'too bright' a luminosity, such as we can now see would naturally be caused by the enhancement, concomitant with the Am nature of the star, of the strontium line. Eggen[39] listed an absolute magnitude of $2^{m}\cdot2$ stemming from an index that he called $[c_1]$, derived from Strömgren photometry; Wolff & Simon[48] obtained $2^{m}\cdot31$, also from Strömgren indices, and Hauck & Curchod[49] obtained $2^{m}\cdot06$ from Geneva photometry. Despite the excellent agreement of all those luminosity estimates, they all appear to be slight *under*-estimates in the light of the *Hipparcos* parallax of $0''\cdot00880 \pm 0''\cdot00103$, which leads to a distance modulus of $5^{m}\cdot28 \pm 0^{m}\cdot25$ and thus to an absolute magnitude of $+1^{m}\cdot3$, with the same uncertainty.

An exciting discovery concerning HR 4454 was made by *Hipparcos*, which noticed a relatively faint companion just under one second of arc away from the principal star. It is noted in the *Hipparcos Catalogue*[50] as being at a distance of $0''\cdot940 \pm 0''\cdot013$ in position angle 244°, and to have a ΔHp of $2^{m}\cdot74 \pm 0^{m}\cdot05$. The 'Double and Multiple Stars' volume of the *Catalogue* (Vol. **10**) does not include any entries for the *Tycho* magnitudes of the components, but that omission was repaired by Fabricius & Makarov[51], who made a special study of the *Tycho* photometry of double and multiple stars, and listed for HR 4454 $V_T = 6^{m}\cdot69$ and $9^{m}\cdot43$, $B_T = 6^{m}\cdot87$ and $10^{m}\cdot21$. Transformed[52] to V and B, those values equate to $V = 6^{m}\cdot67$ and $9^{m}\cdot36$ and $(B-V) = 0^{m}\cdot15$ and $0^{m}\cdot66$. At the distance modulus of $5^{m}\cdot28$ already noted (and not likely to be much increased by interstellar absorption, especially in view of the high galactic latitude of nearly 66°), those apparent magnitudes correspond to absolute V luminosities of approximately $1^{m}\cdot4$ and $4^{m}\cdot1$. The luminosity and colour of the companion indicate that it is a main-sequence star with a type near G0. The projected linear separation of more than 100 AU suggests that the period is likely to be several centuries at least, so there is no possibility that the *Hipparcos* companion could be identified with either of the spectroscopic ones whose presence is demonstrated by the radial velocities discussed below.

There have been a few measurements of the radial and rotational velocities of HR 4454. The earliest radial-velocity measurements were by Harper[53], who in 1923 obtained just two DAO plates which gave almost identical radial velocities of $-9\cdot8$ and $-9\cdot6$ km s^{-1} — by great misfortune they were taken just under nine days apart and so missed discovering the velocity variations whose period is 8·92 days. Young[54] obtained four plates at the DDO, but published only a mean velocity of $-4\cdot1$ km s^{-1} with a 'probable error' of 1·8 km s^{-1}; he gave a DDO classification of A0. While acknowledging that there were only those six radial-velocity measurements — and giving for them a mean (no doubt copied, numerically, from the *Radial Velocity Catalogue*[55]) of -5: km s^{-1} — Eggen[39] unaccountably asserted that HR 4454 was a spectroscopic binary with a period of 2·78 days. (It may be pertinent to note that HR 4535, which is a spectroscopic binary that actually *has* got[56] a period of 2·78 days, also features in Eggen's paper[39].) Abt & Morrell[46] measured a projected rotational velocity of 10 km s^{-1} for HR 4454; Wolff & Simon[48] gave 17 km s^{-1}; Royer *et al.*[57], in a paper whose title promises rotational-velocity measurements but whose substance is accessible only by laborious application to a remote computer, in fact did not give a new measurement but only listed a literature value of 18 km s^{-1}, which they attributed to Abt & Morrell[46], who actually reported 10 km s^{-1} as has just been noted. Fekel[58] found the rotation to be only 7 km s^{-1}. Beavers & Eitter[59] published two radial velocities obtained with the Iowa State University's photoelectric spectrometer[60]; they were very different from one another and could be said to represent the discovery of HR 4454 as a spectroscopic binary.

The star was placed on the Cambridge observing programme (which at that time was being executed exclusively at Haute-Provence with the Geneva Observatory's *Coravel*) in 1993; only one observation was obtained in that year, but the second measurement, early in 1994, was very discordant with it, and the ensuing recognition that the velocity changed on a very short time-scale prompted an effort that resulted in the discovery of the 9-day period in that same season. Intensive observations at the start of the next (1994/5) season did not fit the preliminary orbit at all, and it soon became clear that an enormous change (about -15 km s^{-1}) had taken place in the γ-velocity, in little more than six months. Such a rate of variation was by no means maintained in the ensuing years, but in the course of a decade the original γ-velocity was gradually recovered and recently a second periastron passage has been witnessed in the outer orbit. Owing to the closeness of the period to an integral number of years (it is 10·96 years), an important part of the periastron passage has again been missed although the event was fully anticipated and every effort was made to minimize the inter-season gap; all the same, the orbit is well determined, and the need to keep a watch on the outer orbit has meant that a large number of observations (120) has accumulated, so the inner orbit too is very well covered. HR 4454 is obviously of a very early type for observation with photoelectric radial-velocity spectrometers, and is measurable at all only because of its metallic-lined nature; the depth of the dip in the traces is only about 7% of the continuum. All the same, the brightness of the star makes it possible to obtain quite good velocities if integration times are extended to several minutes.

Four of the 120 measurements have been obtained at the DAO, 57 with the Haute-Provence *Coravel*, and 59 with the Cambridge one. Of the 59, nine were obtained in 1996/7 when the instrument was operating in a preliminary fashion (it then ceased to do even *that* until late 1999), and on the evidence of a statistical survey of the residuals those observations have been weighted 1/4 in the solution of the orbits. As usual, the Haute-Provence measurements have been adjusted by +0·8 km s^{-1}; they are more ragged than the Cambridge ones and have merited a relative weight of 0·15, and the same is true of the DAO ones. The Cambridge velocities seem to need a significant negative offset, which too is usual for stars of early type, and a correction of −0·8 km s^{-1} has been applied to them. The DAO velocities, which were initially reduced to the scale originally set up at Cambridge[61] for four late-type giants, have needed an adjustment of +0·8 km s^{-1}. It has been considered safest not to include in the orbital solution the two pairs of published observations[53,59], but it has seemed fair to apply to them the offset of +0·8 km s^{-1} found[62] between the Lick/IAU scale and the Cambridge one, and in the case of Harper's measurements[53] to make the additional correction of +1·0 km s^{-1} that Wilson[63] determined for early DAO measures of A-type stars. All the offsets mentioned have already been applied to the data as they are listed in Table III. From those data and with those weightings, the two orbits have been computed simultaneously by a program that solves for all 11 unknowns at once; they are illustrated in Figs. 7 and 8, and their elements are given below. The results of the calculation are given for each observation in Table III in the form of the phases and the corresponding computed velocity components arising from each of the orbits, and finally the

TABLE III

Radial-velocity observations of HR 4454

Except as noted, the sources of the observations are as follows:
Up till 1998 — Haute-Provence Coravel (weighted 0·15 in orbital solution);
1999 onwards — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity*	*Outer Orbit*		*Inner Orbit*		*(O−C)*
			Phase	*Velocity*	*Phase*	*Velocity*	
		km s^{-1}		*km s^{-1}*		*km s^{-1}*	*km s^{-1}*
1923 Apr. 23·26*	23532·29	−8·0	$\overline{6}$·510	−2·2	$\overline{2861}$·773	−5·4	−0·4
May 2·24*	541·27	−7·8	513	−2·2	$\overline{2860}$·781	−5·0	−0·7
1981 Feb. 24·27†	44659·29	−4·0	$\overline{1}$·784	+4·8	$\overline{491}$·519	−8·8	0·0
Mar. 20·23†	683·25	+13·7	·790	+5·0	$\overline{488}$·207	+7·1	+1·6
1993 Feb. 16·07	49034·08	+14·9	0·876	+8·1	0·225	+5·9	+0·9
1994 Jan. 5·13	49357·13	+2·2	0·957	+8·3	36·460	−7·0	+0·9
Feb. 16·10	399·09	+16·9	·967	+7·4	41·168	+9·3	+0·2
19·09	402·08	+0·1	·968	+7·3	·503	−8·4	+1·2
21·03	404·02	−1·1	·969	+7·3	·721	−7·8	−0·5
Apr. 29·92	471·91	+2·9	·986	+4·7	49·336	−1·0	−0·8
30·90	472·89	−1·1	·986	+4·7	·446	−6·5	+0·7
May 1·90	473·89	−6·3	·986	+4·6	·558	−9·5	−1·4
2·88	474·87	−6·2	·986	+4·6	·668	−9·3	−1·5
3·93	475·92	−0·1	·987	+4·5	·785	−4·7	+0·1
4·89	476·88	+9·3	·987	+4·5	·893	+3·2	+1·6
Dec. 10·15	696·14	−14·3	1·042	−6·2	74·487	−7·9	−0·1
11·11	697·10	−15·4	·042	−6·3	·594	−9·8	+0·7
11·22	697·21	−15·9	·042	−6·3	·607	−9·9	+0·3
12·15	698·14	−15·1	·042	−6·3	·711	−8·2	−0·6
12·25	698·24	−14·7	·042	−6·3	·722	−7·8	−0·6
13·08	699·07	−8·4	·042	−6·3	·815	−2·7	+0·7

TABLE III (*continued*)

