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A REVIEW OF ASTRONOMY

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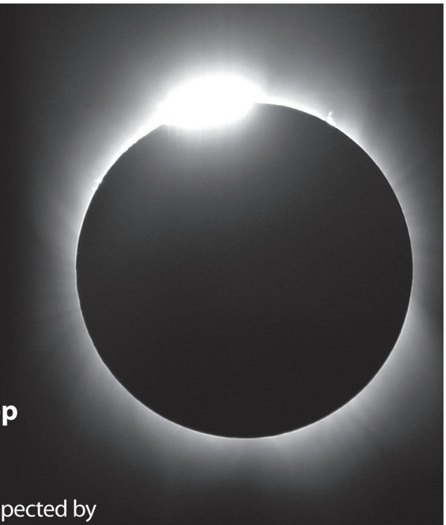

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2008 May 8th at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

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

The President. Welcome to this open meeting. I have a message about applications for RAS grants for the International Year of Astronomy, which, as most of you will know, is 2009. The closing dates are as follows: May 31 for grants announced on July 31, and October 15 for grants which will be announced by December 15. You can find out how to apply on the RAS web site.

Now on to the actual agenda; the first talk is by Professor Andy Lawrence from the University of Edinburgh, on 'Big imaging surveys ...' — when I was at school, I was told not to use the word "big" [laughter], but anyway — 'Big imaging surveys and data access: how to open the floodgates and avoid drowning.'

Professor A. Lawrence. [No summary was received at the time of going to press. The speaker described how much current research in astrophysics relies on large databases, for statistical studies of certain classes of object, for example, or searching for rare objects in a large sample (the 'needle in a haystack'), or in wide-field monitoring of the sky in various wavebands to look for time-variable phenomena, *etc.* Existing and planned instruments and sky surveys, such as UKIDSS, *VISTA*, *LSST*, *SKA*, *etc.*, will deliver tens to hundreds of terabytes of data per year. Hence it is becoming increasingly impractical to consider downloading large volumes of data to analyse with software on one's own machine: the data-centres also need to provide the tools to analyse the data — one downloads the results, not the data.

The speaker then described some of the research being done with the UKIDSS data release, and gave a live demonstration of searching the UKIDSS data server and performing a simple analysis of the output. As an example, he showed how one can query the database using Structured Data Language (SQL) commands to select targets on position, magnitude, colour, *etc.*, and how such a sequence of commands can easily be scripted and modified. Of course, this can be extended to other databases too, and the speaker demonstrated how using the AstroGrid VO interface one could interrogate many databases, across several wavebands, with the same SQL script, and import the results into software for immediate tabulation, plotting, and analysis. A standardized subset of SQL has now been adopted into the so-called Astronomical Data Query Language (ADQL) to facilitate the clean interrogation of many VO databases worldwide. The speaker showed also how one could use PYTHON scripts to incorporate other software tools into the pipeline: in effect, one is now able to bring the code to the data, rather than bringing data to the code. The speaker concluded by commenting that astronomers have relied for many years now on facility-class hardware to acquire their data, and how the collectivization of data and standardization of VO access methods and protocols means that the way astronomers deal with their data is also now becoming 'facility class'.]

The President. Thanks very much, Andy; questions?

Dr. J. Spyromilio. Presumably this costs some money to run, and with everything else that we spend money on in astronomy, it is peer reviewed; at what point does this get peer reviewed?

Professor Lawrence. Every facility or mission has to add that bit more to their data infrastructure, and that's peer reviewed along with the rest of the project. Also the VO projects themselves or other projects that are about defining those standards are peer reviewed. I think the point you're making is that one does not buy the time, anybody can take the data, and that's a very interesting point. At the moment data are free: you have to compete to win three months' telescope time, but you don't have to compete to win fifty gigabytes of space-telescope data, you just go and get it.

Dr. Spyromilio. For the *LSST*, the processing of the data will cost more than the telescope; what you are proposing is that using the data is open to everybody, but the use of that supercomputer will cost as much as using the telescope, per hour — so is that peer reviewed?

Professor Lawrence. Well, there are two routes: either you set it up deliberately for open public access, or, as at the moment, when theorists are burning cpu cycles, that is peer reviewed; using computer time is typically reviewed, but getting the data is not — and so there is a striking difference. We may possibly move in that direction, but it is still early days.

The President. Any other questions?

Dr. G. Q. G. Stanley. Andy, you said that the data are public access; is it truly public access, or is it limited to certain groups to have access to certain data?

Professor Lawrence. What I demonstrated was specifically for UKIDSS, and for UKIDSS each data release is available to anyone in Europe, and is available to the world eighteen months later.

The President. I have a question: not so much about what you've just shown us, but about the possibility that you started off with, of getting the results back and not bothering with the data. In astronomy, a lot of progress has come from serendipity and I'm worried that, in a sense, you're only going to find what you want to find if actually you decide what the results are in advance. So it's absolutely fine if you say you are only going to look at galaxies or stars, but what happens if there's something else out there which you haven't programmed in?

Professor Lawrence. I do agree; if things are set up correctly then you should be able to toy with the data at the server in the same way that you would on your own local machine. So I hope we will be able to preserve that aspect.

The President. I hope so too.

Dr. D. Brand. Just commenting on what you said: from a business/IT background, certainly if you have any large amount of data that you want to get some information from, the first thing I always do is, just pat it, as it were, just probe it a little bit. That's the equivalent of serendipity — you do get interesting results out.

Professor Lawrence. I think that in itself is an argument for surveys as opposed to one-off observing proposals. You find unexpected things every time you do a survey.

The President. Are you saying that the days of looking at individual objects are over? I think that looking over the individual object often has been very formative in astronomy, and that doesn't involve big surveys.

Professor Lawrence. No, we'll clearly do both.

The President. Let's thank Andy again. [Applause.]

The President. The next talk is by Professor Janusz Sylwester from the Space Research Centre in Poland who is going to tell us about 'On-going and future solar X-ray experiments at the Solar Physics Division of the Polish Space Research Centre, Wrocław.'

Professor J. Sylwester. In the late 1960s an opportunity occurred for countries behind the Iron Curtain to start their own exploration of outer space using *in-situ* space-research techniques. Thanks to the enlightened attitude of Professors Jan Mergentaler and Stefan Piotrowski, then in charge of Polish astronomy, in particular solar physics, Poland joined the 'Intercosmos' programme in which Russian space launchers were made available free of charge.

A group was formed in Wrocław, the capital of Lower Silesia, devoted to making a simple *camera obscura* instrument for imaging the solar corona through beryllium and aluminium filters with different energy passbands. These pinhole imagers were launched on a 'Vertical-1' sounding rocket on 1970 November 18. Measured ratios of spectral X-ray intensities from images allowed the maximum temperature of non-flaring active regions to be estimated at $\sim$ 5–6 MK (Jakimiec, *COSPAR Proceedings*, 1972). Over the following years, space instrumentation built at the Solar Physics Division of the Polish Academy of Sciences Space Research Centre advanced rapidly, with new techniques such as grazing-incidence X-ray telescopes and Bragg-crystal scanning spectrometers. This followed techniques established by Western groups, including the MSSL team in the UK.

Seven sounding-rocket flights were launched from the Kapustin Yar rocket range, south of Russia — only one of the launches failed (because a parachute did not deploy in time). Growing experimental experience in the Wrocław group, combined with the knowledge passed on from co-operating teams in Czechoslovakia (Astronomical Institute, Ondřejov) and the Soviet Union (P. N. Lebedev Physical Institute, Moscow), allowed satellite instruments studying solar X-rays to be designed and constructed. The Wrocław team has to date been responsible at the PI level for the construction of two solar spectrophotometers: the *RF15I* soft–hard X-ray photometer aboard the geophysics *Interball–Tail* spacecraft, with highly elongated orbit, and the *Diogeness* scanning Bragg spectrometer aboard the *CORONAS–I* solar mission.

In the mid-1980s, political and economic problems hindered Polish science funding and made it very hard to continue space research. At this point, great help was received from our British colleagues. Thanks to the initiative and encouragement of Profesor Len Culhane, then Director of the Mullard Space Science Laboratory, a joint satellite experiment was designed for the Russian *CORONAS–F* mission. This was the *RESIK* (*REntgenovsky Spektrometr S Izognutymi Kristalami*) instrument, a bent-crystal Bragg spectrometer using spare position-sensitive detectors from the Japanese *Yohkoh* BCS spectrometer (MSSL-led), high-voltage units (from RAL, UK), and crystals provided by NRL (USA). IZMIRAN (Russia) led the *CORONAS–F* mission and provided a substantial contribution to the success of *RESIK*.

Earlier bent-crystal spectrometers, introduced in the mid-1970s under the guidance of Professor Culhane and Dr. Rapley, were launched on two advanced satellites: the NASA *Solar Maximum Mission* (1980–1989) and the Japanese *Yohkoh* (1990–2000). In these pioneering experiments, high spectral resolution was achieved in selected soft-X-ray spectral ranges covering the most intense X-ray lines emitted by solar flares (temperatures $\sim$ 10–20 million K). Advantage was taken of the experience from these spectrometers to build *RESIK,* for which the spectral range was chosen to be 3·34–6·05 Å, with a spectral resolving power of $\sim$ 1000. *RESIK* collected about a million spectra covering solar-activity conditions from very weak (class A9 on the GOES scale), up to X-class flares which have effects on space weather. These spectra revealed a number of findings, among them the following which have now been published in the literature: (*i*) identification of several new spectral lines with transitions belonging to higher members of principal line series in H- and He-like ions of Si, S, and Ar; (*ii*) identification of the line triplet of He-like Cl and determination of the absolute abundance of chlorine (chlorine is a very-low-abundance element for which no accurate absolute coronal abundance measurements exist); (*iii*) a wide range (factor of 100) of abundances for potassium, an element with very low first-ionization potential (FIP), around a mean value equal to the coronal abundance (*i.e.*, four times photospheric), but by contrast a much smaller range of abundance values for the high-FIP element Ar; (*iv*) observational verification of the calculated temperature dependence of satellite-to-parent line ratios for $n = 3$ and 4 transitions in He-like Si. At present, the analysis of *RESIK* spectra is continuing in close collaboration between Polish and British institutes (MSSL, Cambridge).

The success of *RESIK* has paved the way for a new venture for the Wrocław team, namely *SphinX* (*Solar photometer in X-rays*). This instrument is to be launched in 2008 October aboard the Russian *CORONAS–Photon* spacecraft. *SphinX* has been designed and constructed by a consortium including the P. N. Lebedev Physical Institute (Moscow), the Astronomical Institute of the Czech Academy of Sciences (Ondřejov), and the Palermo Observatory (Italy). *SphinX* is a unique spectrophotometer equipped with four Si PIN diode detectors allowing the measurement of coronal X-ray spectra in the energy range 0·5–15 keV. A transition from the thermal to nonthermal character of the emission is generally seen in this energy range. Appropriate selection of the input apertures will allow us to cover a wide (seven orders of magnitude) range of solar variability, from the very weak emission of the low-activity corona (as at present) up to the largest flares observed ($\sim$X30 events). The energy resolution, 250–300 eV, will allow broad spectral features to be seen due to individual groups of Mg, Si, S, Ar, Ca, Fe, and Ni lines. One of the primary goals of *SphinX* will be the determination of the coronal plasma composition for these elements. The instrument has been carefully calibrated on the ground, with a series of end-to-end tests at the BESSY Berlin synchrotron. As a result, an absolute calibration of solar fluxes in the soft-X-ray range of 5% or better should be achieved, establishing a photometric standard in the soft-X-ray range. At present *SphinX* is undergoing a final round of pre-launch tests in Russia. *SphinX* spectra will be in the public domain immediately after data reformatting, accessible from dedicated servers in Wrocław and Ondřejov as well as from European and US solar databases. A *SphinX*-type spectrophotometer is being planned for inclusion on the free-flying platform, under development by the Russian Space Agency, next to the *International Space Station*.

The Wrocław team is also involved in the design of the *STIX* solar hard-X-ray telescope for the planned (2015) ESA *Solar Orbiter* probe. The *STIX* consortium is being led by the ETH group in Zurich, and the instrument proposal is currently being considered by ESA.

As a final remark, I should like to emphasize our thanks for the great help from our British and Russian colleagues over the past 30 years, without which Polish expertise in solar X-ray investigations would not exist at the present level. My present visit to the UK has been possible thanks to a travel grant signed between the Royal Society and the Polish Academy of Sciences. This cooperation is being conducted by Professor Kenneth Phillips, of MSSL (for the British side).

The President. Thank you very much; any questions?

Dr. R. Barber. I was interested in your comment about the carbon triplet and using it as a measure of temperature; you also mentioned earlier on that some of the conditions are non-LTE. Could you use that to make temperature measurements in non-LTE conditions?

Professor Sylwester. This depends on the time resolution. I think that where these lines are formed is best described by so-called 'coronal equilibrium' conditions. If you have a deviation from the Maxwellian distribution of the exciters then you may start to see effects which can be describing non-LTE-like conditions. Having only these three lines it would probably be very hard to distinguish the effects of density, for instance, from the effects of non-Maxwellian exciters or something like that.

Dr. K. Krynicki. I wonder whether you understand well all the physical processes leading to these high kinetic temperatures.

Professor Sylwester. What we do is what we can, probably! There are probably non-Maxwellian distributions present everywhere all the time; however, how far from Maxwellian we cannot say — they are probably sometimes very close to Maxwellian. Sometimes during flare initial phases, where the acceleration of particles takes place, they might be substantially non-Maxwellian. The interpretation depends on the model of the source you have in mind: for some models this is impossible and for some models it is natural to have non-Maxwellian distributions.

The President. I haven't heard before of people doing astronomy from polar-orbiting satellites. I assume you didn't choose that; what fraction of the orbit can you use?

Professor Sylwester. We can use effectively forty per cent of the time because for the other portion of the orbit we are going through the South Atlantic anomaly or polar fingers of radiation of the Van Allen belts. Effectively this is between thirty and forty per cent. On the positive side, the plane of the orbit is nearly perpendicular to the Sun, and therefore you have periods of three to four weeks that the satellite will not enter the Earth's shadow, so this is some compensation.