Date (UT)	*MJD*	*Velocity* km s⁻¹	*Outer Orbit* *Phase*	*Outer Orbit* *Velocity* km s⁻¹	*Inner Orbit* *Phase*	*Inner Orbit* *Velocity* km s⁻¹	*(O–C)* km s⁻¹
1994 Dec. 13·17	49699·16	−8·2	1·042	−6·3	74·825	−2·0	+0·2
13·25	699·24	−9·9	·042	−6·4	·834	−1·4	−2·2
14·08	700·07	+0·1	·043	−6·4	·928	+6·0	+0·5
14·24	700·23	+1·4	·043	−6·4	·946	+7·3	+0·4
28·14	714·13	−16·1	·046	−6·8	76·505	−8·4	−0·8
29·16	715·15	−17·1	·046	−6·9	·619	−9·8	−0·4
31·22	717·21	−6·0	·047	−6·9	·850	−0·2	+1·1
1995 Jan. 2·14	49719·13	+4·3	1·047	−7·0	77·065	+12·2	−0·9
3·10	720·09	+2·5	·048	−7·0	·173	+9·0	+0·5
4·14	721·13	−4·5	·048	−7·0	·290	+1·8	+0·7
5·13	722·12	−11·9	·048	−7·1	·401	−4·5	−0·4
6·16	723·15	−15·3	·048	−7·1	·516	−8·7	+0·5
7·12	724·11	−16·1	·049	−7·1	·624	−9·8	+0·8
8·13	725·12	−14·0	·049	−7·1	·737	−7·2	+0·3
10·18	727·17	+2·1	·049	−7·2	·967	+8·8	+0·5
May 30·96	867·96	−16·1	·084	−9·5	93·759	−6·2	−0·4
June 1·89	869·89	−0·8	·085	−9·5	·975	+9·3	−0·6
2·85	870·85	+2·8	·085	−9·5	94·083	+12·1	+0·2
4·85	872·85	−7·2	·086	−9·5	·307	+0·8	+1·6
5·88	873·88	−16·1	·086	−9·5	·423	−5·5	−1·1
6·86	874·86	−17·8	·086	−9·5	·533	−9·1	+0·8
Dec. 27·13	50078·13	−13·1	·137	−9·8	117·333	−0·8	−2·4
1996 Jan. 1·14	50083·14	−5·0	1·138	−9·8	117·895	+3·4	+1·4
Mar. 29·00	171·00	−17·0	·160	−9·5	127·750	−6·6	−0·9
30·01	172·01	−8·8	·160	−9·5	·864	+0·9	−0·2
30·96	172·96	−0·6	·161	−9·5	·970	+9·0	−0·1
31·97	173·97	+2·9	·161	−9·5	128·084	+12·1	+0·3
Apr. 2·91	175·91	−8·9	·161	−9·5	·301	+1·1	−0·5
3·94	176·94	−14·4	·162	−9·5	·417	−5·2	+0·3
24·96	197·97	−15·4	·167	−9·4	130·775	−5·3	−0·7
25·83	198·84	−8·3	·167	−9·4	·872	+1·5	−0·4
Nov. 21·23‡	408·24	−11·6	·219	−8·4	154·360	−2·4	−0·8
Dec. 15·22	432·23	+3·6	·225	−8·3	157·051	+12·1	−0·2
16·14	433·15	+1·2	·226	−8·3	·155	+9·9	−0·4
25·20	442·21	+1·7	·228	−8·2	158·171	+9·1	+0·8
1997 Jan. 23·09	50471·10	−14·0	1·235	−8·1	161·411	−5·0	−0·9
Feb. 8·09‡	487·10	−0·2	·239	−8·0	163·206	+7·1	+0·7
Mar. 1·11‡	508·12	−17·0	·244	−7·9	165·564	−9·6	+0·5
3·07‡	510·08	−12·1	·245	−7·9	·784	−4·8	+0·6
27·03‡	534·04	−14·5	·251	−7·8	168·471	−7·4	+0·7
29·96‡	536·97	−10·7	·251	−7·7	·800	−3·8	+0·8
Apr. 10·96‡	548·97	+3·6	·254	−7·7	170·146	+10·3	+1·0
17·93‡	555·94	−2·1	·256	−7·6	·928	+6·0	−0·5
May 3·84‡	571·85	−15·3	·260	−7·6	172·712	−8·1	+0·4
Dec. 22·17	804·19	−11·4	·318	−6·3	198·773	−5·4	+0·3
24·18	806·20	+3·1	·319	−6·3	·998	+10·5	−1·1
1998 Apr. 28·92	50931·94	+6·1	1·350	−5·6	213·102	+11·8	0·0
July 7·87	51001·89	+1·3	·368	−5·3	220·948	+7·5	−1·0
24·84	018·86	−6·2	·372	−5·2	222·852	−0·1	−1·0
1999 Apr. 9·30§	51277·32	−6·0	1·436	−3·8	251·843	−0·8	−1·4
17·28§	285·30	−10·3	·438	−3·8	252·738	−7·1	+0·6
July 8·23§	367·25	+2·8	·459	−3·3	261·930	+6·2	0·0
Nov. 4·57§	486·60	−2·3	·489	−2·7	275·316	+0·2	+0·2
Dec. 20·20	532·23	−8·3	·500	−2·5	280·434	−6·0	+0·2

TABLE III (*concluded*)

Date (UT)	*MJD*	*Velocity* km s⁻¹	*Outer Orbit Phase*	*Outer Orbit Velocity* km s⁻¹	*Inner Orbit Phase*	*Inner Orbit Velocity* km s⁻¹	*(O−C)* km s⁻¹
2000 Jan. 9·13	51552·16	−11·8	1·505	−2·4	282·670	−9·3	−0·2
Feb. 20·08	594·11	−5·3	·515	−2·1	287·375	−3·2	0·0
Mar. 22·01	625·04	−3·0	·523	−2·0	290·844	−0·6	−0·4
Apr. 22·90	656·93	−7·4	·531	−1·8	294·421	−5·4	−0·2
June 1·91	696·94	+3·2	·541	−1·6	298·909	+4·5	+0·2
Nov. 17·25	865·28	−5·4	·583	−0·6	317·791	−4·3	−0·5
Dec. 14·20	892·23	−2·5	·590	−0·5	320·814	−2·8	+0·8
2001 Jan. 14·15	51923·18	+2·0	1·598	−0·3	324·286	+2·1	+0·2
Feb. 22·09	962·12	−9·7	·607	0·0	328·653	−9·5	−0·1
Mar. 14·02	982·05	+3·2	·612	+0·1	330·889	+2·9	+0·2
Apr. 28·94	52027·97	+12·6	·624	+0·4	336·040	+11·9	+0·3
May 29·90	058·93	−8·3	·631	+0·5	339·512	−8·6	−0·2
Nov. 5·23	218·25	−2·6	·671	+1·5	357·384	−3·6	−0·5
Dec. 14·27	257·29	−4·4	·681	+1·8	361·763	−6·0	−0·2
2002 Jan. 4·20	52278·22	+13·7	1·686	+1·9	364·110	+11·6	+0·2
Feb. 4·15	309·17	−7·0	·694	+2·2	367·582	−9·8	+0·6
Mar. 1·06	334·08	−0·6	·700	+2·3	370·376	−3·2	+0·3
Apr. 4·00	368·02	+11·1	·709	+2·6	374·183	+8·5	+0·1
May 1·96	395·98	+2·6	·716	+2·8	377·319	0·0	−0·2
June 1·90	426·92	−0·9	·723	+3·0	380·789	−4·5	+0·6
Dec. 5·23	613·25	−4·8	·770	+4·4	401·689	−8·8	−0·3
2003 Jan. 11·14	52650·16	+2·7	1·779	+4·7	405·829	−1·8	−0·2
Feb. 18·06	688·08	+16·4	·788	+5·0	410·082	+12·1	−0·7
Mar. 19·01	717·03	+4·4	·796	+5·2	413·329	−0·6	−0·2
Apr. 15·96	744·98	−1·5	·803	+5·5	416·464	−7·2	+0·2
May 13·92	772·93	−4·5	·810	+5·7	419·600	−9·9	−0·3
June 4·90	794·91	+18·0	·815	+5·9	422·066	+12·2	−0·1
Nov. 28·25	971·26	+7·2	·859	+7·5	441·846	−0·5	+0·3
Dec. 27·25	53000·26	+19·8	·866	+7·7	445·098	+11·9	+0·2
2004 Feb. 9·14	53044·15	+20·1	1·877	+8·1	450·021	+11·5	+0·5
Mar. 2·11	066·12	+0·4	·883	+8·3	452·486	−7·9	0·0
Apr. 14·00	109·00	+10·0	·894	+8·6	457·296	+1·4	0·0
May 18·93	143·93	+15·3	·902	+8·9	461·214	+6·6	−0·2
June 4·93	160·93	+19·8	·907	+9·0	463·121	+11·3	−0·4
Nov. 14·26	323·26	+8·3	·947	+8·9	481·328	−0·5	−0·1
Dec. 26·23	365·23	+20·6	·957	+8·3	486·036	+11·8	+0·4
2005 Jan. 11·19	53381·19	+5·8	1·961	+8·0	487·826	−2·0	−0·2
Mar. 12·09	441·08	−3·1	·976	+6·2	494·544	−9·3	0·0
25·02	454·01	+16·1	·980	+5·7	495·995	+10·4	0·0
Apr. 3·95	463·94	+16·5	·982	+5·3	497·108	+11·6	−0·5
21·94	481·93	+15·8	·987	+4·5	499·126	+11·1	+0·2
May 4·96	494·95	−5·7	·990	+3·9	500·587	−9·8	+0·2
21·92	511·91	−5·0	·994	+3·0	502·489	−8·0	0·0
31·91	521·90	−7·4	·997	+2·5	503·610	−9·9	0·0
Nov. 5·23	679·22	−1·1	2·036	−5·4	521·256	+4·0	+0·3
25·24	699·23	−14·1	·041	−6·2	523·500	−8·3	+0·4
Dec. 17·23	721·22	+1·1	·046	−6·9	525·967	+8·8	−0·8
2006 Jan. 29·14	53764·13	−13·3	2·057	−8·0	530·780	−5·0	−0·3
Feb. 16·10	782·09	−12·0	·062	−8·3	532·794	−4·1	+0·4

*Published DAO observation[53]; weight 0.
†Published Fick observation[59]; weight 0.
‡Observed with Cambridge *Coravel*; weight 0·25.
§Observed with DAO 48-inch telescope; weight 0·15.

residual. The latter is simply the difference between the measured velocity and the sum of its computed components. The civil dates given in Table III are the actual times of observation, but the MJDs have been corrected for light-travel time to the barycentre of the system. The correction ranges up to about 38 minutes ($=(a_1 \sin i)(1+e)/c$).

Element	*Outer orbit*	*Inner orbit*
P (days)	4006 ± 6	8·91530 ± 0·00006
T (MJD)	53535 ± 7	52223·75 ± 0·07
Γ (km s^{-1})	−1·44 ± 0·06	
K (km s^{-1})	9·58 ± 0·08	11·02 ± 0·07
e	0·522 ± 0·005	0·122 ± 0·006
ω (degrees)	77·2 ± 1·1	329·2 ± 3·0
$a_1 \sin i$ (Gm)	450 ± 4	1·341 ± 0·008
$f(m)$ ($M_\odot$)	0·227 ± 0·006	0·001212 ± 0·000023

R.m.s. residual (weight 1) = 0·34 km s^{-1}

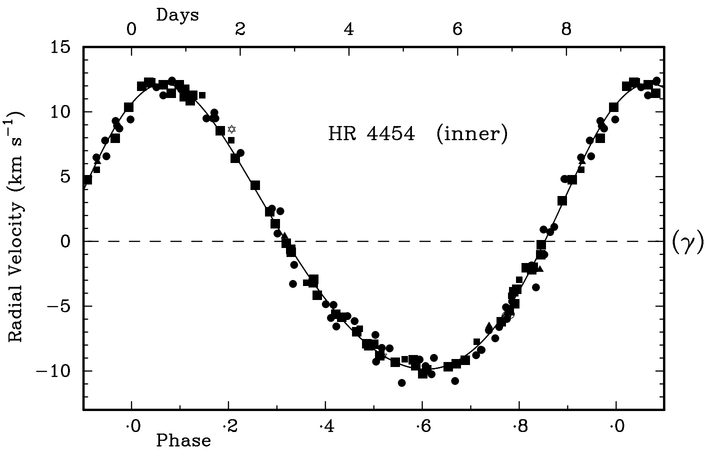

FIG. 7

Radial-velocity measurements of HR 4454, plotted as a function of phase in the inner orbit, with the velocity curve corresponding to the adopted orbital elements drawn through them. Filled symbols are used to plot the writer's own measurements. Squares are for those made at Cambridge; they are plotted with somewhat larger symbols than the others because they are substantially more accurate. Those obtained in 1996/7, however, when the instrument was operating in a preliminary form, are plotted smaller and were weighted 1/4 in the solution of the orbits. Circles are for Haute-Provence and triangles for DAO measures, both weighted 0·15. Open circles with crosses in them (unfortunately almost hidden, near phase ·78) identify two velocities obtained in 1923 by Harper[50], who was unlucky enough to observe them almost exactly one cycle apart; open star symbols (again, one is almost hidden) plot two velocities measured by Beavers & Eitter[55] in 1981. Neither of the pairs of published observations was utilized in the solution of the orbits, although both are seen to be entirely consonant with them.