The President. Well, I think we all wish you well with *SphinX* later this year; let's thank Professor Sylwester again. [Applause.]

Now Dr. Rhaana Starling from Leicester is going to talk to us on 'What can we learn from gamma-ray bursts?'

Dr. Rhaana Starling. About twice per week, gamma-ray satellites catch sight of immensely powerful, short-lived bursts of emission. They happen at random times and from random directions in the sky. These sources, known as gamma-ray bursts (GRBs), were discovered serendipitously by 1970s spy satellites and it wasn't until 1997 that emission at X-ray, optical, and radio wavelengths was also discovered following the GRB: this 'afterglow' lasted much longer — weeks to months — before fading to nothing, establishing their extragalactic nature and opening up these events for detailed study.

At these large distances the energy involved in producing a GRB and its afterglow must be immense: so much so that the emission must be confined to a jet.

Particles accelerated at shocks formed within the jet are thought to create the gamma-rays while the afterglow arises through the interaction of the jet with the surrounding medium. The afterglow spectrum is therefore synchrotron emission, conveniently well represented by a simple set of power laws all the way from the high-energy régime through to the radio bands.

We now know that perhaps three quarters of all GRBs originate in the collapse of a very massive, rotating star. This origin is widely accepted for the long-duration events whose gamma-ray flash lasts for more than 2 seconds (the 'long GRBs'). Those with durations less than 2 seconds are thought to have a different origin or origins, as yet unconfirmed, but popular theories include the merger of two compact objects. These 'short GRBs' are generally fainter and rarer than their long-duration cousins and therefore have been difficult to follow.

These fleeting events have puzzled the community for decades and, while their locations could be accurately determined thanks to the discovery of optical and X-ray afterglows, it took time to repoint X-ray satellites and ground-based telescopes to the GRB position. Large gaps appear in many of the early light curves preventing study of the onset of the afterglow, and a multiwavelength view of the prompt emission. A new mission was clearly needed and in 2004 we saw the launch of *Swift*. The GRB-dedicated *Swift* satellite is revolutionizing our view of GRBs through, amongst other attributes, its unique fast-slew capability. *Swift* is a NASA mission with participation from the US, UK, and Italy, and carries three instruments: the *Burst Alert Telescope* (*BAT*, detecting gamma-rays), an X-ray telescope (*XRT*), and a UV-optical telescope (*UVOT*). Once the *BAT* has detected a GRB the satellite can manoeuvre around to point at that location in just 60–100 seconds, allowing the *XRT* and *UVOT* to begin taking data. The information from any GRB is immediately transmitted to the ground *via* the *TDRSS* network of satellites alleviating the need to wait for a pass over one of the ground-stations. Telescopes on the ground can then be alerted to the new GRB and can begin the crucial follow-up efforts in the optical, near-IR, and radio. This fast reaction time has proven key to observing the transient populations of our Universe.

One of the primary goals of the *Swift* mission is to search for the origins of GRBs. The long-GRB progenitors are the better understood of the two GRB classes, since type-Ibc-supernova signatures were seen in some afterglows, confirming their association with the collapse of massive stars (at least in some cases). But the recipe for creating a GRB from a massive star is not known — rotation is likely a key factor — and observations of nearby GRBs are providing some clues. In 2006 February *Swift* detected a nearby GRB which had a particularly faint afterglow, allowing the supernova contribution to shine through like never before. The unusual X-ray emission was best fit by a thermal spectrum which cascaded down into the UV. The thermal bump was followed by a bump in the optical light characteristic of a supernova and caused by radioactive heating in the supernova ejecta. While the optical bump is a previously observed phenomenon in a number of nearby GRBs, the early thermal emission is thought to be the first time that we have observed the supernova shock breaking out of the star in a GRB-supernova. Another supernova caught in the very act of exploding came along in 2008. This time the observation was entirely serendipitous: *Swift* was pointing towards a supernova in the galaxy NGC 2770 at the very moment that a second supernova occurred in the outskirts of the same galaxy. A sharp rise in the X-ray emission is interpreted as a further example of shock breakout, this time from a type-Ibc supernova not associated with a GRB.

Swift observations have also shed light on the origins of short GRBs, thanks to its fast-slew capability. Short-GRB afterglows tend to be faint, and fade quickly to nothing. They have been notoriously difficult to record, and it was not until 2005 that a short-GRB afterglow was observed. The *XRT* on *Swift* captured a very faint X-ray source following GRB 050509B. Follow-up observations from the ground provided evidence favouring an origin for this GRB in a compact binary merger, when the X-ray position fell on a large elliptical galaxy no longer making stars, together with the distinct lack of any associated supernova. This opened up the field, and it was not long until the first optical afterglow from a short GRB was discovered. A small sample of these afterglows is now in hand.

The immense luminosities of GRBs means they are excellent probes of the very distant Universe. The most distant GRB found to date occurred around 13 Gyr ago — just $\sim$ 700 Myr after the Big Bang. The gamma-rays from this $z = 6 \cdot 3$ source were fainter and more stretched out than an average GRB coming from $z = 2$–3, but could still be picked up by 'image mode' detection with the *BAT* (variability in images rather than a sudden increase in count rate). The *Subaru* ground-based telescope pointed at the *Swift* position and accumulated a spectrum confirming the incredible distance of the source. The spectrum could even provide information on the chemical make-up of its host galaxy, back-lit by the GRB afterglow — a galaxy too faint to be seen by direct imaging. [Dr. Starling has informed us that a GRB at $z = 6 \cdot 6$ was found in 2008 September. — Ed.]

Finally, we are getting closer to the heart of GRB central engines with high-energy observations of their jet emission. Atop the decaying X-ray light we find flares in about half of all afterglows. Flares were not known to be so common and to explain them may require a continuation of the central engine for far longer than originally thought. Just a few days before the discovery of short-GRB afterglows, *Swift* captured a giant X-ray flare from a long GRB which contained almost as much energy as the GRB itself and produced a 500-fold increase in the count rate! The most recent highlight from the GRB field has been the detection of a naked-eye burst. GRB 080319B reached a visible magnitude of 5·3, observable with the naked eye had you been looking up at the right time in the right place. The multi-wavelength dataset collected for this source is arguably the most complete yet, and studies are on-going to understand the workings of this powerhouse, possibly hosting an extremely relativistic jet.

GRBs are very versatile probes of a range of different astrophysical phenomena from relativistic jets to supernovae from the most massive stars. Their incredible brightnesses mean they can be seen out to large distances, revealing the conditions in galaxies in the early Universe. Several giant leaps in our understanding of these events have been made possible by the fast-reacting *Swift* satellite together with dedicated follow-up, and there is a whole lot we can still learn from GRBs.

The President. Thank you for an interesting talk; some questions?

Rev. G. Barber. Are the short bursts harder, higher in energy than the long bursts?

Dr. Starling. Yes, they have harder spectra.

Rev. Barber. And does that put a limit on the range for detection, given that inverse-Compton scattering might absorb very hard gamma rays? Is the inference that the long bursts are the distant ones and the short bursts have to be within a few megaparsecs?

Dr. Starling. Well, the short bursts are turning out to be nearer in redshift than the longer but there is no reason why they shouldn't exist out there. They're much fainter so that's why you can't detect them.

Professor R. Ellis. Massive stars form very early in the Universe at redshifts well above $z = 7$ or so and there was hope that *Swift* would find many very high-redshift gamma-ray bursts, but apart from one that was uncovered by *Subaru* it has been a bit disappointing. Is that because we're missing something? It's not the sensitivity, so why aren't we finding many more of these high-redshift bursts?

Dr. Starling. In *Swift*'s defence, we do have a lot of bursts that we found around a redshift of 4 or in that kind of region; but yes, we are really missing those that we thought we would see at redshifts like $z = 7$, 8, or 9.

Professor Ellis. So what fraction of bursts are simply not followed up?

Dr. Starling. I don't know that number; it's too high anyway. What you need are near-infrared spectra. The one that I showed you was something like a three-and-a-half-hour integration, so that was someone giving up three and half hours of their time on an infrared spectrograph, which is very rare. People obviously don't have enough near-infrared instrumentation to do this routinely.

The President. I am sure Richard would do that, wouldn't you?

Dr. Barber. In the very interesting near-infrared spectrum that you showed us of the galaxy at $z = 6{\cdot}4$, we were looking at the emission lines and I noted that just shortward of the O I line at 9500 Å there is a very strong emission feature. Is that just a common-or-garden hydrogen line that has been redshifted or is it something more interesting? It's such a valuable spectrum I would have thought that more work should have been put in trying to identify features in there.

Dr. Starling. I am not sure that the feature is real.

The President. It looks pretty noisy to me. [Laughter.]

Dr. Barber. If it's noisy then that upward spike is no more noisy than the downward spike off to the right.

Dr. Starling. In general, one is looking for absorption features because the burst lies in star-forming regions in the host galaxies. I don't think that line was identified as an emission line.

Dr. Barber. If you know the redshift you should be able to say immediately what a line that strong is.

Dr. Starling. Yes.

The President. The burst that was observed at fifth magnitude, the really bright one; is it true that if it was anywhere in our Galaxy, and it was pointed at us, it would actually appear brighter than the Sun?

Dr. Starling. Yes, I think so.

Dr. P. T. O'Brien. If it was in the Galactic Centre it would have appeared ten times brighter than the Sun, ignoring the dust.

The President. It puts it in perspective.

The final talk is by Professor Iwan Williams from Queen Mary and Westfield College, who is going to talk about 'Tunguska and the rôle of the event in assessing the NEO threat to Earth.'

Professor I. P. Williams. On 1908 June 30 at 0017 Universal Time a very remarkable event took place in Tunguska. Tunguska is in Siberia, in what is even now a very remote part of Russia, being approximately 1000 km east of the city of Tomsk. It also lies roughly 500 km north of Lake Baikal, the largest fresh-water lake on the planet. The local time of the event was just after seven o'clock in the morning so the local inhabitants were already starting to go about their normal daily activities. Because of the remoteness of the location, the first scientific study of the site was undertaken by Kulik in 1927, approximately 20 years after the event. Kulik also recorded eye-witness accounts. For example, an Evenki tribesman, who was in his hut approximately 90 km from the event location, said (what follows is a slightly shortened version): "My brother and I were in our hut by the river. Suddenly, I fell into the fire. I got scared. The Earth began to move and rock, wind hit our hut and knocked it over. Then trees were falling, the branches were on fire. There were no clouds, our Sun was shining brightly as usual, and suddenly there came a second one! Then in a different place, there was another flash, and loud thunder came. Wind came again, knocked us off our feet."

A little further away at the trading post in the small settlement of Vanavara, a witness (Semenov) described what he saw: "I was sitting by the Vanavara trading post, facing north. The sky split in two and fire appeared high and wide. It grew larger, and the entire northern side was covered with fire. I became so hot as if my shirt was on fire; strong heat came from the northern side, where the fire was. Then the sky shut closed, a strong thump sounded, and I was thrown a few yards. A noise came, as if rocks were falling, the earth shook. When the sky opened up, hot wind raced between the houses which left traces in the ground like pathways."

With our present-day knowledge, we can interpret their description as follows: a big fireball passed overhead (which, from other witnesses accounts as well, travelled roughly in a NW direction). There is a minor problem: there were no accounts of anybody seeing this from Irkutsk, a large town along the path. There was an explosion generating a heat (radiation) wave, an atmospheric pressure wave, and a seismic wave. There may also have been the effect of hot plasma running back up the plume.

When Kulik got to the site of the event, he found signs of great devastation, covering an area roughly equivalent to that within the M25 London orbital road. Most trees had been blown over and were all lying pointing radially away from a fixed point. The few trees left standing were scorched and all the branches stripped off. These trees were mostly near the fixed point mentioned above. No crater was found, which rather surprised Kulik, who had thought the event was the fall of a big meteorite.

The picture is, however, consistent with an aerial explosion about 10 km up in the atmosphere with an energy release of about 5×10^{16} J. The observations of the preceding fireball, both as already described and others, suggest a speed of about 15 km s^{-1} and, with this speed, the energy released is consistent with a 30-m radius asteroid, perhaps similar in nature to the asteroid Mathilde.

Collisions of small objects ($< 0 \cdot 1$ m) with the Earth are common and we can get a good collision rate (one hits the UK every 10 years or so) but they do little damage. Very big events are large enough for most to be known and so again a rate can be obtained. Things like the KT event are so rare as not to be of any real interest for the immediate future, but things like Tunguska are moderately common and can do considerable damage. It is therefore important to get a reasonable understanding of the frequency of such events. Note that evidence of the Tunguska event is rapidly being eroded and, in another 100 years, little evidence of it will be found. Hence we cannot get a reliable estimate of frequency by studying damage on the ground. Of course, a rough estimate can be had by drawing a straight line joining the known data for the very big and the very small in a plot of size against frequency. Doing this gives the frequency of the Tunguska event (*i.e.*, a collision of a 30-m asteroid) as one every several thousand years.

Two very recent developments have taken place. A team from the University of Bologna headed by Dr. Gasperini claims that a fragment of the original body survived the explosion and fell into a lake roughly north of the epicentre (*Terra Nova*, **19**, 245, 2007). They claim that sonar searches indicate a crater at the bottom of this lake. If this is true and the fragment is recovered, this will be very exciting, for it will conclusively determine the composition of the initial body and hence its size.

The second development is theoretical work by Drs. Boslough and Crawford from the Sandia National Laboratories in the USA. They have run numerous computer simulations and claim that when the topography of the region is taken into account, the damage can be caused by an explosion that is three times less powerful than previously assumed, which implies that the original body was only 70% of what has been assumed up to now. If this is the case, then on normal terrain a Tunguska event will do less damage, but the frequency is higher, perhaps one every few hundred years. This estimate perhaps fits in more comfortably with the fact that the last one was only 100 years ago.

Whether these new works are correct or not, Tunguska may be 100 years old but we still do not know everything about it. It is still the only known big impact event almost within living memory. It is important to understand it, for it really does play an important part in standardizing our predictions for collision frequency.

The President. Thanks very much, that was very interesting. Robert?

Dr. R. C. Smith. Iwan, you talk as though Tunguska was quite a unique event, but I understood there was a similar event about which much less is known in the Amazon rainforest in the 1930s?

Professor Williams. Yes, there was a similar event in the Brazilian rainforest in the '30s. Canonical calculations suggest that actually it was about ten times smaller than Tunguska. Now if we say Tunguska was three times smaller, then we're now saying that the Brazilian one was only three times smaller than Tunguska.

Rev. Barber. There was a similar one in Saudi Arabia in the 1920s or '30s.

Professor Williams. That was also smaller. There are a lot of these smaller ones, and it is important to try and get a handle on them. All the papers concentrate on the 'killer asteroid', the thing that will wipe out civilisation; all the films are about saving the Earth from being whitewashed by these major impacts. I think the real threat is not that at all, it is the Tunguska-type object which, if we're unlucky, will destroy a major city. And these objects do hit the Earth on something like a 100-year timescale — well that's what we're arguing about, whether 100 years or 1000 years. I think those are the things we need to worry about and unfortunately, of course, the other point one would make is that they are too small, we can't detect them very well, and we are only finding a small fraction of them.

The President. Derek, you had a question?

Professor D. Ward-Thompson. Surely the result of this work is the optimistic view: obviously, it only flattens London out to the M25 if London is built on a triangular hill. [Laughter.] So turning that around, if Tunguska hadn't landed on a triangular hill what would have been the size of the devastation area?

Professor Williams. What you are saying is that the energy is three times smaller, and therefore presumably the radius of the area is 1·7 times less; so we're talking about inside the North Circular or something. [Laughter.]

Professor D. W. Hughes. Iwan, how can you distinguish between a killer asteroid and a killer comet?

Professor Williams. I can't, and I wasn't particularly trying to, other than calculating the density of what's coming in. All you're really getting is the mass from the energy, if you guess the velocity, and then all the rest is up to what calculations you wish to do, so it is all model dependent in some sense.

Professor I. W. Roxburgh. I'm not quite sure about the conclusion you make because the fraction of the Earth ...

Professor Williams. Well I gave you three! [Laughter.]

Professor Roxburgh. ... the fraction of the Earth covered by major cities is tiny, so the probability of hitting a major city is ...

Professor Williams. ... is tiny, surely.

Professor Roxburgh. So we balance that against the probability of it being much bigger.

Professor Williams. OK, I see what you're getting at. What you're saying is that I'm claiming these things are dangerous because they happen once every hundred years, but in fact only one in a hundred of them will actually hit a major city or something.

The President. Another question?

Dr. Brand. Have there been any satellite photos of the area? I bet they would show up the crater well, would they not?

Professor Williams. No, there is no crater. I think by now it is very clear that there is no crater on the ground.

Dr. Brand. What about the lake?

Professor Williams. There may be a crater at the bottom of the lake, but as I said, forty metres of water were removed before one saw anything like a crater. So I don't think you would actually see it just by looking down.

Dr. C. Trayner. There is another estimate of the energy based on the seismic energy, so velocity-based models are not the only source of the energy. They do corroborate the figures you gave. On the Gasperini paper which reported the sonar modelling of the lake: can you remember whether it was the southern swamp or the eastern swamp they studied?

Professor Williams. The lake is not in the southern swamp. The lake where they are claiming the crater lies is more or less on a slight deviation from continuing the track northwards after the explosion.

The President. Let's just have two more questions, then.

Rev. Barber. The chance of hitting a city is quite small, of course, although the area of cities is growing and has grown considerably in the last hundred years. But four fifths of the Earth is covered by water and these impacts presumably cause a devastating tsunami if they hit an ocean.

Professor Williams. A tsunami may even be devastating, but records of these get lost. There is no evidence of a tsunami very soon afterwards other than in some written records, and if we were trying to go back to find the one, say, prior to Tunguska, which would therefore be four hundred years ago or something, you would be very lucky if you found any evidence.

Rev. Barber. But the danger is greater than it might appear.

Professor Williams. Yes.

The President. Last question.

Mr. C. Barclay. In your talk, I greatly enjoyed your Michael Fish-esque comment that we will not get a KT impact in our lifetime! [Laughter.] I congratulate you on a win–win statement: we won't be able to say you were wrong! [Laughter.]

The President. Well, clearly killer objects are very exciting for everybody.

The meeting is now going to close and the next monthly meeting is going to be held on Friday, October 10. Have a pleasant summer.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

A SYNOPSIS OF PAPERS 151–200

By R. F. Griffin
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This synopsis follows the pattern of its three predecessors which were published after the conclusion of each successive batch of fifty papers in this series. For convenience of reference, the orbital elements of all the binary stars studied in the last fifty publications are collected together. Whereas previously the number of orbits to be summarized from each batch has not been much more than 50, this time it is as many as 134. The adoption of many actual and suspected double-lined binaries onto the observing programme has resulted in the establishing of a lot of orbits having quite short periods, but there remains an underlying trend towards longer and longer periods as the total duration of the programme increases; the final paper summarized here includes orbits having periods exceeding 10 000 days. The steadily improving statistics yielded by the increasing number of data demonstrate ever more convincingly the positive correlation between orbital eccentricity and period. There is still no evidence of the Barr effect (excess of longitudes of periastron in the first quadrant) in the sample of binaries treated in these papers. The synopsis concludes with object and bibliographical indices to the whole series (Papers 1–200) and to the 289 stars whose orbits are determined there.

It seems useful, and follows precedent[1–3], to summarize the orbital elements for the stars treated in the latest set of fifty papers in this series, and to offer a brief discussion of their most notable characteristics. This paper also provides indices, both to the objects and to the papers, in the whole series.

A distinct change occurred in the nature of the series during this fourth batch of papers. Whereas up till Paper 150 it was exceptional for any paper to deal with more than a single object, shortly after that it became quite usual for a paper to treat three or four different stars; the total number of orbits given in Papers 151–200 is 134. The underlying reason is the author's belated recognition that the rate at which his data were trickling into the literature was greatly exceeded, especially after the commissioning of the Cambridge *Coravel*, by the rate at which data relevant to the series were pouring down from Heaven, and as the time was fast approaching for the writer to travel (as might be hoped) in the opposite direction, it would be a good idea to try to reverse the imbalance. That has, alas, not happened, but at least the disparity has been reduced — at the cost, naturally, of corresponding multiplication of effort in the days of nominal 'retirement'. An incidental effect of the change is to satisfy in part Dr. Batten's and Dr. Hills' desire, expressed in their kind letter published[4] in the same issue of this *Magazine* as carried Paper 100 in 1991, for more substantial, if less frequent, papers. Application of cold logic to the matter would require that no additions should be made to the observing programme, and as the work on each star is completed and written up the corresponding entry should be deleted from the programme, which would then run down in an orderly fashion. (It would still not run down to nothing, however long the observer might be spared, because it is quite apparent that not a few of the objects have periods exceeding the human life-span.) But in actual fact the programme is not running down at all, because the observer is not sufficiently strong-minded to resist the temptation constantly to supplement it with fresh objects of newly recognized interest, whether gleaned from the literature or arising from survey projects of his own!

During the time interval covered by this summary the sole source of fresh radial-velocity data has been the *Coravel*-type spectrometer operating at the coudé focus of the Cambridge 36-inch reflector. Its design is based on that of the Haute-Provence instrument[5] master-minded by Dr. M. Mayor, who very generously placed the engineering drawings and other important data (notably the design of the mask with which the spectrum is cross-correlated*) at my disposal. The actual construction was entrusted to a commercial firm, a disastrous experience briefly touched upon in the last synopsis[3]. This is not the place for a blow-by-blow account of the difficulties, but I am pleased to recount that major steps towards the retrieval of the *Coravel* were initially taken by Dr. W. G. Griffin (a local resident, not a relative). Upon encountering a difficulty that he found insuperable, he was resourceful enough to recruit Dr. S. N. Mentha and Mr. J. Schneider, professional software and hardware experts, respectively, both enthusiasts for astronomy, who very kindly and skilfully undertook and succeeded in the task. Not only did they bring the *Coravel* into operation, but they have maintained it ever since that time (late 1999), always on a purely voluntary basis. Whenever there has been a difficulty they have attended to it most promptly and willingly, and I cannot thank them enough for their skill and the good nature with which they deploy it in the interests of this work: without them this whole programme would have collapsed.

Although all of the observations made in the last eight years have come from the new *Coravel*, to such effect that 14 of the 50 papers and 49 of the 134 orbits summarized here have depended on those observations alone†, the majority of the papers naturally depend also on radial velocities obtained previously with other spectrometers. There were five of them: the original Cambridge one[11], with which the cross-correlation procedure was first developed; the second one[12], constructed by Dr. J. E. Gunn and myself for operation at the coudé focus of the 200-inch reflector on Palomar Mountain; the OHP *Coravel*[5]; its clone at ESO; and the spectrometer[13] at the Victoria (DAO) 48-inch coudé. A census of the numerical contributions of the various instruments to Papers 151–200 discloses that, out of the total of 8732 observations, 4749 (54½%) came from the Cambridge *Coravel*, 2354 (27%) from OHP, 1285 (14½%) from the original spectrometer, 221 (2½%) from the DAO, 74 (1%) from ESO, and 49 (½%) from Palomar. The total number of new observations published in this series now stands at 19127.

*A nice example of "Cast thy bread upon the waters . . ."[6] — the design was based upon the spectrum tracings in my *Arcturus Atlas*[7]!

†The statement refers to observations newly contributed by the author; in some cases radial velocities found in the literature have been utilized in addition. Included (after some hesitation on the part of the writer) in the count of 134 are the orbits of γ Cep[9] and 39 Cyg[10], which are very preliminary, and of HR 4964[8], whose period is almost indeterminate.

The last synopsis[3] invited speculation as to the reason why as many as 16 of the 50 papers treated there involved co-authors, whereas jointly-authored papers had previously been exceptional. Whatever the reason may have been, it has not operated as efficiently since: only six of the presently discussed papers have been collaborative. I hereby acknowledge the kind assistance of Dr. J.-M. Carquillat & Mlle. N. Ginestet in Papers 163 and 169, Dr. H. M. J. Boffin in Papers 171 and 191, Mr. J. J. Eitter in Paper 153, and Dr. T. W. Brown (who was at the time a sixth-form student who came to Cambridge for a week's work experience) in Paper 156.

Table I collects together the orbital elements for all the stars in the recent 50 papers. Including HR 4964, whose orbit is of indeterminately long period, there are 134 orbits, of 133 stars (HR 4454 has two orbits). It may be noted that 40 of the 133 objects are sufficiently obviously double-lined to be accorded SB2 orbits, in which it has been possible to measure the secondary stars as well as the primaries and to present values of K_2 and therefore also of the stellar masses (albeit multiplied by the usually unknown factor $\sin^3 i$). Of course all stars that exhibit orbital motion are necessarily double, but it does not follow that they are observably double-lined. Often there is such a disparity in luminosity (usually between a giant primary and a lower-main-sequence or white-dwarf secondary) that the light of the secondary is swamped; in other cases the *spectrum* may be observably composite, but (because the radial-velocity spectrometer cross-correlates it with a mask that mimics a late-type spectrum) the *radial-velocity trace* exhibits only a single feature, corresponding to the late-type component alone. One of the double-lined orbits, that of the visual companion to HR 8082, belongs to a star whose radial-velocity trace actually exhibits *three* dips, one of which is stationary and belongs to a third star that has in fact been seen as a very close visual companion to the double-lined object.

In addition to the many SB2 systems in Table I, there are a few apparently single-lined objects that possess more than one unseen companion. HR 4454 is the only fully-documented one, in which the observed star has been shown to move simultaneously in two orbits having periods of about nine and 4000 days (and, remarkably, quite similar amplitudes). HD 14415, HR 3112, and HD 112445 have all shown long-term secular changes in their γ-velocities, approximated in the papers concerned by linear trends. For HD 14415, and particularly for HR 3112, observations in the literature allow the reconstruction of part of the outer orbit. In the case of HR 3112, the large mass function implicit in that orbit, together with photometric and spectroscopic anomalies already discernible from the literature, led to the recognition that the late-type star must be accompanied by a hot companion of comparable luminosity and that therefore the spectrum ought to be conspicuously composite in the violet and near-UV — an expectation that was immediately confirmed when a spectrum (for which I have to thank Dr. D. Bohlender) was actually obtained. It is remarkable that so bright a companion to a 6^m G giant would have remained undetected until so recently. An object that is already seen as double-lined, but which evidently has an additional unseen companion, is HD 45191 (V455 Aur), which was first drawn to attention through the discovery by *Hipparcos*[14] of eclipses having a period extremely close to π days. It showed a change as great as 6 km s^{-1} in its γ-velocity between the first two observing seasons; it has remained under occasional observation in the ensuing seven years, but there has been little further change, so it must have been caught initially near a periastron passage in an 'outer' orbit of long period and high eccentricity.