It is seen that the published observations[53,59], even those[53] from more than 80 years ago, agree extremely well with the orbit computed purely on the basis

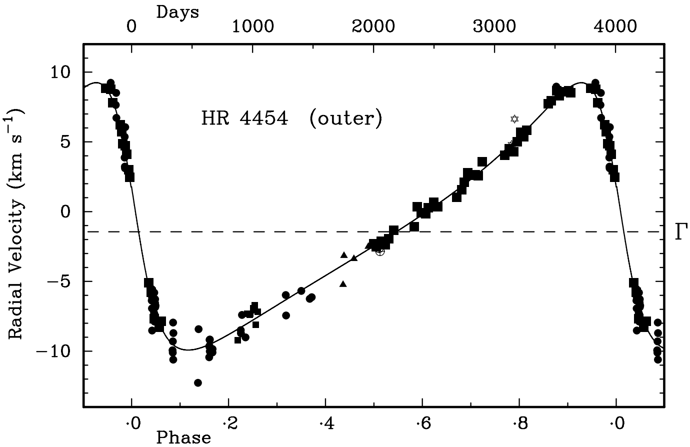

FIG. 8

As Fig. 7, but plotting the *outer* orbit of HR 4454. (The open symbols are all more or less visible in this figure.)

of the newly measured velocities. The standard deviation of about five seconds in the period of the 9-day orbit would multiply up to more than 4 hours (0·02 periods in terms of phase) in the > 3000 periods between the first observations and the modern epoch; those observations are seen to corroborate the phasing at least to that order.

A glance at the mass functions in the table above shows that the companion in the outer orbit must be of very considerable mass, but the one in the inner orbit need not be. The mass of the principal (Am) star is likely[64] to be 2 $M_{\odot}$, perhaps a little more; the minimum mass required for the 9-day secondary is then less than 0·2 $M_{\odot}$, such as could well characterize a mid-M dwarf that would be about ten magnitudes fainter than its primary and therefore altogether undetectable. It must of course be recalled that the quoted mass is only a *minimum* value, and that the actual mass of the secondary could be larger to any degree, depending as it does on the orbital inclination. Statistically, however, inclinations are high, and it would need an unusually low value to raise the luminosity of the secondary to the point where it was at all comparable with that of the primary. In considering the components in the outer orbit, we have to treat the complete 9-day system as the primary, so its putative mass must be put slightly above that of the Am star, at 2·2 $M_{\odot}$ or so. The outer mass function then demands a secondary whose mass is at least about 1·4 $M_{\odot}$, which corresponds[64] to a spectral type of about F4 and a luminosity scarcely as much as two magnitudes fainter than the A star even if the inclination of the outer orbit is so high that $\sin i$ is nearly 1. Among HR 4454's three companions in successive hierarchies, therefore, it is the one in the 4000-day orbit that can be expected to be the brightest, and it should be within two magnitudes of the brightness of the overall primary. There is a loophole in that conclusion, however, inasmuch as there is nothing to prevent the secondary (like the primary) being itself a double star. In that case the joint luminosity of its components could be much fainter than if the secondary were a single star —

a pair of 0·7-$M_\odot$ (about K5 V) stars would be five magnitudes fainter than the Am object. Observationally, no sign has been seen of any component apart from the obvious one. Soon after the interest of HR 4454 became apparent, Dr. H. A. Abt kindly obtained a spectrum of the star with the Kitt Peak coudé-feed system; it seemed not to show anything other than the Am spectrum. It has already been mentioned that even the Am star gives very shallow dips in *Coravel* traces; to see ones that are several times weaker still from a possible F-type companion would be asking rather a lot. Even if a second dip could not be seen as a separate entity, however, it could be expected often to blend with the main dip, thereby creating velocity errors substantially larger than the r.m.s. value of 0·34 km s^{-1} that has actually been obtained with the Cambridge instrument. It is tentatively concluded, therefore, that either the 4000-day companion is double, or else its dip in radial-velocity traces is smeared into invisibility by rapid rotation.

Mean values for the rotational velocity of the Am star have been determined at 7·4 km s^{-1} by the Haute-Provence traces and at 6·3 km s^{-1} by the Cambridge ones, in each case with a formal standard deviation less than 1 km s^{-1}; we could take 7 km s^{-1} as a representative value, and we note its exact agreement with Fekel's[58]. The pseudo-synchronous rotation period for the period and eccentricity of the inner orbit is close to 8·1 days; compatibility with the rotational velocity would require that $R_\star \sin i \sim 1 \cdot 1\ R_\odot$. Since the radius of the star is likely to be 2 $R_\odot$ or so, synchronization would imply that $\sin i \sim 0 \cdot 5$ or $i \sim 30°$, which is altogether plausible but cannot be claimed as a definite conclusion.

The projected major axis of the 4000-day orbit of the principal star measures just 3 AU. We have seen above that the object that is in orbit with it must have a mass that is not much less than 2/3 of that of the primary system, so in round numbers the projected major axis of its orbit can be no more than 5 AU, making the total for the relative orbit at most 8 AU. Not much increase can be expected from any allowance for $\sin i$, otherwise the mass function becomes unacceptable. Therefore a characteristic angular separation of the components should be about eight times the parallax, or 0″·07 — smaller by a factor of about 13 than the distance of the *Hipparcos* companion, but nevertheless large enough to encourage efforts at resolution by speckle or other forms of optical interferometry.

Acknowledgements

I am very grateful to Dr. D. Bohlender for obtaining very promptly the spectra of HR 3112 that confirm so definitely its composite-spectrum nature, as well as to Dr. R. E. M. Griffin whose familiarity with the DAO observing schedules enabled her to direct a request for such spectra to such a favourable quarter.

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REVIEWS

Extinction: How Life on Earth Nearly Ended 250 Million Years Ago, by D. H. Erwin (Princeton University Press, Woodstock), 2006. Pp. 296, 24 × 16·5 cm. Price £15·95/$24·95 (hardbound; ISBN 0 691 00524 9).

Two hundred and fifty million years ago, life on Earth suffered a catastrophic mass extinction. The collapse was sudden, occurring certainly within 160 000 years and probably within 20 000 to 30 000 years. Over that timescale or less, over 90% of all marine species disappeared. On land, at the same time, animal species disappeared *en masse*, 82% of vertebrate families becoming extinct at the Permo-Triassic (PT) boundary. Insects suffered their only mass extinction in the whole of their evolution, the number of insect families falling from about sixty to practically none at the PT boundary. Coals disappeared globally, in Antarctica, Australia, India, Russia, and China, at the same time as plant fossils changed in character. The end-Permian collapse was the 'mother of mass extinctions': it approached the extinction of life on Earth. The new, Mesozoic world which gradually emerged was profoundly different from the Paleozoic one which had gone before, a difference which feeds through to life forms today. So what caused it?

Douglas Erwin is a leading authority on this cataclysmic event and this is his second book on the subject, written in a more popular style than his previous monograph. He writes in the first person throughout, which carries risks in scientific writing, but he carries off this personal style with panache and modesty, more often than not telling the reader how wrong he was in his ideas at various stages of his studies of the 'Great Dying'. And his description of the many controversies which surround this enigmatic mass extinction seems entirely balanced; he even confesses that his personal preference for a multiplicity of causes has been badly damaged by new evidence for the rapidity of extinction, which rather suggests a single trigger. The result is in essence a detective story told in a chatty, unstuffy style, which makes for a pleasant and entertaining read while showing no discernible loss in academic rigour.

The book opens with a captivating description of the canyons and caves of the Guadalupe Mountains in Texas, seen through the eyes of a geologist standing on the sea floor of the Permian basin looking up towards a reef some 1200 feet above, as if all the water was removed: "hiking up the Permian Reef Trail in McKittrick Canyon is just like walking (or better, swimming) up to the face of the reef, as it was millions of years ago." This evocative description leads into a discussion of the fossils to be found on the hike, and thence to an overview of the extinction itself, and thumbnail descriptions of the other major extinctions of the past 600 million years. The discussion of the Cretaceous-Tertiary (KT or KP) extinctions — the dinosaur event — is somewhat uncritical, with no mention made of the fierce debate which still rages about whether a single or multiple impact was involved, whether the extinctions were instantaneous, and what rôle was played by the huge outpouring of basalt which occurred at the same time and covered much of India to a depth of some kilometres. Since the KT event might provide clues to the PT one, a more critical discussion would have been beneficial.

In fact, the Permo-Triassic extinction was at least a twin event, two massive events separated by a few million years. Occurring at around the same time was — again — a massive outpouring of basalt (about 4×10^6 km^3), this time in

Siberia. The seas became anoxic, and the atmosphere and oceans showed a distinct double-dip in the carbon isotope ratio $^{13}C/^{12}C$, implying that a huge volume of organic carbon (plants prefer ^{12}C for photosynthesis) was added to the oceans and atmosphere at the time of the mass extinction. This chemical change took less than 160 000 years and there are hints of several such spikes. There is no consensus about cause and effect in this complex situation, but Erwin leads the reader carefully through the major issues in a clear fashion. Out of a cacophony of hypotheses, Erwin considers impact and volcanism — the latter creating a harsh world of acid rain, massive releases of carbon dioxide, and thermal pulses — as the prime candidates.

Was it an impact? In spite of 25 years of investigation, the evidence for impact remains at best scant and controversial, and the connection with the basalt outpourings — surely not coincidental — is not understood.

Here lies a problem with the field. Because of its interdisciplinary nature, it is all but impossible for a single individual to have a full, professional grasp of all the relevant factors. The KT and PT extinctions appear to have occurred when, on reasonable Galaxy models, the Sun was passing through the Sagittarius and Scutum spiral arms, respectively. Several processes could act to shift global climate during such passages, changing the moment of inertia of the mantle and creating stresses at the core-mantle interface, possibly with the creation of superplumes. Such models have been discussed several times in the literature. But the Galaxy doesn't get a mention in Erwin's book, nor molecular clouds, nor Oort Cloud disturbances, nor cometary dusting. And yet multiple bombardments during passage through a spiral arm, coupled possibly with prolonged climatic disturbances, could well turn out to provide the most satisfactory framework for understanding this drastic event.

Erwin's earlier monograph *The Great Palaeozoic Crisis* was written in 1993, and it is interesting to see how fashions have changed in the discussion of possible causes. Insofar as astronomical causes are concerned, cosmic rays are out (they no longer rate a mention) and impacts are in (a couple of pages in 1993, extensive discussions throughout the book in 2006). It will be interesting too to see what's in and what's out in another 15 years. — BILL NAPIER.

The Moon and How to Observe It, by P. Grego (Springer, Heidelberg), 2005. Pp. 276, 23·5 × 17·5 cm. Price £19·95/$29·95/€29·95 (paperback; ISBN 1 852 33748 6).

As its title suggests, *The Moon and How to Observe It* is divided into two parts. The first quarter of the book describes the evolution and physical nature of the Moon. Part 2 is dedicated to observational topics. This is not a book for those readers looking for the rôle of the Moon in the cultures of the world or for a history of space travel.

How much knowledge is the reader expected to have? The book briefly describes what volatiles and elliptical orbits are but mentions the Roche limit without explanation, either in the main text or in the glossary, so some previous reading in astronomy is a definite asset. No knowledge of mathematics is required.

Part 1 provides a concise prelude to the longer, observational part of the book. Some of the best colour illustrations in this part are the ones by the author himself. Grego provides a refreshingly clear explanation of how the Moon's surface and interior reached their present state, while refraining from the common practice of drowning the astronomy enthusiast in a sea of normally unwelcome geological jargon. The section comparing Earth's moon to the moons of other planets in the Solar System is particularly interesting, leaving the reader with many easily remembered facts with which to entertain members of the public as they queue for a look at the Moon through his or her telescope.