TABLE I

Elements of spectroscopic binary orbits published in Papers 151–200

Paper no.	*Star*	*HR*	*HD*	*P days*	γ *km s*$^{-1}$	*K km s*$^{-1}$	*e*	ω *degrees*	*T or* T_0 *MJD*	*a sin i Gm*	*f(m) or* m_{min} $M_\odot$
151			21484	1446·6	−28·45	11·36	0·550	175·1	48950·1	188·8	0·128
152			146117	1468	+2·77	8·01	0·651	115·4	49277	123	0·034
153		7798	194152	1124·06	−24·56	7·81	0·759	108·1	49281	78·5	0·0153
154			202710	1217·20	−16·61	14·70	0·8084	318·3	49809·1	144·8	0·0819
155			137074	2002	−64·14	4·93	0·351	302·2	49098	127·1	0·0205
			140282	845	−2·93	3·38	0·30	277	49495	37·5	0·0030
156			187003	7·58922	+13·94	48·73	0	—	51678·0776	5·086	0·3757
						49·45				5·161	0·3702
157			192644	3381·1	−18·01	14·30	0·719	9·8	50770·2	462	0·344
158	72 Psc	308	6397	50·3855	+4·34	36·01	0·4998	317·6	50341·74	21·61	0·783
						39·93				23·96	0·706
159			1917	2·4966503	−8·00	32·44	0	—	50717·5281	1·114	0·00855
			4271	11·43932	+12·45	41·52	0·5286	155·01	51748·692	5·544	0·0520
			218687	3·631626	−0·12	22·17	0	—	51690·7626	1·107	0·00411
160	V454 Aur		44192	27·0197	−40·43	46·91	0·3790	229·59	51823·834	16·13	1·163
						52·71		—		18·13	1·035
	V455 Aur		45191	3·14578	var.	96·09	0·0078	128	51863·7085	4·156	1·263
						100·27				4·337	1·210
	UW LMi		92823	3·874307	−32·33	88·46	0	—	50613·0983	4·713	1·153
						89·97				4·794	1·133
161	BD +45°41			441·10	−14·93	15·20	0·269	105·8	49653·5	88·8	0·143
			214974	231·491	−13·22	30·57	0	—	50303·91	97·3	0·687
162			193216	418·77	−33·84	12·48	0·084	243	50218	71·6	0·0836
163			213503	2150·7	−10·89	22·79	0·4974	22·9	49450·0	584·9	1·727
			220636	117·527	−5·98	21·52	0	—	47589·50	34·77	0·1216
	γ Cep	8974	222404	24135	−42·82	2·04	0·389	166	48625	624	0·016
164			181658	5074·2	−2·81	13·68	0·7284	218·5	52038·4	654	0·434
165			20230	4377	+3·89	4·50	0·471	260	52053	239	0·0285
			22046	9749	+3·68	3·40	0·347	337	49928	427	0·033
			22939	4942	+3·84	4·23	0·381	7	51977	266	0·0306
166		2054	39743	83·1296	+0·19	7·59	0·122	338·4	51378·7	8·61	0·00369
	7 Lyn	2376	46101	125·594	−9·44	16·84	0·046	95	51933·9	29·05	0·0621
167			109179	289·021	−17·11	6·69	0·823	313·4	50245·54	15·10	0·00165
			112914	710·6	+27·51	5·61	0·326	65·0	49220	51·9	0·0110
			114761	472·0	+15·97	1·45	0·421	174	50632	8·55	0·000112
168		8361 A	208132/3	8·30344	+7·61	21·80	0·194	72·9	50038·74	2·442	0·00843
169			21771/2	5730	−14·96	11·88	0·8263	346·5	52208·2	527	0·178
170	V741 Cas		553	9·05997	−37·48	63·79	0	—	52020·964	7·948	1·046
						65·98				8·222	1·011
	V511 Lyr		337518	2·734776	+6·90	45·82	0	—	52200·5359	1·723	0·1494
						53·41				2·009	0·1282
171	GK Dra		152028	9·97380	+2·23	64·97	0·0815	82·0	52558·36	8·881	1·776
						81·14				11·09	1·422
	V1094 Tau		284195	8·9881	4·59	65·30	0·2697	333·2	52656·260	7·772	1·099
						70·98				8·448	1·011
172			83509	25·61381	−3·49	38·85	0·6232	155·29	51410·578	10·70	0·3162
						40·00				11·02	0·3069
			95547	122·8616	−9·88	31·18	0·5433	305·7	51399·89	44·22	0·984
						32·33				45·86	0·949
			190275	16·33845	−11·99	34·55	0·424	192·7	51862·585	7·03	0·212
						34·85				7·09	0·210
173			111306	61·504	−0·65	57·3	0·7790	135·0	52495·408	30·39	0·296
			113023	3453·8	+6·19	14·07	0·9097	293·9	52779·62	277·4	0·0715
			117901	156·623	−8·86	58·8	0·9119	312·6	52659·208	51·9	1·055
						63·1				55·8	0·982
			142474	233·112	−29·50	10·99	0·8272	339·7	50926·32	19·81	0·00571
174			14914	6194	+16·57	2·12	0·335	288	49388	170	0·0051
		2599	51424	6007	−5·90	3·50	0·138	100	47266	287	0·0260
			221422	7182	+7·16	6·18	0·259	309·0	50972	589	0·158

TABLE I (*continued*)

Paper no.	*Star*	*HR*	*HD*	*P* *days*	γ *km s*$^{-1}$	*K* *km s*$^{-1}$	*e*	ω *degrees*	*T or* T_0 *MJD*	*a sin i* *Gm*	*f(m) or* m_{min} $M_\odot$
175	BD +48°1048			371·12	−22·33	33·42	0·0822	357·5	50802·6	170·0	1·424
		1736	34533	2563·2	+15·59	10·22	0·339	96·3	50647	338·9	0·237
		3416	73451	284·728	+34·87	20·23	0·248	237·6	49890·7	76·74	0·2227
			199378/9	1200·37	−10·90	15·96	0·4244	36·1	50025·0	238·5	0·376
176			142353	63·497	−5·52	16·03	0	—	52758·972	14·00	0·02715
			164025	3·6550085	−23·13	57·64	0·0334	148·8	51089·324	2·895	0·07256
			165007	91·532	−27·28	30·25	0·2598	97·8	52633·91	36·77	0·2370
			209746	13·0985	−25·08	18·59	0	—	52712·221	3·349	0·00874
177	85 Peg	9088	224930	9610	−36·22	4·49	0·372	285·0	47737	551	0·0722
178			109118	43·6985	−41·63	17·77	0	—	49119·330	10·68	0·0255
			112138	139·002	+0·74	15·68	0·148	30·4	50119·5	29·63	0·0538
			112445	1136·6	(−25·79)	10·33	0·226	321·9	49763	157·3	0·1203
			114941	4572	−1·89	8·33	0·326	190·4	48937	495	0·232
179			108547	928·7	−0·11	7·64	0·539	251·2	50854·7	82·1	0·0257
			113093	5820	−26·34	4·11	0·518	335·9	52957	282	0·0263
			113393	1418	−11·08	2·91	0·126	326	50147	56·3	0·0035
			113638	27·8606	+10·77	9·21	0·675	252·9	50834·53	2·60	0·00091
180	ζ Aur	1612	32068	972·164	+12·11	23·22	0·3930	327·5	47204·8	285·4	0·983
181			49635	1132·1	+21·12	7·93	0·596	284·7	50810·3	99·1	0·0303
			49635 B	1256	+28·99	8·8	0·488	152	51107	132	0·058
			50730	1540·9	+22·10	25·32	0·4586	98·8	50924·6	476·7	1·823
			201563	115·0818	+4·47	32·11	0	—	50267·44	50·81	0·3957
			203340	1593·0	−26·00	18·11	0·6561	95·2	51239·5	299·4	0·422
182	22 Cam		37070	81·463	+20·30	9·52	0·136	0	51969·9	10·57	0·0071
			156051	556·213	−10·54	31·16	0·8610	51·0	52636·65	121·2	0·989
						32·31				125·7	0·954
		6890	169268	10·37026	−17·55	73·41	0·4307	31·7	52750·284	9·45	1·516
						80·66				10·38	1·380
			221757	347·99	+27·67	20·34	0·4344	0·0	52464·43	87·7	1·034
						21·92				94·5	0·959
183			98031	271·19	+69·32	6·82	0·232	214·6	51483·7	24·73	0·0579
						8·97				32·5	0·0440
			112573	832·4	−29·99	11·34	0·092	118	49559	129·2	0·598
						12·41				141·5	0·546
			197913 A	1790	−26·40	10·92	0·257	342·6	52729	260	0·964
						11·46				273	0·918
184			106383	782·9	−41·90	4·91	0·121	356	51374	52·5	0·0094
			109070	248·910	−18·65	9·51	0·216	134·7	50259·1	31·79	0·0207
			118157	1869·8	+3·77	7·97	0·076	162	50554	204·4	0·098
			121213	506·23	−34·06	14·35	0·416	211·0	50653·4	90·9	0·1169
185			15850	443·49	−6·86	16·96	0·582	284·4	52359·0	84·1	0·555
						18·17				90·1	0·518
		2452	47703	936·9	+82·63	14·29	0·139	296·9	52542	182·2	1·22
						15·01				191·4	1·16
		5769	138525	581·84	−46·39	13·61	0·6554	135·2	52644·58	82·3	0·452
						17·70				107·0	0·348
			193468	289·42	−15·19	26·66	0·5720	264·4	52898·19	87·0	1·260
						26·69				87·1	1·259
186	56 Peg	8796	218356	111·140	−26·51	1·47	0	—	51738·8	2·26	0·0000371
187		3936	86358	33·703	+39·78	29·2	0·063	123	53202·9	13·50	0·087
			100215	47·881	−16·56	28·0	0·240	251·5	53141·8	17·90	1·40
						50·3				32·2	0·78
188			14544	728·8	−2·17	4·79	0·120	191	52682	47·7	0·00815
			237201	364·09	−14·71	10·36	0·159	111·1	52598·7	51·2	0·0405
	66 Ori	2145	41380	1091·8	+25·02	11·90	0·246	223·1	51788	173·1	0·174
			216218	728·62	−17·81	7·84	0·269	320·2	51862·7	75·7	0·0326
			220102	373·62	−29·47	5·69	0·392	169·2	51247·3	26·88	0·00555
189			14415	704	(+11·71)	4·26	0·525	229·9	53447·3	35·1	0·00348
		3112	65448	97·533	(+19·13)	10·69	0·505	299·2	53001·92	12·37	0·00796
		4454	100518	4006	−1·44	9·58	0·522	77·2	53535	450	0·227
				8·91530	—	11·02	0·122	329·2	52223·75	1·341	0·001212

TABLE I (*concluded*)

Paper no.	*Star*	*HR*	*HD*	*P days*	γ *km s*$^{-1}$	*K km s*$^{-1}$	*e*	ω *degrees*	*T or* T_0 *MJD*	*a sin i Gm*	$f(m)$ *or* m_{min} $M_\odot$
190			109484	5182	−24·12	6·63	0·401	208·0	52827	433	0·121
			110376	1275·5	−9·28	3·89	0·187	292	50997	67·1	0·0074
			119334	648·26	−19·85	7·50	0·800	273·2	51835·57	40·1	0·00614
			120531	4717	+25·72	4·06	0·830	225·9	51723·0	146·6	0·0057
191			17310	27·819	+25·8	24·0	0·19	125	53485·4	9·0	0·038
			70645	8·4402	+14·53	33·1	0·077	66	53764·26	3·82	0·0314
			80731	10·6744	−0·78	22·82	0·392	265·7	53731·19	3·08	0·0103
192			172401	8631	+2·44	7·52	0·8485	307·3	53096·5	472	0·0565
193			47467	843·6	+1·65	12·60	0·5109	239·1	52996·6	125·7	0·451
						12·68				126·4	0·448
		3451	74243	700·3	+1·43	13·39	0·381	174·5	52387·8	119·2	0·518
						12·97				115·4	0·535
			223323	1175·1	−9·56	16·38	0·604	77·8	53230·0	211·1	1·091
						16·40				211·3	1·089
194			113997	1991	−33·41	4·09	0·080	6	49085	111·6	0·0140
			114931	2144	+4·22	6·14	0·551	284·9	49914	151	0·0299
			115588	314·61	−18·91	21·63	0·201	161·2	49540·3	91·7	0·311
			116880	120·373	−10·13	15·72	0·162	291·8	50081·3	25·67	0·0466
195			50730 B	270·33	+104·75	8·33	0·079	231	53626	30·9	0·0161
			213014 B	27·85180	−38·31	58·78	0·7288	100·2	51580·345	15·42	1·057
						69·3				18·19	0·896
		8082 B	201051 B	206·38	−3·44	21·02	0·140	321	52428·7	59·1	1·015
						24·03				67·5	0·888
196		770	16399	269·03	+26·01	10·86	0·134	62	53351·8	39·8	0·310
						15·92				58·3	0·212
			64207	152·719	+32·71	20·24	0·247	175·9	53292·73	41·19	0·521
						21·12				42·97	0·500
			187160	1743·3	+2·20	9·21	0·217	89·9	51968	215·4	0·839
						11·55				270	0·668
			212790	1815·3	−27·31	11·37	0·5030	290·3	52841·0	245·3	0·84
						12·31				266	0·776
197			10262	2136	+5·53	16·0	0·693	248·6	53227·7	339	1·39
						16·1				342	1·38
			116127	548·03	+9·35	12·9	0·8803	268·3	53153·69	46·0	0·092
						17·02				60·8	0·070
198	48 Psc	106	2436	621·39	−7·44	10·09	0·325	192·7	51871·9	81·5	0·0561
	16 Aur	1726	34334	434·16	−27·65	14·35	0·1189	70·1	51727·2	85·09	0·1305
	5 Her	5966	143666	1222·1	−17·85	3·58	0·294	137·2	52159	57·5	0·00509
	β Sct	7063	173764	833·26	−21·30	14·74	0·3207	35·2	51644·4	160·0	0·2354
199			105443	1697	−23·93	6·58	0·289	115	52179	147·1	0·244
						7·72				173	0·208
			108576	1968·6	−6·59	13·61	0·661	298·0	52058·4	276·3	1·10
						15·30				311	0·981
			112276	1919·2	+6·39	10·69	0·636	240·9	51636·0	217·8	0·468
						10·93				222·6	0·458
			112641	87·3857	−11·10	23·59	0·2455	236·0	50602·41	27·48	0·653
						28·79				33·54	0·535
		4964	114357	(50000)	−19·53	5·78	0·780	222·9	51367	2486	2·00
						8·1				3500	1·42
200	κ Per	941	19476	10528	+28·54	3·74	0·340	159·5	54553	509	0·0476
	β LMi	4100	90537	14100	+6·38	7·97	0·683	215·2	51400	1129	0·289
	56 UMa	4392	98839	16460	+1·01	3·84	0·555	286·8	51521	724	0·056
		4593	104438	13060	+25·51	6·59	0·586	275·6	47305	960	0·207
	39 Cyg	7806	194317	31292	−12·01	3·23	0·495	177	53794	1207	0·072

The synopses[1–3] of Papers 1–50, 51–100, and 101–150 have listed 50, 50, and 57 sets of orbital elements, respectively; the number of stars concerned is one fewer than the number of orbits, since two orbits were presented for HD 158609, a case analogous to HR 4454 in the currently discussed batch of papers.