The bulk of the second part of the book is dedicated to descriptions of the author's favourite lunar features, accompanied by photographs, CCD images, and sketches. The latter, having been created by several observers, demonstrate a variety of drawing styles. Grego's own observational drawing of the crater Cleomedes is the most remarkable one in the book. To this reviewer, the sketch is almost hypnotic for its ability to convey the true experience of viewing a lunar feature with high magnification under less-than-ideal seeing conditions.

The book was obviously produced with great care. Only a few peculiarities escaped the final proofreading, such as in the section on lunar occultations where 20 milliseconds of arc is described as "the apparent diameter of a star 50 km away."

With the Moon included as a destination in NASA's new 'Vision for Space Exploration', this thoroughly up-to-date book may prove to be well suited for the intermediate amateur astronomer seeking more specialized knowledge of a timely subject. — BRIAN CHAPEL.

Pluto and Charon, 2nd Edition, by A. Stern & J. Mitton, (Wiley, Chichester), 2006. Pp. 244, 22 × 15 cm. Price £29·95 (hardbound; ISBN 3 527 40556 9).

Seventy-six years ago, a young technician named Clyde Tombaugh made history by discovering Pluto, the first planet-like object orbiting beyond Neptune. This book tells the story of astronomers' struggles to learn more about the remote ninth planet from the Sun and its large satellite, Charon. Written in an entertaining style, the authors — one a leading planetary scientist, the other a respected editor and science writer — successfully explain for the non-specialist reader how improving technology has enabled scientists to piece together a coherent picture of the Pluto system. Black-and-white photos and diagrams help to elucidate basic principles and bring to life the major characters in this tale of discovery.

This second, "expanded and updated" version comes along eight years after the first edition, and was obviously timed to coincide with a renewal of interest in the Pluto system after the January launch of NASA's *New Horizons* mission. Indeed, one of the major revisions is the addition of a chapter about the struggle to persuade NASA to go ahead with the mission and the scientific promise of this long-awaited expedition. Perhaps not surprisingly, the other changes are quite modest and simply endeavour to include more recent information about Pluto's changing atmosphere, the growing understanding of the Kuiper Belt, and the discovery of 'exotic' ices on Charon.

Unfortunately, the book was revised too early to include more than a passing mention of 2003 UB313, the so-called 'tenth planet', which is now known to be larger than Pluto. Also written before the discovery of two small satellites at the end of 2005, it demonstrates the risks associated with prediction, since the authors state, "Nothing larger than 5% of Charon's diameter — a mere 50 kilometers or so — could be hiding there, still unknown to us." At least one, and perhaps both, of the newly discovered satellites are likely to be larger than this limit.

If recent results are anything to go by, our knowledge of these fascinating worlds will continue to improve even before the landmark *New Horizons* fly-by in 2015, but if you want an engaging account of how we reached our current state of knowledge, then this book is highly recommended. — PETER BOND.

Utilization of Space: Today and Tomorrow, edited by B. Feuerbacher & H. Stoewer (Springer, Heidelberg), 2006. Pp. 410, 24·5 × 19·5 cm. Price £46/$79·95/€59·95 (hardbound; ISBN 3 540 25200 2).

This book aims "to serve as a single, authoritative reference covering the state of the art and future developments in the various dimensions of scientific and application oriented activities in space." In this (rather convoluted) aim I think it has been broadly successful. Certainly it is comprehensive, with chapters on space applications (*e.g.*, remote-sensing, communications, and meteorology), space-based geophysics, space-based astronomy, planetary exploration, and the use of space as a laboratory for fundamental studies in physics, materials science, and biology.

All the chapters are competently written by experts in their respective fields, although, as is inevitably the case with compilations of this kind, some are easier to read than others. The illustrations are good and up-to-date, although many unfortunately lack references to their original sources. Indeed, I would say that while just about adequate, the references listed at the end of the chapters are a little thin for what aspires to be a reference work. On the other hand there is a good index, which certainly enhances the book's value as a reference. I am happy to recommend it for university and technical libraries, and for scientists and engineers working in one area of space-related activity (astronomy, say) who wish to know what is going on in other areas (*e.g.*, planetary exploration or microgravity research).

I personally found the last three chapters, on fundamental research in the space environment, to be the most interesting. These describe research in fundamental physics, materials science, and the life sciences conducted on a range of space platforms (*e.g.*, *Spacelab* and *Mir*), and look forward to work to be conducted on the *International Space Station* (*ISS*). It will come as a surprise, I think, to many in the space-science/astronomy community just how much fundamental science is planned to be done on the *ISS*, including tests of both relativity and quantum theory, studies of the crystallization of solids (including industrially important crystals and alloys), and the response of living systems to the space environment (including studies in human physiology and medicine likely to be of benefit to medical practice here on Earth).

At a recent RAS meeting I heard a senior astronomer stand up and declare that the *ISS* has been "a complete waste of money". Perhaps he should read this book. The *ISS* is not, and was never intended to be, an astronomical facility (although a number of interesting astronomical observations are in fact planned to be conducted from it). However, astronomers should not, on that account, dismiss its potential for discoveries in fundamental physics, materials science, and biology, of which they are largely ignorant. If this book helps broaden minds, and lessen ignorance, about the very wide range of sciences that stand to benefit from research in the space environment then it will have served an important purpose. — IAN CRAWFORD.

The Amateur Astronomer, 12th Edition, by Patrick Moore (Springer, Heidelberg), 2005. Pp. 298, 24 × 16 cm. Price £24·50/$39·95/€39·95 (hardbound; ISBN 1 852 33878 4).

I have on one shelf of my little library at home a book whose impact on me was probably greater than that of any other tome to be found on those shelves, and that said after a lifetime of collecting. It has a black and yellow dust jacket, pages that would probably serve as blotting paper if I got really desperate, and is entitled *The Amateur Astronomer, New Revised Edition* (in fact the 3rd Edition, published by Lutterworth in 1960). I received it as a 4th-form prize at my secondary school (now demolished!) in 1961 and I'm sure that it contributed strongly to steering me into astronomy.

I was thus somewhat curious to see how the book had fared in the last 45 years and accordingly grabbed the 12th Edition, recently published by Springer, to review (even though I can't ever really claim to have been an amateur astronomer — amateurish, perhaps). I confess that I have some sympathy for the maxim, "if it ain't bust, don't fix it", and the contents and layout of the new edition are reassuringly familiar. Patrick takes us on a gentle journey from home, kitted out with just the naked eye, binoculars, or small telescopes (and none of that nasty modern electronic kit; come to that, not even an ordinary camera) through the Solar System (which occupies much of the book) to the stars and on to the galaxies. His celebrated enthusiasm for the subject shines through and his experience as an observer is employed to good effect in letting the reader know just what to expect.

It's a book of two halves. The first part comprises 18 chapters with the by-now very familiar headings, 'Astronomy as a Hobby' through to 'Beginnings and Endings'; the second holds the 30 Appendices, with all sorts of details for the budding observer, many of which haven't changed since the 3rd Edition.

There, however, the similarity unfortunately ends, for the latest edition is ruined, in my view, by the appalling number of proof-reading errors. For the *Here and There* enthusiast we have a rich hunting ground, finding such wonders as, "Saturn has a silicone core" (p. 99), "Tempel's periodical comet" (p. 114), and "… the Pole Star is 500 light years away, so that its light takes 500 yards to reach us" (p. 130), and many more. Rather more frustrating are the numerous instances of references in the text to appendices (numbered sometimes with Arabic numerals, sometimes with Roman), which are quite incorrect, leading to the suspicion that up-dating from a previous edition has been done in a haphazard way. The same is true for quite a few of the figures, whose numbers do not correspond to the text references. Indeed, that it has been drawn largely from earlier editions is given away in several instances: in one case a footnote informs us that "Greenwich was accepted as the zero meridian … almost 100 years ago", when of course it is now more like 120 years ago; and in another, there is a reference to "late 2004" being in the future (when *Huygens* was due to land; p. 101).

Generally, as one would hope, the astronomy is fine (although I don't recall the Hyades having any B-type stars (p. 150); and most would not consider Sirius a giant (p. 136)), but I wonder whether the younger generation of would-be astronomers might be more at home with metric (or even SI) units rather than the Imperial ones beloved by old duffers like me. They might also appreciate a much bigger bibliography than is on offer in the 12th Edition; just six books are mentioned, in contrast to the five pages given to it in my 3rd Edition.

It comes hard having to criticize a book coming from the rickety old typewriter of Britain's favourite astronomer, and maybe the blame for the book's many faults lies more with the publisher. Let's hope that the 13th Edition will sort out the mess. — DAVID STICKLAND.

Ultraviolet Atlas of the Arcturus Spectrum, 1150–3800 Å, by K. Hinkle, L. Wallace, J. Valenti & T. Ayres (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 354, 28·5 × 22 cm. Price \$77 (about £44) (hardbound; ISBN 1 583 81204 0).

This atlas is the third (and final?) one in the series of atlases of Arcturus brought out by Hinkle and his colleagues. It complements the infrared one[1] published in 1995, made with a Fourier-transform spectrometer at the Kitt Peak 4-m telescope and covering the wavelength region 0·9–5·3 μm, and the visible-region one[2] published in 2000, made with an échelle spectrograph plus CCD at the Kitt Peak coudé-feed system and covering the region λλ 3727–9300 Å. The new one extends the coverage far into the ultraviolet, to λ 1150 Å. The space-ultraviolet spectra, from the short-wavelength limit up to λ 3140 Å, were taken with a high-resolution spectrograph on the *Space Telescope* — and very beautiful spectra they are, too. The section from λ 3140 to λ 3800 Å was observed with the same Kitt Peak spectrograph as was used for the visible atlas, save that below λ 3310 Å an ordinary low-order grating was used in place of the échelle system, and the resolution was substantially lower at a claimed 45 000 against well over 100 000 elsewhere.

Like its predecessors in the series, the atlas is presented as an ordinary-sized book; the spectrum is plotted in 247 panels each about 8 inches long, 'landscape' on successive pages, each panel covering 10 Å of the spectrum (15 Å below λ 1700 Å, where there is relatively little to see). The panels are 3 inches high, but there is no means of specifying the height of the continuum because no such thing exists in the relevant region: at the short-wavelength end the spectrum consists of emission lines, some of which grossly overflow the panels (they are plotted again with the scale of ordinates reduced by a factor of 30), while at the long-wavelength end the high points in the plotted spectrum occupy much of the height of the panels. Each page carries not only the Arcturus panel but also a similar panel showing a solar-type spectrum of the same region. It says something for the *Space Telescope* that no solar spectra of quality comparable with that of the Arcturus atlas could be found, so the authors of the atlas felt obliged to fall back upon a spectrum of α Centauri A that was also taken by the *Space Telescope*. Above λ 3140 Å the Kurucz *et al.*[3] solar-flux atlas is plotted.

It is only in the region above about λ 3000 Å that there is a family resemblance between the Arcturus and solar-type spectra. Late-type stellar spectra are of an emission-line character far down in the ultraviolet, and the wavelength region in which they change to absorption varies from star to star. It is easy to see in a general way that the changeover wavelength will be longer the cooler the star, because it occurs where the Planck law for the black-body curve indicates that the continuum intensity is down nearly to nothing in its shortward fall-off. Thus, in the early part of the atlas under review, both spectra are emission-line spectra, although for reasons that are not germane to this review they are astonishingly different from one another. Then, weak continuous spectra begin to appear, and first α Cen at about λ 1700 Å and then Arcturus at about λ 2100 Å start to show absorption lines, although emission is not overwhelmed for several hundred Ångströms more — indeed there is strong emission not only in the Mg II lines near λ 2800 Å but in the familiar *H* and *K* lines more than 1000 Å still further longward.

As the author of an Arcturus spectral atlas[4] published nearly 40 years ago, I (the reviewer) naturally have a keen interest to see how the new work agrees with my own, whose principal shortcoming is that it was produced (from photographic spectra) before the age when everything had to be digital. The two works overlap only in the relatively small region λλ 3600–3800 Å. Additionally, however, in collaboration with Dr. R. E. M. Griffin, I published a supplementary atlas[5], admittedly at lower resolution and compressed onto one page of the *ApJ Supplements*, of a region further into the ultraviolet. It covered the λλ 3200–3600 Å region of the Arcturus spectrum, with the evident (if undeclared) purpose of pulling the rug out from under an atlas[6] prepared for an overlapping region from spectra taken from a balloon and consisting in that region largely of scattered light.

There is no overlap between the reviewer's work and that majority of the new atlas that was made from the *Space Telescope*, which as far as can be assessed is absolutely excellent: one has to welcome it as *sui generis* and apparently beyond compare even with solar spectra, and it will obviously constitute a mine of interesting data for a long time to come. The early panels (derived from spectra taken with a conventional low-order grating) of the ground-based part of the atlas appear to be of very similar resolution and quality to the piece published[5] long ago in the *ApJS*, and as far as can easily be told they agree well photometrically too. The new work is printed at a much larger scale, but its principal advantage is supposed to be that it is available digitally, although no digital record accompanied the volume under review. In fact, unless there is some oversight in this review, nowhere is there any suggestion that any digital version is actually available. Indeed, right opposite the *Preface* there is a draconian prohibition telling us that the work is copyright and that "No part of the material … may be reproduced or *utilized* [reviewer's emphasis] in any form or by any means … without written permission from the Astronomical Society of the Pacific." So what good is *that*?

The overlap between the new atlas and the reviewer's old one[4] occurs where the new one is based on ground-based échelle spectra; again, the two appear very comparable with one another in all respects. The cores of certain strong lines appear to be a little deeper in the new work. That was noticed and illustrated in the preceding atlas[2] of the visible region, which refers with apparent approval to Peterson *et al.*[7] having stated that "there is apparently a problem with the intensity scale in the Griffin atlas". That is not actually what Peterson *et al.* said (they referred to scattered light rather than the intensity scale), but at the risk of appearing over-sensitive on the issue and abusing the editorial hospitality of this review I would like to say that I do not believe that photometric errors other than random ones of order 1% have ever been demonstrated in my atlas[4]. It is, however, certainly true that deep lines are portrayed there as somewhat less deep than they really are, owing to effects of the instrumental profile of the spectrograph used. That profile was carefully investigated and illustrated in the atlas itself, and its effects were equally carefully investigated and published in detail[8] the following year. It is very possible that modern gratings have superior instrumental profiles, and/or that some of their bad effects are removed in the normal course of the digital manipulation of the observational data, notably in the subtraction of the "large scale scattered light common in echelle spectrographs”[2].

In addition to giving the actual spectrophotometric profiles, the ultraviolet atlas gives suggested identifications for many of the lines that it portrays, both for Arcturus and for α Cen or the Sun. The compilation of the identifications must have represented a lot of work, and to check them with a view to giving a considered opinion on their veracity would entail the same and has not been attempted, although a partial comparison of the solar identifications with the *Revised Rowland*[9] listing of 1928 (to which the reviewer still remains loyal) leads to cautious approval. The identifications are not only marked on the tracings but are also listed in wavelength order, in emission and absorption categories, star by star and element by element. Numerous molecular lines are also included.

All in all, this is a worthy complement to previous atlases and should be warmly welcomed by all astronomers concerned with the spectra of late-type stars, provided that they are allowed access to, and free use of, the digital data. It is a good buy at $77, but much better still is the ASP’s offer of all three atlases (this one plus refs. 1 and 2) for $111. — R. F. GRIFFIN.

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(8) R. F. Griffin, *MNRAS*, **143**, 319, 1969.
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From Nazis to Nasa: The life of Wernher von Braun, by R. J. Ward (Sutton Publishing, Stroud), 2006. Pp. 368, 24 × 16 cm. Price £19·99 (hardbound; ISBN 0 750 94303 3).

A couple of years ago I reviewed *The Rocket Team* by Ordway & Sharpe (*The Observatory*, **124**, 218, 2004). That excellent book explored the technicalities of the work of Wernher von Braun and his team of rocket pioneers but had one failing in that it did not really reveal the character of von Braun. Nor did it attempt to address the very real issues of how a member of the Nazi party and key part of the German war machine was subsumed into the US missile activity after the Second World War and ultimately achieved heroic status as the force behind the successful Apollo programme. This new book, written by Bob Ward, fills in that gap admirably.

Bob Ward is a former editor of the *Huntsville Times* who has written extensively about the US space programme. Like Ordway and Sharpe, he developed a close relationship with von Braun but, perhaps because of his background as a journalist, is less willing to gloss over the difficult issues in his book. In fact, this is very much a book about Wernher von Braun as an individual, exploring in great detail his motivations and his driving personality, through the reminiscences of friends and colleagues, rather than a book about the technical triumphs of the Moon landings. Ward really does capture the essence of the man and made me feel that I understood well the complexities of one of the greatest scientists and engineers of the 20th Century.

Of particular interest to me were the mixed reactions von Braun generated from colleagues throughout his career, partly because of his past, but also because of his 'star' status world-wide. It certainly seems that the jealousy of rivals in the NASA hierarchy led to a rather sad end to his NASA career, sidelined at Washington HQ in the early seventies as Richard Nixon pulled the plug on the Apollo programme. The recent upheavals in NASA would have struck a chord with von Braun, had he lived to see them. — MARTIN BARSTOW.

Teaching and Learning Astronomy: Effective Strategies for Educators Worldwide, edited by J. M. Pasachoff & J. R. Percy (Cambridge University Press), 2005. Pp. 268, 25·5 × 18 cm. Price £65/$120 (hardbound; ISBN 0 521 84262 X).

Teaching and Learning Astronomy represents the publication of the papers presented at a Special Session on 'Effective teaching and learning of astronomy' at the 2003 (25th) General Assembly of the International Astronomical Union (IAU). The book is highly organized into ten topical parts each with an editorial introduction, presented papers followed by items extracted from the following discussion, and summary abstracts of the associated poster papers. The volume has a list of contents, and an author and subject index. Only the discussion items did not seem worthwhile — but recording and editing discussion is notoriously hard to make effective in a printed volume. The ten sections were: 'Astronomy in the curriculum around the world'; 'Astronomy education research'; 'Educating students'; 'Educating teachers'; 'Astronomy and pseudoscience'; 'Astronomy and culture'; 'Astronomy in the developing countries'; 'Public outreach in astronomy'; 'The education programmes of the IAU'; and 'Conclusion'. The papers presented highly interesting accounts of work in progress or critical reviews of past efforts and form a valuable resource for astronomical education. The sectional editorials are full of wisdom and good sense. Once again IAU Commission 46 has provided a service for all who are working to promote and improve astronomical education.

It would be tedious to review each of the 21 presented papers, so I will confine my attention to a mere six, which I found of particular personal interest — with apologies to the excluded fifteen. The first of these was 'Distance/Internet astronomy education' by David H. McKinan. He courageously addressed the question of the gifted pupil. In our egalitarian times one is supposed to provide education for all — a very worthy and essential aim. But in so doing it is the abler end of the spectrum that can be neglected. The gifted pupil needs stimulation and encouragement too. If such pupils are not stimulated and intellectually challenged, they are prone to boredom and may no longer achieve their potential. They may not realize the range of opportunity open to them in tertiary education. This is of particular concern in an age of drift away from mathematics and the sciences (even the biological sciences are no longer immune). The result is closure of science departments — most notably in physics and chemistry. Only in the last year has it come to public attention in the UK that physicists are in short supply; soon it will be chemists. If we are going to maintain a sufficiency of scientists, we need to pay attention to the education of the gifted pupil. Creation of intellectual interest and enthusiasm is the only antidote to the irrelevant excuse often bandied about that the mathematical/physical sciences are 'hard'. If the interest and enthusiasm are there, the alleged perception of 'difficulty' is likely to remain absent. McKinan gives an example of Australian experience in awakening and sustaining the interest of the gifted pupil, which is worthy of extended consideration in the debate on how properly to educate the bulk of pupils while extending the educational experience of the gifted.

Under 'Educating teachers', the two papers in that section by M. K. Hemenway and M. Gerbaldi are full of hard-won experience. Mary Kay Hemenway reminds us all that in our enthusiasm for new curricular developments we do need to work with and not — as so often happens by inadvertence — against the responsible educational authorities. Michele Gerbaldi at the end of her informative paper makes the point that teacher education depends on teachers' and astronomers' commitment to developing long-term relationships for maximal effectiveness. Both points may be glaringly obvious — but are often forgotten.

Jay Pasachoff drew attention to the unintentional effects of legislation designed to enhance education but which, in practice, may be counter-productive. He cites the US 'No Child Left Behind' Act — a worthy-sounding endeavour. *Inter alia*, he raised the issue of the requirement for all students to make improvements year on year. If one category out of some dozen for a school stays the same, that school is labelled 'failing'. Think of a school noted for its sustained high performance — is it 'failing' if it simply sustains that high performance? We have a similar issue in the UK with 'added value' points in school league tables.

J. Narlikar and J. Pasachoff both have interesting issues to raise on pseudoscience. While written from an Indian and US perspective, respectively, they raise a universal point. Why is so much attention given currently to pseudoscience? To some extent the scientific community is to blame for this. There is such spectacular achievement in, for example, cosmology and the structure of matter, so much achievement in space engineering, such excitement in understanding the basis of genetics that it becomes easy to confuse real science with science fiction. Indeed, much of the media presentation of 'real' science does not draw clear distinctions between what is known for 'certain' and what is speculation (however reasonable) beyond the established understanding. Astronomy in particular is prone to such over extension because it lends itself to spectacular computer graphics — which often have no basis in physics. But rarely are we told where the boundary between 'real' science and speculation actually lies — such programmes should carry health warnings! The problem is compounded by spectacular admissions of faked results or results based on inadequate data: such personal tragedies shake public faith in, and reduce esteem for, science. Pseudoscience, poor media presentation, and misleading newspaper headlines are, and appear to be, an increasing problem for the maintenance of the reputation of science for integrity.

Finally, the editors make the point that astronomical outreach programmes should reach beyond the *élite*. That is very true — but I would hope that McKinan's point, about the need to keep the *élite* challenged and sustained, will not be forgotten. Information about our science is an important public service. As a community we do not pay sufficient attention to it — notwithstanding the heroic efforts described in this volume and its predecessors. Of course our subject is of overwhelming interest to us, but we need to convey our personal enthusiasm and dedication to our patrons — the taxpayers. We need to make our subject accessible to all, and we need to enthuse up-coming generations to consider astronomical studies at tertiary level. Therein lies the mountain that IAU Commission 46 is attempting to scale, and, if this volume is anything to go by, making upward progress. — D. McNally.

Cosmic Explosions in Three Dimensions: Asymmetries in Supernovae and Gamma-Ray Bursts, edited by P. Höflich, P. Kumar & J. C. Wheeler (Cambridge University Press), 2004. Pp. 383, 23·5 × 18 cm. Price £70/$120 (hardbound; ISBN 0 521 84286 7).