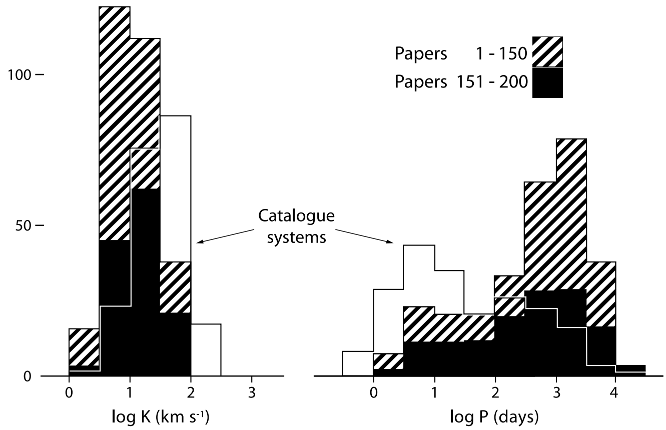

FIG. 1

The distribution of the amplitudes (left) and the periods (right) of the orbits derived in this series of papers, in comparison with those listed in the *Seventh Catalogue*[16] as being tolerably well determined. The maxima of the frequency distributions of the periods of the *Catalogue* and *Observatory* orbits are seen to differ by 2½ logarithmic units; the principal cause is without doubt observational selection, which is particularly fierce in the case of the *Catalogue* although it must still operate to a considerable extent in the same sense even for the *Observatory* sample.

The total number of orbits published in this series up to no. 200 is therefore 291, of 289 stars*.

Previous synopses have contrasted the distribution of the radial-velocity amplitudes and periods of the orbits determined in this series of papers with the corresponding distributions of the orbits to be found in the *Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems*[16], which was published in 1978, comparatively soon after this series of papers was started (1975) and before the photoelectric cross-correlation method had contributed many orbits to the compilation. The selection of orbits from the *Catalogue* was restricted to those of quality *c* and better (merely to reject orbits that were scarcely determinate) and to those of systems that included at least one component of spectral type F5 or later (so as to be comparable with those observed in this series). There were 204 of them; thus, in terms of quantity, this series has now easily surpassed the *total* number of orbits that had been tolerably well determined for late-type stars by about the time that the series started. Fig. 1, whose character will be familiar to readers whose memory reaches back to the earlier synopses, compares the distributions of the amplitudes and periods of the *Catalogue* orbits with those determined in the present series. The distributions are plotted in 'bins' half a logarithmic unit wide. Orbits published in the most recent 50 papers are

*If the 'object indices' in the third synopsis[3] and this present one appear to be two stars short, that is only because the entries for ξ UMa and HD 51565/6 each refer to two stars, constituting in each case a visual binary for which spectroscopic orbits have been given for both components. As a footnote to a footnote, it could be mentioned that the double designation of HD 51565/6 in the *Henry Draper Catalogue*[15] was not intended to refer to the visual-binary components, both of which are Am stars: the types were given as A2 and G, and the object was thought to possess a composite spectrum. At the time that the *Henry Draper Catalogue* classifications were made, neither the visual duplicity of HD 51565/6 nor the existence of Am-type spectra had been recognized.

distinguished from those in the earlier papers. Right from the start, such diagrams have revealed the enormous difference in character between the new orbits and the *Catalogue* ones. The difference is naturally most marked in the histogram of periods, since radial-velocity amplitudes scale as the inverse cube roots of periods, other things being equal, resulting in the range of amplitudes being greatly compressed in comparison with that of periods. The extraordinary difference between the two collections of orbits is exhibited in the manner in which their histograms are both heavily skewed *but in opposite senses*. The concentration of *Catalogue* orbits on short periods, and concomitantly on large amplitudes, has been confidently attributed to observational selection. A strong bias towards short periods and large amplitudes still remains even in the orbits presented in the current series of papers, but it is much less than in the *Catalogue*. With the development of the cross-correlation method and the availability of appropriate observing time (and patience!) the writer has been enabled to maintain a watch, such as would scarcely have been practicable previously, on a large number of binary systems many of which have proved to exhibit only small and slow velocity changes.

That said, it may be noticed from Fig. 1 that the large batch of new orbits represented by the solid black shading actually reduces slightly, rather than adding to, the extreme skewness of the amplitude and period distributions corresponding to the previous 150 papers. The reason lies in the addition to the observing programme of a large number of known or suspected double-lined objects, in particular about 100 F-type systems most of which were specifically suspected of duplicity by Suchkov[17] and many of which have indeed proved to be double-lined[18]. Except in instances of high eccentricity, amplitudes sufficient to make objects appear observably double-lined cannot occur in orbits with periods greater than a few years, although temporal variations in line profiles may permit the recognition of incipient duplicity at long periods. The last 50 papers have therefore included a lot (quite disproportionate to their true relative frequency) of orbits with periods less than a year or so. Even so, the maximum frequency of the orbits charted in Papers 151–200 is still in the bins on either side of 1000 days (roughly 1–9 years), and there is a significant number in the 3162–10 000-day bin as well as an initial entry into the next one, embracing periods from 10 000 to $10^{4.5}$ days (27 years to a lifetime or so), the latter time being all-but reached by the final (but none-too-well determined) orbit, of 39 Cygni, and probably exceeded by the almost indeterminate period of HR 4964.

It is impossible to be dogmatic about the effect that observational selection still plays in the distributions of amplitudes and periods charted in Fig. 1 for the orbits published in the present series. More than half of all those orbits have been derived for stars whose binary nature has been discovered in the course of the author's own survey programmes. Even in those cases there are selection effects related to period, inasmuch as binaries of very long period are less likely to have been discovered, and even those that are discovered are under-represented in Fig. 1 because quite a few of them have still not completed a single orbital cycle. The first set of 50 papers treats 50 stars, 45 (90%) of which are objects whose binary natures were discovered in Cambridge surveys, or in a few cases through casual observations not inspired by any reason to suppose that the objects concerned were binaries. The proportion of 'own discoveries' — objects not taken onto the observing programme in response to any prior knowledge about them — has progressively fallen; there are 49 such objects (37%) among the 133 discussed in Papers 151–200. The rest of the stars have come to the writer's attention through the literature or have been commended to his attention for one reason or another, and some fraction of them certainly has biasses such as the 'Suchkov' one mentioned in the preceding paragraph. Many of them were not *known* to be spectroscopic binaries at the times that they were respectively adopted onto the observing programme, but there were reasons to see them as prospective ones — for example 18 of them had been classified as having composite spectra. Even where the likelihood of their being binary, however, has not influenced the objects' adoption, the actual characters of the objects themselves are very strongly biassed towards high luminosities, because the surveys from which they have arisen have been restricted to specific ranges or limits of apparent magnitudes.

Despite the admitted heterogeneity of the objects sampled in this series of papers, it may still be of interest to demonstrate where their orbits fall in two particular statistical distributions. One is the relationship between orbital eccentricity and period. A plot of the e–log$P$ relationship for the first 100 papers and orbits was presented in the synopsis[2] published after Paper 100, in 1991. It was at about that time that it began to be widely appreciated that there is a very clear relationship between those quantities and that it is very significant, although what the significance actually *is* (beyond the readily comprehended one concerning the circularization of orbits at very short periods) has proved less easy to establish. At the conference held to celebrate the publication of Paper 100, so many participants independently demonstrated the relationship as found for various different groups of stars that it seemed likely[19] that the meeting would go down in history (if at all) as 'the e–log$P$ conference'!

A new plot, showing the eccentricities of all the orbits in the whole series, Papers 1–200, appears here as Fig. 2. Those from Papers 1–100 are plotted with open symbols, and ought exactly to mimic Fig. 2 of ref. 2; those of the subsequent hundred papers are represented by filled symbols. In both cases, squares distinguish the orbits of double-lined objects from those of single-lined ones,

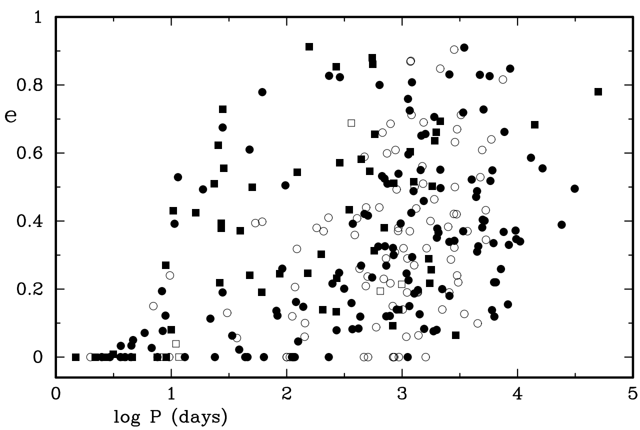

FIG. 2

Distribution of the eccentricities of the 291 orbits published in this series of papers, as a function of the logarithm of the orbital periods expressed in days. Orbits from Papers 1–100, for which a diagram analogous to this one was presented in ref. 2, are plotted with open symbols, whereas the symbols representing orbits from Papers 101–200 are filled. Single-lined systems are shown as circles, double-lined ones as squares. Comment is made in the text concerning the appearance of many of the later orbits, the majority of which are double-lined, in an area towards the top left of the diagram which was not populated at all by the earlier set.

which are plotted as circles. The now-expected rise of mean eccentricity with period appears probably to continue right through to the longest periods. Perhaps the next-most-conspicuous feature of the diagram, however, is the population by the more recent set of orbits of an area that was previously vacant, to the top left-hand side of the distribution, and the preponderance of double-lined objects contributing to that population. It is noteworthy that the great majority of the objects in the newly occupied area of the diagram are of F or Am types. There is no doubt that if Fig. 2 were plotted in such a way as to distinguish between giant and dwarf stars, the latter would be seen to be concentrated in the new region of short periods and substantial eccentricities, few of whose denizens have stemmed from unbiassed surveys.

In a paper given at a recent conference, Abt[20] discussed the statistics of orbital eccentricities. He noted that double-lined systems have larger mean eccentricities than single-lined ones, which accords with the qualitative impression given (at least for the shorter periods) by Fig. 2. He referred also to the progressive loss of the highest eccentricities towards short periods, and in particular remarked upon the highest values found within the period bins $10^{1 \cdot 5}$–10^2 and 10^1–$10^{1 \cdot 5}$-day bins (32–100 and 10–32 days). He said that there were no binaries with $e > 0 \cdot 8$ in the former bin; no doubt the limiting value was that of one of the orbits reviewed here, that of HD 111306 with $P = 61 \cdot 5$ days, $e = 0 \cdot 779$. The limit in the 10–32-day bin was $0 \cdot 7$, but that has been exceeded now by one of the objects in Paper 195, HD 213014 B, with $P = 27 \cdot 85$ days, $e = 0 \cdot 729$.

The other distribution that *would* be of interest *if* it demonstrated anything is that of the longitudes of periastron, to check whether there is any evidence of the 'Barr Effect'[21] in these orbits. The Barr Effect is a preponderance of longitudes in the first and second quadrants, a preponderance which one might think ought not to occur but certainly does occur in some groups of orbits. For example, Batten[22] has shown a 'Barr diagram' for all the orbits having non-zero eccentricity in his *Sixth Catalogue of the Orbital Elements of Spectroscopic Binary Systems*[23] and, instead of showing a statistically uniform distribution of longitudes as one might expect, it demonstrates an enormous excess in the first quadrant and the first part of the second. It has been suggested[24,25] that the velocity curves of some binaries, particularly those of early types and short periods, may be distorted by streams of gas or other interactions, but it seems difficult to credit such a large effect to such a specialized origin even if it were true in particular instances. The interest here, however, is not so much to explain the effect in other people's orbits as to look for it in the present set, and that is done in Fig. 3. The number of data

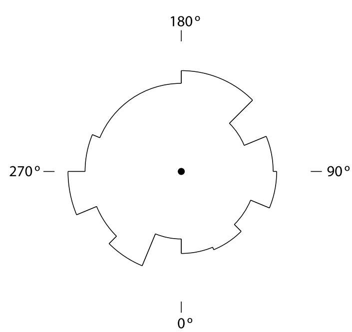

FIG. 3

Barr[21] diagram for the 252 orbits that have non-zero eccentricities. The radius of each '16-ant' (the 'word' is an admittedly clumsy analogue of *octant*, intended to mean the analogous division of the circle but with twice as many sectors) is proportional to the square root of the number of orbits having longitudes of periastron within the corresponding sector, so its area is proportional to that number. Sets of orbits that show the Barr Effect — and some certainly *do* — have a surplus of longitudes in the range 0°–135°, but the ones plotted here clearly do not. In fact their numbers appear marginally deficient in that region, but the discrepancies between different sectors are actually just what could be expected for a random distribution.

is such that it has seemed worthwhile to split the sample not into quadrants, or even octants as was done in the Paper 100 synopsis[2] but into '16-ants' (whatever they may correctly be termed). There are 252 orbits with non-zero eccentricities, so the mean number of objects per 16-ant is just under 16; the r.m.s. deviation of the numbers in the individual sectors is very close to 4. In fact the sum of the squares of the deviations is 262, extremely close to the sample size of 252, so the variance is almost exactly equal to the mean, which is just what it ought to be for a statistically uniform distribution. It should be mentioned that Fig. 3 has been drawn according to a different principle from the corresponding Figure in ref. 2, inasmuch as the radii of the sectors have been made proportional to the *square roots* of the numbers that they represent, so that it is the *areas* of the sectors and not the radii directly that demonstrate the numbers; the conventional form of the plot tends to be visually misleading.

Errata

No matter how careful an author tries to be, it seems impossible to avoid making the occasional mistake! Errors that have been noticed in this series, and for which I apologize, are as follows:

Paper 108 (HD 13728/9): p. 33, line 9, the year given as 1988 should be 1990.

Paper 137 (HD 51565/6): p. 354, line 7 from foot, the object is mistakenly called *HR* 51565/6.