Cosmic Explosions in Three Dimensions is the proceedings of a workshop held in honour of Craig Wheeler's 60th birthday in Austin, Texas in 2003 June. It consists of over 20 lengthy review contributions (typically ten pages), and another 20 shorter contributions (typically six pages) by leading researchers in the field. The volume is divided into several main topics. The first chapter summarizes observational evidence for asymmetries in supernovae from recent spectropolarimetric observations of both thermonuclear and core-collapse supernovae, the spectroscopic and photometric diversity amongst individual supernovae of a given type, supernova remnants, and circumstellar-medium interaction. The second chapter is on modelling thermonuclear supernovae in 3D, covering numerical simulations of thermonuclear explosions and spectral-synthesis techniques. The third chapter reviews the theory of core-collapse supernovae, the effects of rotation, and magnetic fields, as well as binary-progenitor models. There are also some contributions covering magnetars, neutron stars, and pulsars. The final chapter is on gamma-ray bursts, including observational evidence for the supernova/gamma-ray-burst connection provided by the association of SN 2003dh with GRB 030329 only a couple of months before the meeting.

Although some time has already passed since the workshop, the in-depth reviews of the volume can still make it a valuable resource for graduate students and researchers. — Seppo Mattila.

Tidal Evolution and Oscillations in Binary Stars: Third Granada Workshop on Stellar Structure (ASP Conference Series, Vol. 333), edited by A. Claret, A. Giménez & J.-P. Zahn (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 316, 23·5 × 15·5 cm. Price $77 (about £44) (hardbound; ISBN 1 583 81196 6).

This volume contains the proceedings of a workshop held in Granada, Spain, in 2004 May. The host institution, the Instituto de Astrofísica de Andalucía, not only provided the entire LOC, but also three of the seven SOC members, with a fourth being a Spanish expatriate. The remaining three, from Austria, France, and the United States, respectively, provide some international perspective. All the SOC members played active rôles in the workshop itself. The total attendance was thirty-five people, fifteen of them from the host institution. Of the remainder, the great majority were Europeans, but there were also five from the United States and a Korean. It seems as if the underlying rationale for the meeting was that the senior members of the Instituto wished to expose their students first-hand to the ideas of the current leaders in the fields covered by the meeting, certainly a laudable intent.

The meeting covered two main topics, tidal evolution and oscillations in binary stars, and the bulk of this volume is similarly divided. The meeting format seems to have followed tradition in having a few invited papers, plus some oral contributed ones. It is not easy to deduce which of the published papers fall into each of those categories, however, since little indication is given in the table of contents, save for the use of bold italic print for the titles of the first five papers in each section. Those papers are also, on average, longer than the rest, and one is left to conclude that they were the invited ones. Just one paper in the proceedings has none of its authors listed among the participants, despite referring to some of those authors as a team.

The papers in the first section, on tidal evolution, are primarily theoretical, beginning with a masterly summary of the topic by J.-P. Zahn, which reads as if it could be readily expanded into a postgraduate-level lecture course. Those that follow cover not only interesting new work on tidal circularization, but also some significant advances in the connection between tides and apsidal motion in binaries whose orbits have not yet become circular.

The second section, on pulsation, concentrates to a considerable extent upon the complex observational problem of separating the observable effects of pulsation, often at several frequencies, from those of the geometrical effects of orbital motion, including, but not limited to, eclipses. Three of the contributed papers in this section were co-authored by several, presumably younger, people from the host institution, thus giving almost all participants some representation in the publications arising from the workshop.

The workshop concluded with three open discussions, led by J.-P. Zahn, R. D. Mathieu, and M. Breger, each of whom has provided a summary of those events. These are collected together at the end of the volume, and with the final summary by A. Giménez, form a very useful conclusion. The volume as a whole is freer of minor editorial and typographical errors than some others discussed recently by this reviewer in these pages, and provides useful coverage of much of the recent development in the fields of the workshop's title. — Colin Scarfe.

Astrometry in the Age of the Next Generation of Large Telescopes (ASP Conference Series, Vol. 338), edited by P. K. Seidelman & A. K. B. Monet (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 380, 23·5 × 15·5 cm. Price $77 (about £44) (hardbound; ISBN 1 583 81205 9).

This book provides an overview of the present status of most of the current and planned astrometric studies, ranging from current ground-based to planned space missions, as presented at a meeting in 2004 October at Lowell Observatory. As such, it serves as a reference for the developments in this field, and presents what is needed in instrumentation to provide reliable, accurate measurements of elementary astrometric quantities like parallax and proper motion. This is supplemented by an overview of recent, mainly ground-based, results, a small but very relevant section on education and outreach, and a final section called 'Instruments and methods', which covers a wide range of topics from radio astrometry, through quality of plate copies, to reference systems, subjects which somehow didn't fit into any of the preceding sections.

The overview of the space missions is dominated by the now-approved *Gaia* mission, the aims of which, when fulfilled, will overshadow most other programmes. Overviews of *SIM* and astrometry with *HST* are also presented, as well as a look ahead at the possibilities of *JWST*.

The overview of the ground-based experiments naturally focusses on differential measurements like speckle astrometry and extensions of the ICRS from the *Hipparcos* definition to fainter magnitudes. Many of the projects presented were at the time of the conference still in the planning phase; some of those, like the *Discovery Channel Telescope* and *PRIMA*, are now close to being built, while others, like *URAT*, seem to have disappeared. This highlights a major problem with this volume: as part of its aim should be to serve as a reference for the state of art in this field at the time of the meeting, the many references that are provided as web-links will be non-existent in the not-too-distant future, and thus effectively lost.

The section on science results starts surprisingly with a paper on the *SIM* mission, probably not to be launched before 2015, and it is not the only paper in this section that presents future possible results. The main *actual* results are presented in papers on the SDSS and 2MASS surveys, with limited astrometric applications. Some poor editing is found in this section, in, for example, the paper by Lampens & Fremat, in the use of references (systematically repeating names of authors in references). Some of the papers present little or no astrometric aspects (being focussed on spectroscopic binaries, for example).

In the section about education and outreach, van Altena notes the alarming state of education in the area of astrometry, with very few astrometrists left, and hardly any courses being available, leaving the impression that astrometry is simple and doesn't need any teaching. Experience with the *Hipparcos* data after its release shows that rather the opposite is true: proper use, and even more so proper preparation, of astrometric data requires a very high level of understanding of the instrumentation with which the data were obtained, and of statistical properties of the reduced data.

This book seems to me a failed opportunity: where it should provide an historical stock-taking of astrometric techniques and instrumentation, existing and under development, there is too much reliance in the papers on referencing web pages, most of which will have a very limited lifespan. In science results there is very little on actual recent astrometric studies. The education-and-outreach section presents an alarming picture for the future of astrometry, although there are currently well-developed initiatives in Europe to reverse this trend, not least through the stimulant of the *Gaia* mission. — FLOOR VAN LEEUWEN.

The Hatfield SCT Lunar Atlas: Photographic Atlas for Meade, Celestron and Other SCT Telescopes, edited by J. Cook (Springer, Heidelberg), 2005. Pp. 122, 28·5 × 22 cm. Price £24·95/$39·95/€39·95 (hardbound; ISBN 1 852 33749 4).

This atlas is the third in a series[1,2] of photographic lunar atlases based on plates and films taken with a 12-inch reflector by the late Commander Henry Hatfield between 1965 and 1967. The present edition prints the images with north at the top and lunar east at the left, as seen in Schmidt–Cassegrain telescopes (SCT) with right-angle eyepieces. SCTs are deservedly popular and widely available nowadays. This orientation is equally applicable to any astronomical telescope with a right-angle adaptor. Stellar astronomers may need to be reminded that the modern convention is to call the Moon's limb with smallest right ascension the east limb, the opposite to the star field surrounding the Moon.

Apart from the orientation, the present atlas differs little from its predecessors. The projection is naturally orthographic and the Moon's near side is divided into sixteen equal squares. Each square has a sketch map and two or more photographic prints taken at different illuminations on a scale corresponding to a whole-disc diameter of 64 cm. There are further photographs of interesting areas with a corresponding disc diameter around 94 cm. The optical libration is indicated graphically; the diurnal and physical librations have been ignored. Each print is accompanied by a mirror-image thumbnail.

Dependent on illumination and magnification, the smallest craters shown have diameters of about 3 km (1·6 arcsec), which is the Rayleigh limit of a 100-mm telescope. However, the only real test is a comparison of the atlas with the Moon, viewed through a suitable telescope. I did this with my 125-mm SCT and found the atlas to perform admirably. — DEREK JONES.

References

(1) H. Hatfield, *Amateur Astronomer's Photographic Lunar Atlas*, 1968; reviewed in *The Observatory*, **89**, 240, 1969.
(2) J. Cook (ed.), *Hatfield Photographic Lunar Atlas*, 1998; reviewed in *The Observatory*, **119**, 303, 1999.

Maps of the Cosmos (IAU Symposium No. 216), edited by M. Colless, L. Stavely-Smith & R. Stathakis (Astronomical Society of the Pacific, San Francisco), 2005. Pp. 411, 24 × 16 cm. Price $95 (about £55) (hardbound; ISBN 1 583 81202 4).

Maps of the Cosmos, presents the proceedings of IAU Symposium No. 216 held during the IAU General Assembly XXV, 2003 July 14–17, in Sydney. The volume contains 40 invited reviews and contributions to the symposium, and is organized into sections covering the cosmic microwave background (CMB), the formation of large-scale structure, local structure, galaxy evolution and clusters of galaxies, the intergalactic medium, the distant Universe, and future studies.

The main criteria by which conference proceedings can be judged are the quality and quantity of the included presentations and also by their continued topicality or longevity. This last criterion in particular determines the working 'shelf-life' of a conference volume. *Maps of the Cosmos* scores well on all three counts. The two strongest sections are those that discuss the CMB (Section 1) and the formation of large-scale structure (Section 2), as measured by galaxies, QSOs, and *via* weak-lensing experiments. The strength of these two sections is easily understood given the publication of major results papers by the science teams of the *Wilkinson Microwave Anisotropy Probe* and the *2dF* Galaxy Redshift Survey over the period 2001 to 2003. As a result, each contribution (typically five to fifteen pages in length) strikes a good balance between providing the theoretical framework underpinning the research and presenting the discussion and results of now-mature data sets.

The only drawback that should be noted with *Maps of the Cosmos* is that galaxy clusters, both their large-scale distribution and astrophysics, were discussed at an IAU Joint Discussion (Number 10) at the same General Assembly. This organizational point does mean that Section 4 of *Maps of the Cosmos* ('Galaxy evolution and clusters of galaxies') is rather unsatisfying and results in a rather lop-sided overview of universal structure.

Overall though, *Maps of the Cosmos* represents another high-quality collection of proceedings and will occupy a deserved place on the working astronomer's shelf. This volume will be most rewarding for graduate students seeking to broaden their view of a given field and for specialist researchers who require a detailed 'snapshot' of a wide range of linked research topics. — JON WILLIS.

The Celtic Gods: Comets in Irish Mythology, by Patrick McCafferty & Mike Baillie (Tempus, Stroud), 2005. Pp. 224, 23·5 × 15·6 cm. Price £15·99 (paperback; ISBN 0 7524 3444 6).

Encke's Comet is a remarkable object. It moves in a short-period, low-inclination, high-eccentricity orbit ($i = 12°$, $P = 3·3$ yr, $e = 0·847$) which lies entirely inside that of Jupiter. Orbital precession with a half-period of about 2600 years ensures that it has undergone a series of close encounters with the Earth at such intervals. It was seen as a naked-eye object about a score of times in the 19th Century, being recorded as a fourth magnitude object several times. In the 20th Century it achieved this magnitude just three times, and it is now a faint object even for binoculars. Associated with this small comet is an old, dispersed meteor stream — the Taurids, actually a complex of closely related streams. Numerical modelling of the Taurid meteor complex makes it hard to avoid the conclusion that this material derived from a body at least 10 km across (and probably several tens of kilometres) which underwent a major disintegration in prehistoric if not early historical times. A mass imbalance in the current Zodiacal cloud suggests that the progenitor comet may have been substantially larger than this, but that takes us further back in time, to the last ice age. Such a body, tracking along a bright Zodiacal cloud, disappearing and reappearing, disintegrating over the centuries, with its associated phenomena such as recurring meteor and fireball storms, must have dominated the Neolithic night sky, especially during the epochs of nodal intersection.