Paper 160 (HD 45191): p. 326, the value of ω for the inner orbit should be 128° (in place of 138°).*

Paper 176 (HD 164025): p. 194, Table III, the calendar dates and MJDs of the observations listed as 2003 Aug. 10 and Sept. 25 should be reduced by 1.* (The input file and calculations were correct. In most output tables the dates are given only to two decimals, and in such a case the decimal part of the date, ·996 in each case here, would have been rounded to .00 and the integer advanced by 1 accordingly. Through an oversight in the computer program, the integer was increased even though the decimal was, exceptionally, in view of the short period of HD 164025, printed to three decimals and so was not rounded up.)

Paper 179 (HD 113093): p. 439, Table VII, the standard error of P should be 54 days, not 0·54 days.

Paper 181 (HD 50730): p. 95, Table VI, the value of T should be MJD 50924·6, not 52924·6.*

Paper 185: p. 381, in the table of orbital elements of the four stars (Table VI), T for HR 2452 should be MJD 52542, not 53542*, and K_2 is erroneously written as K_1.

Paper 189: p. 272, HR 3112 should have been recorded as being 4°, not 4′, north-preceding *o* UMa.

Acknowledgements

It is made clear in the third paragraph of this paper how very much I am indebted to Dr. W. G. Griffin, Dr. S. N. Mentha, and Mr. J. Schneider for the existence of the Cambridge *Coravel* as an operational entity and thereby for my being able to observe at all, and I take this opportunity to reinforce that heartfelt expression of gratitude here.

*Error identified by Dr. D. Pourbaix, who kindly alerted me to it.

I am very grateful to Dr. D. Pourbaix for his vigilance in ensuring that my orbital solutions are accurate and for informing me when they are not. Furthermore, I am pleased to thank Ms. A. Smith for producing Figs. 1 and 3 for this paper. The analogues of those figures in the earlier synopses (as well as all the figures in Papers 1–100) were drawn on tracing paper with pen and ink by my own hand, with shading printed on self-adhesive transparent sheet material cut to size and stuck on, but that is not the way that it is supposed to be done nowadays. To draw Fig. 1 on my computer was beyond my powers, so I appealed to Ms. Smith to ask hers to draw a diagram as similar as possible to the corresponding one in the previous synopsis[3], and I gave her a copy of that diagram and a listing of the heights needed for the various columns in the new one. The identity of character that she achieved between Fig. 1 and its immediate predecessor makes it hard to believe that the two diagrams could have been produced in such very different ways: it just goes to show how a sufficiently skilful person can do *anything* on a computer!

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Bibliographical index to Papers 1–200

The last entry in each column refers to the synopsis of the papers in that column

Paper no.	*Reference*	*Paper no.*	*Reference*	*Paper no.*	*Reference*	*Paper no.*	*Reference*
1	**95**, 23, 1975	51	**103**, 199, 1983	101	**111**, 299, 1991	151	**120**, 137, 2000
2	**95**, 98, 1975	52	**103**, 252, 1983	102	**112**, 10, 1992	152	**120**, 188, 2000
3	**95**, 143, 1975	53	**103**, 284, 1983	103	**112**, 41, 1992	153	**120**, 260, 2000
4	**95**, 187, 1975	54	**104**, 6, 1984	104	**112**, 111, 1992	154	**120**, 320, 2000
5	**95**, 289, 1975	55	**104**, 80, 1984	105	**112**, 168, 1992	155	**120**, 397, 2000
6	**96**, 18, 1976	56	**104**, 148, 1984	106	**112**, 219, 1992	156	**121**, 55, 2001
7	**96**, 56, 1976	57	**104**, 189, 1984	107	**112**, 283, 1992	157	**121**, 91, 2001
8	**96**, 98, 1976	58	**104**, 224, 1984	108	**113**, 32, 1993	158	**121**, 162, 2001
9	**96**, 153, 1976	59	**104**, 267, 1984	109	**113**, 53, 1993	159	**121**, 221, 2001
10	**96**, 188, 1976	60	**105**, 7, 1985	110	**113**, 128, 1993	160	**121**, 315, 2001
11	**96**, 241, 1976	61	**105**, 29, 1985	111	**113**, 193, 1993	161	**121**, 372, 2001
12	**97**, 18, 1977	62	**105**, 81, 1985	112	**113**, 263, 1993	162	**122**, 14, 2002
13	**97**, 86, 1977	63	**105**, 126, 1985	113	**113**, 294, 1993	163	**122**, 90, 2002
14	**97**, 169, 1977	64	**105**, 201, 1985	114	**114**, 21, 1994	164	**122**, 158, 2002
15	**97**, 173, 1977	65	**105**, 226, 1985	115	**114**, 45, 1994	165	**122**, 210, 2002
16	**97**, 196, 1977	66	**106**, 16, 1986	116	**114**, 102, 1994	166	**122**, 275, 2002
17	**97**, 235, 1977	67	**106**, 35, 1986	117	**114**, 167, 1994	167	**122**, 329, 2002
18	**98**, 14, 1978	68	**106**, 67, 1986	118	**114**, 231, 1994	168	**123**, 36, 2003
19	**98**, 47, 1978	69	**106**, 108, 1986	119	**114**, 268, 1994	169	**123**, 69, 2003
20	**98**, 118, 1978	70	**106**, 154, 1986	120	**115**, 16, 1995	170	**123**, 129, 2003
21	**98**, 158, 1978	71	**106**, 197, 1986	121	**115**, 84, 1995	171	**123**, 203, 2003
22	**98**, 232, 1978	72	**107**, 1, 1987	122	**115**, 129, 1995	172	**123**, 286, 2003
23	**98**, 257, 1978	73	**107**, 58, 1987	123	**115**, 193, 1995	173	**123**, 344, 2003
24	**99**, 1, 1979	74	**107**, 114, 1987	124	**115**, 243, 1995	174	**124**, 22, 2004
25	**99**, 36, 1979	75	**107**, 154, 1987	125	**115**, 323, 1995	175	**124**, 97, 2004
26	**99**, 87, 1979	76	**107**, 194, 1987	126	**116**, 19, 1996	176	**124**, 190, 2004
27	**99**, 124, 1979	77	**107**, 248, 1987	127	**116**, 98, 1996	177	**124**, 258, 2004
28	**99**, 145, 1979	78	**108**, 16, 1988	128	**116**, 162, 1996	178	**124**, 371, 2004
29	**99**, 198, 1979	79	**108**, 49, 1988	129	**116**, 233, 1996	179	**124**, 429, 2004
30	**100**, 1, 1980	80	**108**, 90, 1988	130	**116**, 298, 1996	180	**125**, 1, 2005
31	**100**, 30, 1980	81	**108**, 114, 1988	131	**116**, 373, 1996	181	**125**, 81, 2005
32	**100**, 73, 1980	82	**108**, 155, 1988	132	**117**, 51, 1997	182	**125**, 134, 2005
33	**100**, 113, 1980	83	**108**, 220, 1988	133	**117**, 82, 1997	183	**125**, 253, 2005
34	**100**, 161, 1980	84	**109**, 12, 1989	134	**117**, 140, 1997	184	**125**, 300, 2005
35	**100**, 193, 1980	85	**109**, 55, 1989	135	**117**, 208, 1997	185	**125**, 367, 2005
36	**101**, 7, 1981	86	**109**, 79, 1989	136	**117**, 288, 1997	186	**126**, 1, 2006
37	**101**, 51, 1981	87	**109**, 142, 1989	137	**117**, 351, 1997	187	**126**, 119, 2006
38	**101**, 79, 1981	88	**109**, 180, 1989	138	**118**, 14, 1998	188	**126**, 186, 2006
39	**101**, 115, 1981	89	**109**, 222, 1989	139	**118**, 78, 1998	189	**126**, 265, 2006
40	**101**, 175, 1981	90	**110**, 7, 1990	140	**118**, 158, 1998	190	**126**, 338, 2006
41	**101**, 208, 1981	91	**110**, 40, 1990	141	**118**, 209, 1998	191	**126**, 401, 2006
42	**102**, 1, 1982	92	**110**, 85, 1990	142	**118**, 273, 1998	192	**127**, 45, 2007
43	**102**, 27, 1982	93	**110**, 126, 1990	143	**118**, 350, 1998	193	**127**, 113, 2007
44	**102**, 82, 1982	94	**110**, 150, 1990	144	**119**, 27, 1999	194	**127**, 171, 2007
45	**102**, 136, 1982	95	**110**, 177, 1990	145	**119**, 81, 1999	195	**127**, 225, 2007
46	**102**, 200, 1982	96	**111**, 29, 1991	146	**119**, 131, 1999	196	**127**, 313, 2007
47	**102**, 223, 1982	97	**111**, 67, 1991	147	**119**, 213, 1999	197	**127**, 379, 2007
48	**103**, 17, 1983	98	**111**, 108, 1991	148	**119**, 272, 1999	198	**128**, 21, 2008
49	**103**, 56, 1983	99	**111**, 155, 1991	149	**119**, 320, 1999	199	**128**, 95, 2008
50	**103**, 145, 1983	100	**111**, 201, 1991	150	**120**, 1, 2000	200	**128**, 176, 2008
1–50	**103**, 273, 1983	51–100	**111**, 291, 1991	101–150	**120**, 195, 2000	151–200	**128**, 448, 2008

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

Name	*HR*	*HD*	*Paper no.*
V640 Cas	5	123	144
		483	126
V741 Cas		553	170
		1917	159
		2343	26
48 Psc	106	2436	198
		4271	159
		5373	86
		5665	107
72 Psc	308	6397	158
		6645	101
		6645 B	101
φ Psc	360	7318	99
φ Psc B	360 B	7318 B	100
		7426	80
		8997	76
		9313	2
χ And	469	10072	140
		10262	197
		11579	27
	551	11613	40
61 Cet	610	12641	121
		12871	115
	616	12923	87
		13725	53
		13728/9	108
		13738	16
		14415	189
		14346	63
		14544	188
		14914	174
		14985	64
14 Tri	736	15656	117
		15850	185
	770	16399	196
		16448	84
		17198	71
		17310	191
	913	18894	33
κ Per	941	19476	200
V510 Per		19942	103
	965	20084	88
		20214	79
		20230	165
		20394	130
		21484	151
		21771/2	169
		22046	165
	1105	22649	58
		22939	165
		25099	61
		27144	39
ζ Aur	1612	32068	180
		33708	45
16 Aur	1726	34334	198
	1736	34533	175
22 Cam		37070	182
	1970	38099	5
	2054	39743	166
1 Gem B	2134 B	41116 B	10
66 Ori	2145	41380	188
	2236	43358	131
	2259	43821	66
		43930	11
V454 Aur		44192	160
		45088	1
	2317	45168	22
V455 Aur		45191	160
7 Lyn	2376	46101	166
	2452	47703	185
		47467	193
18 Mon	2506	49293	59
		49635	181
		49635 B	181
		50730	181
		50730 B	195
	2599	51424	174
		51565/6	137
		55510	69
		57339	52
	2879	59878	119
	2879 B	59878 B	119
	2918	60803	135
		64207	196
	3112	65448	189
ζ Cnc C	3210	68256	150
		70645	191
	3325	71433	120
	3416	73451	175
	3451	74243	193
6 UMa	3531	75958	146
17 Hya	3553	76370	123
		80492	116
		80655	49
		80731	191
		81564	91
	3805	82674	38
		83065	65
10 Leo	3827	83240	60
		83509	172
	3936	86358	187
		90385	8
		90442	77
		90524	46
β LMi	4100	90537	200
UW LMi		92823	160
44 LMi	4230	93765	139
	4249	94363	34
		95547	172
		96342	70
		96953	28
		97810	143
73 Leo	4365	97907	95
		98031	183
ξ UMa	4375/4	98231/0	142
		98439	97
56 UMa	4392	98839	200
		99903	125
		100215	187
	4454	100518	189
62 UMa	4501	101606	147
	4593	104438	200
		105443	199
		106383	184
		106495	36
		107401	111
		108078	30
		108547	179
		108576	199
		109070	184
		109118	178
		109179	167
		109484	190
		110376	190
		111306	173
	4896	112048	48
		112138	178
		112276	199
		112445	178
		112573	183
		112641	199
		112914	167
		113023	173
		113093	179
		113393	179
		113638	179
		113997	194
	4964	114357	199
		114761	167
		114931	194

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PHOTOMETRIC STUDY OF A SOLAR-TYPE CONTACT BINARY — DOES GSC 2766 0775 HAVE A HEMISPHERE-SIZED SUPER-LUMINOUS REGION?

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Bob Jones University,

W. Van Hamme
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We present the first high-precision observations, taken at Lowell Observatory and Kitt Peak National Observatory, of the recently discovered large-amplitude WU Ma system, GSC 2766 0775 (Peg). A complete photometric analysis of the *BVRI* light curves is presented. This includes three major elements: a photometric spectral-type determination, a simultaneous light-curve analysis, and a mass-ratio search. GSC 2766 0755 is found to be a solar-type contact binary. Several model solutions are presented. The spotted models surprisingly iterated to include hemisphere-sized regions only $\sim$250 K different than the remaining surface. The model with a region of slightly elevated temperature, *i.e.*, the hot-spot model, gives the lowest-residual solution.

Introduction

GSC 2766 0775 (Peg) [SAVS J233710+313611, *2MASS* J23371069+3136112, $\alpha(2000) = 23^h\ 37^m\ 10^s\cdot 69$, $\delta(2000) = +31°\ 36'\ 11''\cdot 4$ (ICRS[1])] was observed as a part of our student/professional collaborative studies of interacting binaries from data taken in conjunction with the National Undergraduate Research Observatory (NURO) and the Southeastern Association for Research in Astronomy (SARA).