Celestial images and events in the night sky seem to have played an important part in the cultural development of early civilisations. Certainly astronomical motifs occur worldwide in their myths, icons, and belief systems: lunar and solar calendars are encoded in Egyptian myth, the precession of the equinoxes is found in the *Epic of Gilgamesh* fifteen hundred years before Hipparchus, and so on. We ought, therefore, to see evidence of this spectacular comet history in the record left by our ancestors. So where is it?

The answer, according to the authors, lies in mythology. That is, the ancient, worldwide myths of the sky gods handed down through the generations are anthropomorphized descriptions of this cometary activity, including meteor and fireballs storms, which took place in the prehistoric sky. The hypothesis seems reasonable (at least to this reviewer: he co-authored a book proposing it over 20 years ago), but the field is vast and it is probably beyond a single scholar to make more than a superficial survey of the world's myths with this interpretation in mind. McCafferty & Baillie concentrate on Irish mythology. The tales in the few surviving Irish manuscripts describing these early pagan myths fall into five principal groups, or cycles, the oldest of them purportedly telling the history of Ireland from the time of Noah to the arrival of the Celts. Celtic myths are awash with superhuman characters that fill the sky and are on occasion highly destructive. The characters might be quasi-historical figures, the absurd superhuman trappings added over time; or a pantheon of sky gods imported from other countries; or real celestial entities, their appearance and behaviour described in anthropomorphic terms. In opting for the latter interpretation, McCafferty & Baillie weave a large number of complex myths involving larger-than-life heroes into a framework which is often highly speculative. Nevertheless, there are enough cometary motifs to make a credible case that much of Irish myth does indeed involve descriptions of recurring close encounters with one or more exceptional comets. McCafferty & Baillie even find hints of a ~3·25–3·5-year periodicity in some of the tales.

They write in a popular style and little background knowledge is assumed. The properties of comets are introduced piecemeal, in chapters which interleave with Irish myth, in which various aspects of comets are related to motifs in the stories. The stories have a distinctly catastrophist flavour and are played out against a backdrop which seems terrestrial but is in fact celestial. Castles, for example, are often metaphors for the sky. McCafferty & Baillie are helped enormously in their task of pattern-matching by the fact that many apparently earthbound deities/heroes have been recognized by earlier myth researchers as celestial gods, and their rumbustious adventures as actually taking place in the sky. However, lacking the essential astronomical paradigm — the cometary ingredients — those scholars could only think in terms of 'solar deities'. A flavour of their argument can be given by the example of Lugh, a European god who gives his name to Lyon in France, Leiden in the Netherlands, Lugo in Spain, and so on. Lugh was described as a solar deity because of his celestial setting and the fact that he is always described as bright in the myths (McCafferty & Baillie give examples of scholastic massaging of the translation to fit the preconception). But what, then, are we to make of his title, Lugh of the Long Arm, who rose in the west, could be as bright as the Sun, and is red all night? And what solar deity can, on occasion, cast a spear, as does Lugh, which devastates the land? Other aspects of his appearance have a distinctly cometary tinge, especially when comparison is made with descriptions of comets in classical times by, for example, Pliny. The authors make a reasonable case that many of the principal characters of Irish myth — Lugh, Balor, Cuchulain, and others — are one or more periodic comets.

The result is an interpretation of Irish mythology which is often persuasive, sometimes suggestive, and occasionally comes into the 'pushing your luck' category. If the basic story is right, then the celestial myths are a key to understanding the religious and intellectual development of societies in prehistory. In summary, we have a bold, speculative, multi-disciplinary exercise, developing a paradigm which is bound to outrage some and stimulate others, but which is not going to go away. The book is recommended — along with mine if you can find it (*The Cosmic Serpent*, by S. V. M. Clube & W. M. Napier (Faber), 1982). — BILL NAPIER.

Redshift 5·1 Deluxe Edition (Focus Multimedia Ltd., Rugeley), 2005. CD-ROM. Price £29·99 (ISBN 1 843 26237 1).

It's almost exactly ten years since *Redshift v2* was one of the first software products reviewed in these pages. A decade on, its latest incarnation, the *v5·1* 'deluxe' edition*, keeps it at the forefront of the now familiar 'desktop planetarium' market.

Installation is straightforward, and everything can be run from hard disk (although on-line registration is required to enable full functionality). On start-up, the initial impression is of the almost overwhelming amount of content available (I'm impressed that it can all squeeze onto just two CDs): lectures and

*There isn't a standard, or any other, edition, although Focus' *Teaching-you Astronomy Skills* appears to be a cut-down, entry-level version.

'guided tours', video and image libraries, sky charts, orbital calculations, eclipse mappings, a dictionary of astronomy, sky diary, detailed catalogues of Solar System, stellar, and extragalactic objects … and yet the interface is sufficiently well thought through that, while complicated things are possible (say, plotting the orbit of a new comet, or computing the circumstances of a solar eclipse), simple things are still simple. The software is therefore attractive for anyone with just a casual interest in astronomy, but is also powerful enough to be a valuable tool for the most advanced amateur (and even a Windows-bound professional might find it a handy resource).

System requirements ten years ago were quite demanding; now, they're rather greater in absolute terms, but minimal in contemporary real terms: MS Windows (Me or later), a 300-MHz Pentium II with 64 Mb (!) of RAM, and 1·2 Gb of disk space. The only obvious functionality that isn't available is integrated software control of the increasingly popular small 'go-to' telescopes, available in some competing products but typically at a hefty price premium. Even at the official price of £30, *Redshift* would be a good buy; a couple of minutes on the web should let you buy it for not much more than half the headline cost. It is a mature, sophisticated product that surely represents the best value for money in the market outside of open-source/freeware. — Ian D. Howarth.

Space Shuttle Columbia: Her Missions and Crews, by B. Evans (Springer, Heidelberg), 2005. Pp. 500, 24 × 17 cm. Price £19·50/$39·95/€32·95 (paperback; ISBN 0 387 21517 4).

Columbia was 'the' prototype space vehicle, the first re-useable space shuttle that transformed the concept of 'space research' into an achievable and almost affordable off-site science laboratory where experiments, sponsored by many different nations, could take advantage of unique conditions of near-zero gravity. Between 1981 and 2003 *Columbia* flew 28 such missions, lasting anywhere from 3 to 17 days. In a tragic and very public event, at the very end of its 28th mission the spaceship disintegrated over Texas during re-entry, causing enormous grief, not only at the of loss of a superb team of seven astronauts but also at the loss of the ship herself. This book provides detailed accounts of each of those 28 missions, partly to celebrate their accomplishments and partly as a memorial to a familiar and almost noble, though very extraordinary, vehicle.

Evans documents in painstaking detail the purposes, personnel, and procedures associated with each mission, relaying edited excerpts of conversations and verbatim interviews and leading the reader through the pre-flight preparations (and seemingly inevitable delays), the seconds of countdown, the controlled explosive launch to orbit, the minutiae of the many highly varied experiments that constituted the precious and often weighty payloads, to the moments of re-entry and touchdown. The pages are illustrated with reasonable-quality photographs of entire crews (floating at some crazy angle, but that's what the camera saw), of individuals at work, and of some of the equipment carried. Some emphasis is laid on 'firsts' — the first return and re-use of a shuttle, the first spacewalk, the deployment of new satellites or new equipment, and (in considerable detail) the first service mission to the *HST* carried out by this particular shuttle.

The author is clearly an enthusiast; he communicates his passion amply, and writes well. I noticed only a dozen or so typos or grammatical mistakes, though a scarcity of commas did present the occasional humorous ambiguity. It takes a clear head to memorize the acronyms that pepper the text, for unfortunately there is no glossary though there *is* a helpful calendar of all the missions with listings of the payloads, crews, and any unique parameters. In one place a launch is described as "exceptional" when it meant to say "unexceptional", and in another it mentions cooling liquid He to a temperature "far below minus 268 Celsius". Although the author's publisher, affiliation, and spelling are all definitely English he uses enough American wording (like "envisaged", to "firstly go", and even "insightfull") that one wonders whether to attribute it to an expectation of an American readership, to prolonged exposure to the American source materials, or merely to a desire to impress. I did find that somewhat incongruous in a British book.

Immense amounts of information have been documented regarding the many missions of what became a team of space shuttles, and by filtering off just the *Columbia* story this book offers a very readable selection. The energy with which its opening chapters describe the concept and realization of a re-useable shuttle continues unabated through each succeeding mission. There is scarcely any waving away of details with the excuse, 'much as before'; the author does not permit such shortcuts, and in any case almost every aspect of each flight was different — even launches rarely seemed to follow identical patterns. The author's affinity for *Columbia* is infectious, and his second-by-second description of the eventual failure is quite heart-rending as a good old friend succumbs to the insurmountable forces of re-entry when (though unbeknown) it was already fatally damaged from debris that struck wing panels during launch.

This book is both eulogy and elegy. The accounts of the many scientific experiments attempted in near-zero gravity reveal *Columbia* in her unique rôle of scientific pioneer, yet at the same time the slightly too frequent reminders of impending doom (phrases like "little did they know ...", "but it was not to be ...") make one a little unsure whether to be glad at the gains or mad at the expense and the losses. However, it is not a book about astronomy. (An astronomer would probably have spotted the typo in "21 Velpecula", would not have given the date of the Magellanic Cloud supernova as 1989, nor have described California as "about 8 hours" behind GMT.) Except for the launch of satellites like *Chandra* (and several non-scientific ones) and the highly successful service and repair to *HST* in 2002 March, the scientific focus of *Columbia* was to manage microgravity experiments in disciplines as diverse as materials science, biophysics, and cell culture. Many of those experiments were controlled on-line from the home base, with *Columbia* in the dual rôle as off-site field-station and test-bed for the coming *International Space Station*. Not all were fully successful, but each contributed unique information and many are described in fascinating detail.

Whether the benefits of space experiments outweigh their cost, in both money and (twice to date) in human life, is a moral question that will long be debated. The *Columbia* book leaves the reader in little doubt that the benefits to Earth-bound research, which should accrue through the addition of new knowledge determined in microgravity, ought to be well worth their monetary price, though since each launch was something of an experiment in itself there was always a high risk in human terms too. It is left to the reader to weigh up such bittersweet reflections.

There are, and will be, a good many books about space flight. Some concentrate on feats of engineering, others on selected aspects such as the multidisciplinary payloads, or women in space[1]. The non-specialist will not need to read them all, and for a readable, well-balanced, factual history of a worthy cross-section of what has been going on in low orbit over the past 25 years this book is probably one of the best choices to make. At only £19·50 it is also good value for money. — ELIZABETH GRIFFIN.

Reference

(1) R. E. M. Griffin, *The Observatory*, **126**, 134, 2006. (Review of *Women in Space: Following Valentina*, by D. J. Shayler & I. Moule (Springer, Heidelberg), 2005.)

Evolution of Stars and Stellar Populations, by Maurizio Salaris & Santi Cassisi (John Wiley & Sons, Chichester), 2005. Pp. 374, 24·5 × 17 cm. Price £32·50 (paperback; ISBN 0 470 69220 3).