The variability of GSC 2766 0775 was discovered by the Semi-Automatic Variability Search[2] (SAVS, http://www.astri.uni.torun.pl/~gm/SAVS/). The ephemeris given by SAVS is

$$\text{HJD}\ T_{\min 1} = 2453254\cdot 587540 + 0\cdot 375736\,E \qquad (1)$$

The variable was classified as an EW type with a maximum magnitude of $V = 13^m\cdot 36$ and an amplitude of $0^m\cdot 78$. From archived SAVS data, we calculated six new timings of minimum light by fitting parabolae to the available eclipse curves (see Table III). Our preliminary report on this variable was presented at a recent American Astronomical Society (AAS) meeting.[3]

Observational materials, reductions, and standardized magnitudes

Our 2005 BVR_cI_c observations were secured on September 30 with the LN-cooled CCD camera with a metachrome-coated TEK 512 × 512 chip at the Lowell 0·81-m. Our 2006 observations were also taken with the 0·81-m reflector of Lowell Observatory at Anderson Mesa, near Flagstaff, Arizona, on September 27 with a thermoelectrically cooled (−100° C), 2048 × 2048 Loral NASA CAM and with standard $UBVR_cI_c$ filters. On October 9 at Kitt Peak National Observatory (KPNO) in remote mode we took additional data with the 0·9-m *SARA* reflector and a thermoelectrically cooled (−30° C) 1K × 1K Finger Lakes camera. The 2007 observations were taken on January 3 and 25 in *BVRI* on the *SARA* telescope. The 2005, 2006, and 2007 observations were taken by RM, RS, HC, DF, and CL. Reduction and analyses were carried out primarily by RS and CL.

The 2006 curves, being complete, are modelled here with a synthetic-light-curve program. The other data were used in the period determination. Fifty-six individual observations were taken in 2005 in *B* and in *R*, 53 in *V*, and 57 in *I*. In 2006 we took 23 in *U*, 163 in *B*, 167 in *V*, 164 in *R*, and 164 in *I*; and 50 *BVRI* observations were taken in 2007. Two similar, nearby field stars were used as comparison (C) (GSC 2766 0387, $\alpha(2000) = 23^h\ 37^m\ 19^s{\cdot}36$, δ (2000) $= 31°\ 36'\ 08''{\cdot}7$) and check (K) (GSC 2766 1205, $\alpha(2000) = 23^h\ 37^m\ 07^s{\cdot}42$, δ (2000) $= 31°\ 34'\ 19''{\cdot}5$). The finding chart is shown in Fig. 1. We first created our delta- magnitude curves as variable minus comparison but we found large scatter in the comparison values so we now show the curves as variable minus check. (The comparison may be a low-amplitude erratic variable.) Our observations are given in Table I.

After a number of attempts, usable standard magnitudes were determined in *V*, *V–I*, *V–R*, and *R–I* from observations of nine Landolt standard stars and comparison-star magnitudes taken on 2007 January 25. The spectral type of the

FIG. 1

Finder chart of GSC 2766 0755 (V), comparison (C), and check (K)

TABLE I

Observed delta magnitudes (variable–check), GSC 2766 0755

HJD 2454000+	*ΔU*	*HJD* 2454000+	*ΔU*	*HJD* 2454000+	*ΔU*	*HJD* 2454000+	*ΔU*	*HJD* 2454000+	*ΔU*
7·6794	0·578	7·7049	0·614	7·7269	0·723	7·7484	0·979	7·7692	1·168
7·6874	0·564	7·7091	0·62	7·7302	0·739	7·7517	1·025	7·7763	1·179
7·6913	0·608	7·7124	0·645	7·7335	0·763	7·7587	1·115	7·7799	1·139
7·6942	0·619	7·7156	0·658	7·7408	0·864	7·7626	1·164		
7·6971	0·609	7·7235	0·699	7·7451	0·926	7·7659	1·182		

HJD 2454000+	*ΔB*	*HJD* 2454000+	*ΔB*	*HJD* 2454000+	*ΔB*	*HJD* 2454000+	*ΔB*	*HJD* 2454000+	*ΔB*
7·6853	0·676	7·8313	0·787	7·9808	1·177	18·7224	0·780	18·8658	1·345
7·6892	0·703	7·8346	0·755	18·5990	0·732	18·7259	0·759	18·8697	1·246
7·6922	0·698	7·8378	0·740	18·6057	0·727	18·7302	0·736	18·8732	1·176
7·6951	0·696	7·8448	0·718	18·6092	0·753	18·7337	0·727	18·8772	1·092
7·7028	0·715	7·8483	0·719	18·6127	0·793	18·7384	0·713	18·8807	1·019
7·7068	0·723	7·8516	0·739	18·6170	0·789	18·7419	0·716	18·8848	0·964
7·7101	0·757	7·8549	0·709	18·6205	0·801	18·7464	0·738	18·8882	0·924
7·7134	0·780	7·8624	0·715	18·6240	0·842	18·7498	0·707	18·8921	0·872
7·7212	0·822	7·8670	0·738	18·6282	0·880	18·7555	0·690	18·8956	0·845
7·7246	0·838	7·8703	0·726	18·6317	0·902	18·7590	0·686	18·8996	0·831
7·7279	0·868	7·8736	0·743	18·6352	0·936	18·7703	0·714	18·9031	0·791
7·7311	0·886	7·8807	0·762	18·6397	0·990	18·7737	0·693	18·9071	0·774
7·7386	0·980	7·8845	0·782	18·6432	1·027	18·7782	0·710	18·9106	0·763
7·7428	1·017	7·8878	0·799	18·6471	1·075	18·7816	0·757	18·9146	0·756
7·7461	1·097	7·8911	0·814	18·6506	1·150	18·7890	0·749	18·9181	0·739
7·7494	1·121	7·8988	0·876	18·6545	1·210	18·7925	0·778	18·9227	0·717
7·7564	1·234	7·9038	0·884	18·6580	1·253	18·7990	0·824	18·9261	0·684
7·7603	1·307	7·9071	0·909	18·6620	1·328	18·8025	0·874	18·9306	0·654
7·7635	1·327	7·9104	0·941	18·6655	1·307	18·8079	0·891	18·9341	0·644
7·7668	1·326	7·9187	1·010	18·6696	1·296	18·8113	0·900	18·9382	0·686
7·7740	1·353	7·9235	1·076	18·6731	1·257	18·8157	0·949	18·9416	0·675
7·7776	1·302	7·9267	1·105	18·6768	1·218	18·8191	1·035	18·9455	0·662
7·7808	1·266	7·9300	1·170	18·6803	1·134	18·8235	1·072	18·9490	0·616
7·7842	1·223	7·9371	1·306	18·6842	1·083	18·8270	1·093	18·9531	0·630
7·7914	1·118	7·9405	1·382	18·6877	1·034	18·8313	1·200	18·9566	0·673
7·7948	1·068	7·9437	1·444	18·6922	1·006	18·8348	1·296	18·9607	0·649
7·7981	0·998	7·9470	1·515	18·6957	0·951	18·8393	1·400	18·9642	0·628
7·8014	0·960	7·9540	1·545	18·6998	0·913	18·8427	1·413	18·9683	0·646
7·8098	0·893	7·9575	1·528	18·7032	0·873	18·8470	1·437	18·9717	0·690
7·8133	0·875	7·9613	1·519	18·7071	0·836	18·8505	1·462	18·9757	0·695
7·8165	0·861	7·9688	1·432	18·7105	0·823	18·8547	1·473	18·9791	0·724
7·8198	0·846	7·9735	1·333	18·7149	0·815	18·8582	1·440		
7·8269	0·770	7·9772	1·246	18·7184	0·816	18·8623	1·378		

variable at phase 0·0 (mostly the secondary component) is approximately G6, that of the check is G9, and that of the comparison is G2[4]. Full information is given in Table II. *2MASS* values of *J–H*, *H–K*, and *J–K* imply spectral types of G2, G0±3, and G3 for the variable[4,5].

Period determination

Six times of minimum light were calculated from our present observations: HJD I = 2453644·9871 ± 0·0002, 2454018·8517 ± 0·0004, and 2454007·9550 ± 0·0004; HJD II = 2453644·8008 ± 0·00014, 2454018·6649 ± 0·00018, and

TABLE I (*continued*)

HJD 2454000+	*ΔV*	*HJD* 2454000+	*ΔV*	*HJD* 2454000+	*ΔV*	*HJD* 2454000+	*ΔV*	*HJD* 2454000+	*ΔV*
7·6863	0·623	7·8356	0·705	18·5970	0·740	18·7312	0·738	18·8667	1·341
7·6902	0·610	7·8389	0·685	18·6066	0·733	18·7346	0·712	18·8707	1·193
7·6931	0·633	7·8459	0·676	18·6101	0·740	18·7393	0·717	18·8741	1·113
7·6960	0·658	7·8494	0·672	18·6136	0·751	18·7428	0·708	18·8782	1·026
7·7038	0·669	7·8527	0·653	18·6179	0·761	18·7473	0·720	18·8816	0·996
7·7078	0·664	7·8560	0·669	18·6214	0·803	18·7508	0·691	18·8857	0·938
7·7111	0·664	7·8634	0·665	18·6249	0·831	18·7565	0·663	18·8892	0·885
7·7144	0·704	7·8681	0·679	18·6291	0·860	18·7599	0·645	18·8931	0·839
7·7223	0·736	7·8714	0·661	18·6326	0·930	18·7629	0·647	18·8965	0·806
7·7256	0·748	7·8746	0·678	18·6361	0·935	18·7648	0·661	18·9005	0·824
7·7289	0·785	7·8818	0·683	18·6406	0·975	18·7670	0·672	18·9040	0·763
7·7322	0·820	7·8855	0·706	18·6441	0·996	18·7712	0·689	18·9080	0·753
7·7396	0·906	7·8888	0·742	18·6480	1·057	18·7746	0·666	18·9115	0·725
7·7439	0·934	7·8921	0·757	18·6515	1·163	18·7791	0·725	18·9155	0·733
7·7472	1·005	7·8998	0·782	18·6554	1·185	18·7826	0·729	18·9190	0·730
7·7504	1·038	7·9049	0·829	18·6589	1·290	18·7900	0·762	18·9236	0·709
7·7575	1·172	7·9081	0·842	18·6630	1·297	18·7934	0·730	18·9271	0·682
7·7613	1·211	7·9114	0·857	18·6665	1·302	18·7999	0·820	18·9315	0·614
7·7646	1·249	7·9198	0·937	18·6706	1·284	18·8034	0·892	18·9350	0·606
7·7679	1·268	7·9245	0·993	18·6740	1·196	18·8088	0·899	18·9391	0·633
7·7751	1·251	7·9278	1·044	18·6778	1·175	18·8123	0·926	18·9425	0·668
7·7786	1·200	7·9311	1·107	18·6813	1·103	18·8166	0·960	18·9465	0·668
7·7819	1·159	7·9381	1·223	18·6852	1·001	18·8200	0·991	18·9499	0·607
7·7852	1·133	7·9415	1·294	18·6886	1·006	18·8244	1·065	18·9540	0·618
7·7925	1·017	7·9448	1·356	18·6931	0·965	18·8279	1·106	18·9575	0·632
7·7959	0·976	7·9481	1·401	18·6966	0·933	18·8323	1·227	18·9617	0·627
7·7992	0·914	7·9551	1·460	18·7007	0·878	18·8357	1·274	18·9651	0·604
7·8025	0·907	7·9586	1·449	18·7041	0·816	18·8402	1·387	18·9692	0·633
7·8109	0·829	7·9625	1·445	18·7080	0·794	18·8436	1·436	18·9726	0·735
7·8143	0·779	7·9700	1·298	18·7115	0·802	18·8479	1·453	18·9766	0·685
7·8176	0·778	7·9748	1·225	18·7158	0·840	18·8514	1·400	18·9801	0·686
7·8209	0·755	7·9784	1·130	18·7193	0·809	18·8556	1·451		
7·8279	0·735	18·5940	0·660	18·7233	0·735	18·8591	1·437		
7·8323	0·711	18·5956	0·688	18·7268	0·751	18·8632	1·386		

2454007·7697 ± 0·0007. A linear ephemeris was calculated which included all timings of minimum light (covering some 2000 cycles):

$$\text{HJD } T_{\min 1} = 2454018{\cdot}8524 \pm 0{\cdot}0011 + 0{\cdot}3757431 \pm 0{\cdot}0000013\, E \qquad (2)$$

The ephemeris determined by the Wilson Code used to phase our light curves was:

$$\text{HJD } T_{\min 1} = 2454018{\cdot}85200 \pm 0{\cdot}00015 + 0{\cdot}375683 \pm 0{\cdot}000008\, E \qquad (3)$$

The complete list of minima along with epoch and their O–C residuals are given in Table III. The plot of residuals is given in Fig. 2. At this time we cannot determine a period change from the data.