With the current intensive efforts being devoted to observational cosmology, detailed understanding of the evolution of stars and stellar populations for chemical evolution and the construction of synthetic colours and spectra has become ever more of a requirement.

In this book, two expert stellar-evolution modellers give an up-to-date description of the physics of stellar structure and evolution, followed by several applications to stellar populations. After a fairly detailed overview of cosmology, the authors go on to introduce equations of state, ionization, degeneracy, *etc.*, leading on to the equations of stellar structure, nuclear reactions, and the computation of evolutionary models. There are then in-depth descriptions of the successive phases of gravitational contraction, core and shell hydrogen burning, helium burning, evolution along the AGB, planetary nebulae, and white dwarfs. Massive stars come next, with carbon burning and subsequent reactions leading up to core-collapse supernova explosions, novae, type-Ia supernovae, neutron stars, and black holes.

The remaining 40% or so of the book is devoted to comparison with observations. There is a detailed description of photometric systems, and colour–magnitude diagrams using different wave-bands are compared. Simple stellar populations (SSPs, as in most globular clusters) are discussed with reference to luminosity functions, age, metallicity and distance criteria, and for composite populations some examples are given of how star formation and metallicity histories of nearby systems such as the Magellanic Clouds have been disentangled from deep H–R diagrams obtained with the *HST*. The final chapter discusses unresolved stellar populations — describing the relative contributions of different stages of stellar evolution to the luminosity of SSPs in different wave-bands, and their passive luminosity and colour evolution — the Lick indices, the age–metallicity degeneracy and its resolution, and the surface-brightness technique for distance determination.

Well and clearly written and well referenced and illustrated, this book is a good introduction for students and others, although I did not much like the description of the triple-α process, and some relevant topics are not covered, *e.g.*, stellar nucleosynthetic yields (perhaps a wise omission), galactic chemical evolution beyond the 'Simple Model', and the recent exciting developments in the study of young and old stellar populations at high red-shift. But within its chosen terms of reference it is a valuable and welcome contribution. — BERNARD PAGEL.

OBITUARY

Eric William Crew (1916–2005)

Present and past Editors of this *Magazine* are sorry to report the demise of E. W. Crew on 2005 December 2, about three weeks after he suffered a debilitating stroke. Until then his health and enthusiasm for life had held up exceptionally well. Eric Crew has been well known to the Editors through his submissions to *The Observatory*. Between 1974 and 2000 he had a dozen letters, articles, and reviews published; a veil must be drawn over the census of those submitted but not published, but it may be mentioned that the submissions were frequently of a controversial character, and that the writer of this note, who for some years was the Editor charged with communicating with contributors, certainly had a substantial correspondence with him! Despite the bad news that that correspondence occasionally brought to Crew, good humour prevailed at all times and led to a continuing friendship.

Eric Crew was born on 1916 October 25 in Hanley, Stoke-on-Trent, to Bertram Crew (a Private in the Highland Light Infantry) and his wife Maud. Bertram Crew's occupation in peacetime was as a sign-writer, whose greatest claim to fame was the gilding of the angel on top of Burslem Town Hall. Eric Crew was a pupil at Wolstanton Grammar School from 1928 when it first opened; he went on to read electrical engineering at Birmingham University, graduating in 1938. He eventually joined BP in London, but travelled widely, installing switchgear in power stations. He became a Fellow of the Institute of Electrical Engineers. When he retired from BP, he developed a fire-protection system for cables in industrial plants and underground railways.

Crew was passionately interested in all aspects of science, but particularly in astronomy. He became a Fellow of the RAS in 1973, and a member and sometime council member of the Society for Interdisciplinary Studies (SIS). He shared with Dr. C. E. R. Bruce, another of this *Magazine*'s contributors who was concerned professionally with switchgear in electrical power stations, a conviction that electricity plays a far greater rôle in astronomy than has so far been recognized, and some of his contributions to this *Magazine*, as well as to *Nature*, *QJRAS*, *J. Meteorology*, and *SIS Review* are on that topic. The layout of reference lists in *The Observatory* was altered in 1984 at his suggestion. He exhibited remarkable good nature in the willingness he repeatedly showed to review off-beat books, despite recognizing the reason why the Editors had selected him for such tasks. Indeed, he seemed to savour the implication: in one instance (**114**, 176), his review begins, "Written work from original thinkers always presents a problem to editors", and continues for a complete page with a description of how to determine a "crank rating" for a book, before he finally presents a third of a page describing the book that he is ostensibly reviewing!

He was also very interested in all things natural, and enjoyed walking in the countryside both in England and abroad. A 'naturist', he regularly contributed articles to *Starkers* magazine, and once made the front page of the local newspaper — stark naked — his decency preserved only by a strategically placed Ordnance Survey map! He was an inveterate recycler, and at his own wish is being recycled himself, buried in a bamboo coffin in a woodland burial site. He leaves a widow, June, who has most kindly provided much of the material for this notice, and five children, three of whom were born to his first wife, Catherine, who died in 1964. — R. F. GRIFFIN.

NOTES

Regular readers of this *Magazine* may recall that in the August issue last year, there appeared a *Note* informing the readership in the USA that the entire consignment of the 2005 February issue (No. 1184) that should have been delivered to them by 'surface mail' had gone missing. So far as we are aware, they have still not surfaced and customers who have not yet claimed replacement copies may wish to do so (although the number of spare copies is now very limited).

What beggars belief is that exactly the same fate seems to have befallen the February issues in 2006 (No. 1190)! It may be that they will miraculously appear in the not too distant future but if that is not the case, customers should claim replacements from the Managing Editor at the address given on the back cover. It is intended that a more reliable method of despatch to the USA will have been instigated for the 2006 June and following issues, although there may ultimately be a price penalty to pay for it.

Here and There

EXPERTS IN REMOTE OBSERVING PERHAPS?

... only a few more [visual binary stars] were resolved, namely: ... in 1685, α Cru by Farther Fontenay [and] in 1689, α Cen by Farther Richaud — *Rev. Mex. A & A.*, **11**, 23, 2001.

MAYBE WE NEED MICROSCOPES RATHER THAN TELESCOPES

A new short-wavelength radio image of Sgr A* has made it possible [to] establish the intrinsic size of Sgr A* for the first time. It is 1 atomic unit ... across. — *Nature*, **438**, No. 7064 (2005 November 3), p. ix.

AND WE THOUGHT THAT THE MOON WAS SLOWLY RECEDING!

On March 29, a total eclipse of the Sun will be visible from over half the Earth. — *The Daily Telegraph*, 2005 December 30, p. 15.

A GREAT APPROXIMATION

... Alpha Centauri A [is] between 11 and 20 Earth-Sun distances from Proxima. — *The Daily Telegraph*, January Night Sky, 2006.

INNUMERATE GEOLOGISTS

We now know, thanks to Lyell's pioneering work, and that of innumerable geologists and palaeontologists, that the planet is 40 billion years old. — *The Daily Telegraph*, 2006 January 9, p. 21.

OUR LOSS IS YOUR GAIN

... a ring of gas can be seen around NGC 4262. This material was presented to the American Astronomical Society meeting ... — *PPARC Media Release*, 2006 January 12.

Advice to Contributors

The Observatory magazine is an independent journal, owned and managed by its Editors (although the views expressed in published contributions are not necessarily shared by them). The Editors are therefore free to accept, at their discretion, original material of general interest to astronomers which might be difficult to accommodate within the more restricted remit of most other journals. Published contributions usually take one of the following forms: summaries of meetings; papers and short contributions (often printed as *Notes from Observatories*); correspondence; reviews; or thesis abstracts.

All papers and *Notes* are subject to peer review by the normal refereeing process. Other material may be reviewed solely by the Editors, in order to expedite processing. The nominal publication date is the first day of the month shown on the cover of a given issue, which will normally contain material accepted no later than four months before that date. There are no page charges. Authors of papers, *Notes*, correspondence, and meeting summaries are provided with 25 free reprints if required; additional reprints may be purchased.

LAYOUT: The general format evident in this issue should be followed. ALL MATERIAL MUST BE DOUBLE SPACED. Unnecessary vertical spreading of mathematical material should be avoided (*e.g.*, by use of the solidus or negative exponents). Tables should be numbered with roman numerals, and be provided with a brief title. Diagrams should be numbered with arabic numerals, and have a caption which should, if possible, be intelligible without reference to the main body of the text. Lettering should be large enough to remain clear after reduction to the page width of the *Magazine*; figures in 'landscape' format are preferable to 'portrait' where possible.

REFERENCES: Authors are requested to pay particular attention to the reference style of the *Magazine*. References are quoted in the text by superscript numbers, starting at 1 and running sequentially in order of first appearance; at the end of the text, those references are identified by the number, in parentheses. The format for journals is:

(No.) Authors, journal, volume, page, year.

and for books:

(No.) Authors, [in Editors (eds.),] Title (Publisher, Place), year[, page].

where the bracketed items are required only when citing an article in a book. Authors are listed with initials followed by surname; where there are four or more authors only the first author '*et al.*' is listed. For example:

(1) G. H. Darwin, *The Observatory*, **1**, 13, 1877.
(2) D. Mihalas, *Stellar Atmospheres (2nd Edn.)* (Freeman, San Francisco), 1978.
(3) R. Kudritzki *et al.*, in C. Leitherer *et al.* (eds.), *Massive Stars in Starbursts* (Cambridge University Press), 1991, p. 59.

Journals are identified with the system of terse abbreviations used (with minor modifications) in this *Magazine* for many years, and adopted in the other major journals by 1993 (see recent issues or, *e.g.*, *MNRAS*, **206**, 1, 1993; *ApJ*, **402**, i, 1993; *A&A*, **267**, A5, 1993; *A&A Abstracts*, §**001**).

UNITS & NOMENCLATURE: Authors may use whichever units they wish, within reason, but the Editors encourage the use of SI where appropriate. They also endorse IAU recommendations in respect of nomenclature of astronomical objects (see *A&AS*, **52**, no. 4, 1983; **64**, 329, 1986; and **68**, 75, 1987).

SUBMISSION: Material may be submitted as 'hard copy', or (preferably) by electronic mail to the address on the back cover.

Hard copy: *Three* copies should be submitted. Photocopies are acceptable only if they are of high quality.

Email: contributions may be submitted by email, preferably as standard (LA)TEX files. REFERENCE TO PERSONAL MACROS MUST BE AVOIDED. Those submitting letters, book reviews, or thesis abstracts are encouraged to use the *Magazine's* LATEX templates, which are available on request. Word files are also welcome provided they conform to the *Magazine*'s style.

Figures may be submitted, separately, as standard Adobe PostScript files, but authors must ensure that they fit properly onto A4 paper.

The Editors welcome contributions to the *Here and There* column. Only published material is considered, and should normally be submitted in the form of a single legible photocopy of the original and a full reference to the publication, to facilitate verification and citation.

CHECKLIST: Double-spaced? Reference style? Three copies?

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NOTES TO CONTRIBUTORS

'THE OBSERVATORY' is an independent magazine, owned and managed by its Editors, although the views expressed in submitted contributions are not necessarily shared by the Editors. All communications should be addressed to

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Publication date is nominally the first day of the month and the issue will normally include contributions accepted four months before that date.

Publishers: The Editors of 'THE OBSERVATORY'

Subscriptions for 2006 (six numbers, post free): £58 or U.S. $110

A lower subscription rate is available, on application to the Editors, to personal subscribers who undertake not to re-sell or donate the magazine to libraries.

Printed in 9/10 Plantin by
Cambridge Printing, the printing business of Cambridge University Press.

For advertising contact the Editors

ISSN 0029-7704