Synthetic-light-curve modelling

We first hand-fit each light curve individually with BINARY MAKER 3·0[6] using standard convective parameters and limb-darkening coefficients from reasonable

TABLE I (*continued*)

HJD 2454000+	*ΔR*	*HJD* 2454000+	*ΔR*	*HJD* 2454000+	*ΔR*	*HJD* 2454000+	*ΔR*	*HJD* 2454000+	*ΔR*
7·6789	0·600	7·8286	0·680	7·9792	1·106	18·7216	0·762	18·8689	1·248
7·6869	0·588	7·8330	0·656	7·9829	0·954	18·7294	0·745	18·8724	1·151
7·6908	0·605	7·8363	0·643	18·6049	0·742	18·7329	0·707	18·8764	1·078
7·6937	0·602	7·8396	0·636	18·6084	0·746	18·7376	0·701	18·8799	0·997
7·6966	0·620	7·8466	0·635	18·6119	0·756	18·7411	0·700	18·8840	0·980
7·7044	0·638	7·8501	0·621	18·6162	0·777	18·7456	0·724	18·8874	0·922
7·7085	0·626	7·8534	0·619	18·6197	0·788	18·7490	0·730	18·8913	0·892
7·7118	0·664	7·8566	0·628	18·6232	0·828	18·7547	0·679	18·8948	0·834
7·7151	0·668	7·8641	0·624	18·6273	0·854	18·7582	0·657	18·8988	0·802
7·7229	0·712	7·8688	0·607	18·6308	0·901	18·7694	0·706	18·9023	0·852
7·7263	0·731	7·8720	0·634	18·6343	0·938	18·7729	0·686	18·9063	0·767
7·7296	0·769	7·8753	0·633	18·6389	0·965	18·7774	0·701	18·9097	0·764
7·7329	0·772	7·8825	0·668	18·6423	0·987	18·7808	0·763	18·9138	0·792
7·7403	0·879	7·8862	0·670	18·6463	1·023	18·7882	0·687	18·9172	0·771
7·7446	0·924	7·8895	0·688	18·6497	1·111	18·7917	0·745	18·9218	0·730
7·7478	0·982	7·8928	0·709	18·6537	1·188	18·7982	0·783	18·9253	0·692
7·7511	1·011	7·9005	0·744	18·6572	1·253	18·8016	0·864	18·9298	0·653
7·7582	1·151	7·9056	0·776	18·6612	1·299	18·8070	0·904	18·9333	0·619
7·7620	1·194	7·9088	0·805	18·6647	1·328	18·8105	0·907	18·9373	0·631
7·7653	1·201	7·9121	0·824	18·6688	1·274	18·8148	0·908	18·9408	0·658
7·7686	1·200	7·9205	0·901	18·6723	1·260	18·8183	0·985	18·9447	0·669
7·7758	1·196	7·9252	0·964	18·6760	1·211	18·8227	1·035	18·9482	0·637
7·7793	1·148	7·9285	1·005	18·6795	1·132	18·8261	1·112	18·9523	0·595
7·7826	1·119	7·9318	1·067	18·6834	1·061	18·8305	1·176	18·9557	0·681
7·7859	1·085	7·9388	1·222	18·6869	1·014	18·8340	1·288	18·9599	0·631
7·7932	0·970	7·9422	1·249	18·6914	1·006	18·8384	1·300	18·9634	0·593
7·7966	0·909	7·9455	1·328	18·6949	0·969	18·8419	1·379	18·9674	0·640
7·7999	0·870	7·9488	1·380	18·6989	0·924	18·8462	1·472	18·9709	0·676
7·8031	0·846	7·9558	1·400	18·7024	0·860	18·8496	1·440	18·9748	0·738
7·8116	0·780	7·9593	1·388	18·7063	0·823	18·8539	1·411	18·9783	0·727
7·8150	0·760	7·9633	1·393	18·7097	0·796	18·8573	1·432	18·9825	0·756
7·8183	0·733	7·9709	1·286	18·7141	0·814	18·8615	1·385	18·9863	0·561
7·8216	0·718	7·9756	1·176	18·7175	0·831	18·8649	1·360		

values related to the period[7]. In these models we used dark spots to fit the asymmetries. Using our starting values and the temperature and temperature-related values, as dictated by the standardized photometry, we proceeded to compute a simultaneous four-colour light-curve solution with the updated Wilson Code[8–11], which includes full Kurucz stellar atmospheres rather than black bodies, two-dimensional limb-darkening coefficients, and a detailed reflection treatment also with 2-D limb-darkening coefficients. Our fixed inputs included standard convective parameters, gravity darkening with $g = 0 \cdot 32$, and an albedo value of $0 \cdot 5$. Adjustable parameters include those accompanied by errors: the inclination, i, the temperature of the secondary component, T_2, the potential, Ω, the mass ratio, q, the normalized flux (at 4π) at each wavelength, L, the phasing ephemeris, JD_o, the period, and the four spot parameters. First we adopted a dark spot (a magnetic spot) in our solution to account for asymmetries in the light curve. The solution produced a spot on component one (the more massive component) with a low, 0·96, T-Factor (the ratio of the temperature of the spot to that of the average photospheric surface temperature), but with a radius of 91° at a co-latitude of 92° and a longitude of 30°. Thus, it covered a complete hemisphere on the star. This model was presented at the AAS meeting[5]. Binary-star researchers there suggested that the spot might be due to mass exchange, which would create a hot spot. So

TABLE I (*concluded*)

HJD 2454000+	*ΔI*	*HJD* 2454000+	*ΔI*	*HJD* 2454000+	*ΔI*	*HJD* 2454000+	*ΔI*	*HJD* 2454000+	*ΔI*
7·6794	0·578	7·8292	0·658	7·9798	1·057	18·7208	0·754	18·8641	1·351
7·6874	0·564	7·8336	0·644	7·9835	0·926	18·7242	0·757	18·8681	1·274
7·6913	0·608	7·8369	0·643	18·6041	0·741	18·7286	0·716	18·8716	1·198
7·6942	0·619	7·8401	0·624	18·6076	0·735	18·7321	0·708	18·8756	1·101
7·6971	0·609	7·8472	0·597	18·6111	0·752	18·7368	0·679	18·8791	1·040
7·7049	0·614	7·8507	0·616	18·6154	0·768	18·7403	0·702	18·8832	0·976
7·7091	0·620	7·8539	0·602	18·6189	0·800	18·7448	0·715	18·8866	0·947
7·7124	0·645	7·8572	0·603	18·6224	0·813	18·7482	0·715	18·8905	0·869
7·7156	0·658	7·8647	0·594	18·6265	0·837	18·7539	0·668	18·8940	0·827
7·7235	0·699	7·8693	0·602	18·6300	0·881	18·7574	0·661	18·8980	0·807
7·7269	0·723	7·8726	0·616	18·6335	0·888	18·7686	0·696	18·9014	0·800
7·7302	0·739	7·8759	0·609	18·6380	0·965	18·7721	0·685	18·9055	0·778
7·7335	0·763	7·8830	0·629	18·6415	0·998	18·7766	0·675	18·9089	0·755
7·7408	0·864	7·8868	0·647	18·6455	1·059	18·7800	0·716	18·9130	0·756
7·7451	0·926	7·8901	0·671	18·6489	1·109	18·7874	0·698	18·9164	0·733
7·7484	0·979	7·8934	0·692	18·6529	1·161	18·7909	0·741	18·9210	0·732
7·7517	1·025	7·9011	0·717	18·6564	1·203	18·7974	0·771	18·9245	0·690
7·7587	1·115	7·9061	0·736	18·6604	1·302	18·8008	0·807	18·9290	0·663
7·7626	1·164	7·9094	0·777	18·6639	1·294	18·8062	0·857	18·9324	0·622
7·7659	1·182	7·9127	0·814	18·6680	1·263	18·8097	0·889	18·9365	0·649
7·7692	1·168	7·9210	0·898	18·6715	1·233	18·8140	0·910	18·9400	0·666
7·7763	1·179	7·9258	0·943	18·6752	1·247	18·8175	0·978	18·9439	0·644
7·7799	1·139	7·9290	0·992	18·6787	1·167	18·8219	1·019	18·9474	0·652
7·7832	1·098	7·9323	1·056	18·6826	1·090	18·8253	1·053	18·9515	0·593
7·7864	1·059	7·9394	1·197	18·6861	1·041	18·8297	1·177	18·9549	0·653
7·7937	0·949	7·9428	1·273	18·6906	0·994	18·8332	1·250	18·9591	0·657
7·7972	0·863	7·9460	1·310	18·6940	0·935	18·8376	1·312	18·9626	0·652
7·8004	0·860	7·9493	1·349	18·6981	0·932	18·8411	1·408	18·9666	0·596
7·8037	0·801	7·9563	1·364	18·7016	0·865	18·8454	1·431	18·9701	0·633
7·8122	0·741	7·9598	1·321	18·7055	0·814	18·8488	1·447	18·9740	0·721
7·8156	0·745	7·9639	1·348	18·7089	0·802	18·8531	1·390	18·9775	0·716
7·8189	0·690	7·9714	1·222	18·7133	0·829	18·8565	1·420	18·9816	0·705
7·8221	0·695	7·9762	1·122	18·7167	0·797	18·8607	1·394		

we introduced a moderate-sized hot region on the secondary component (~25°) with a large T-Factor (~1·4). The Wilson Code, surprisingly, iterated our input spot, to produce a large super-luminous region (radius of 94°), with a low T-Factor of 1·05. Next we performed a q-search to help narrow down the mass ratio. The q-search results are shown in Fig. 3. The results are bimodal with a minimum at $q \sim 0 \cdot 65$ and a slightly deeper minimum at $q \sim 1 \cdot 0$. We give both solutions in Table IV. Both reveal a contact configuration with an unusually large super-luminous region covering a full hemisphere. The synthetic-light-curve solution overlaying the *BVRI* light curves are given in Fig. 4 for the $q = 1 \cdot 0$ solution (the other solution gives similar results). The geometrical models of the photosphere for the $q \sim 0 \cdot 65$ solution is given in Fig. 5, and for $q \sim 1 \cdot 0$ in Fig. 6. To round out our modelling, we determined a dark-spot solution beginning with parameters from our best-mass-ratio solution. This solution was slightly poorer than the other two noted above. In addition, at the suggestion of the referee, we computed an unspotted model with a mass ratio of ~1·0 and the weighted sum of square residuals for that solution was 16·712, which is about twice that of our spotted solutions given in Table IV.

TABLE II

Standard magnitudes and spectral types for GSC 2766 0755, comparison, and check stars

	V (mag)	*V–R*	*R–I*	*V–I*	*<SP>*
GSC 2766 0755 (phase 0·0)	12·68 ± 0·06	0·34 ± 0·03	0·41 ± 0·04	0·75 ± 0·03	G6 ± 5
Comp	11·97 ± 0·06	0·30 ± 0·03	0·38 ± 0·02	0·70 ± 0·02	G2 ± 5
Check	11·52 ± 0·06	0·25 ± 0·03	0·33 ± 0·04	0·60 ± 0·02	G9 ± 5

TABLE III

GSC 2766 0755: linear residuals of equation 2

	Epochs, HJD 2400000+	*Cycles*	*Weighting*	*Linear Residuals*	*Reference*
1	53254·405	−2034·5	0·1	0·0018	(1)
2	53255·349	−2032·0	0·1	0·0065	(1)
3	53258·342	−2024·0	0·1	−0·0065	(1)
4	53258·536	−2023·5	0·1	−0·0003	(1)
5	53291·414	−1936·0	0·1	0·0001	(1)
6	53300·435	−1912·0	0·1	0·0033	(1)
7	53323·349	−1851·0	0·1	−0·0030	(1)
8	53644·8008	−995·5	1·0	0·0006	This Paper
9	53644·9871	−995·0	1·0	−0·0010	This Paper
10	54007·7697	−29·5	1·0	0·0016	This Paper
11	54007·9550	−29·0	1·0	−0·0009	This Paper
12	54018·6649	−0·5	1·0	0·0003	This Paper
13	54018·8517	0·0	1·0	−0·0008	This Paper

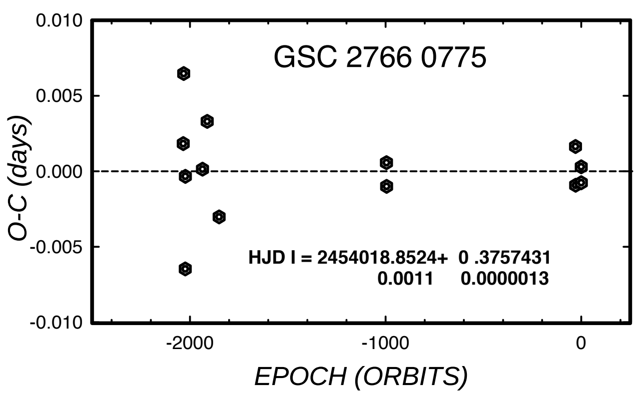

FIG. 2

O–C residuals for GSC 2766 0755, calculated from equation (2)

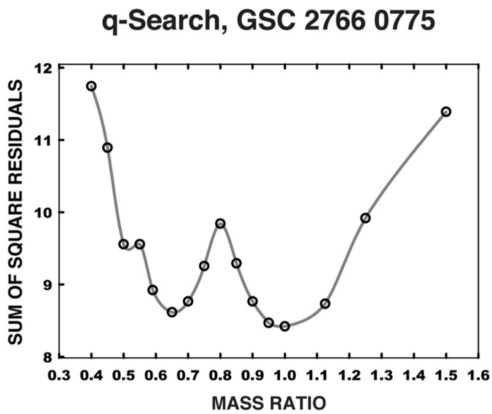

FIG. 3

Mass-ratio (q) search, q *vs*. sum of squared residuals from Wilson Code

TABLE IV

Synthetic-light-curve parameters for GSC 2766 0755

	Initial Model, q = 0·65	*Bright Region Model, q = 1·0*	*Dark-Region Model, q = 1·0*
$\lambda_B, \lambda_V, \lambda_R, \lambda_I$ (nm)	440, 550, 640, 790	440, 550, 640, 790	440, 550, 640, 790
$xbol_{1,2}$, $ybol_{1,2}$	0·620, 0·620 0·099, 0·099	0·620, 0·620 0·099, 0·099	0·620, 0·620 0·099, 0·099
$x_{1I,2I}$, $y_{1I,2I}$	0·607, 0·607 0·246, 0·246	0·607, 0·607 0·246, 0·246	0·607, 0·607 0·246, 0·246
$x_{1R,2R}$, $y_{1R,2R}$	0·691, 0·691 0·251, 0·251	0·691, 0·691 0·251, 0·251	0·691, 0·691 0·251, 0·251
$x_{1V,2V}$, $y_{1V,2V}$	0·762, 0·762 0·232, 0·232	0·762, 0·762 0·232, 0·232	0·762, 0·762 0·232, 0·232
$x_{1B,2B}$, $y_{1B,2B}$	0·839, 0·839 0·145, 0·145	0·839, 0·839 0·145, 0·145	0·839, 0·839 0·145, 0·145
g_1, g_2	0·32	0·32	0·32
A_1, A_2	0·50	0·50	0·50
Inclination (°)	80·93 ± 0·12	79·38 ± 0·11	81·3 ± 0·1
T_1, T_2 (K)	5750, 5325 ± 3	5750, 5309 ± 12	5750, 5334 ± 3
Ω_1, Ω_2	3·0777 ± 0·0049	3·660 ± 0·005	3·630 ± 0·006
q (m_2/m_1)	0·6520 ± 0·0018	1·001 ± 0·011	0·999 ± 0·003
Fill-out	21·2%	16·9%	21·8%
$L_1/(L_1+L_2)_I$	0·655 ± 0·013	0·567 ± 0·011	0·562 ± 0·011
$L_1/(L_1+L_2)_R$	0·664 ± 0·007	0·577 ± 0·006	0·572 ± 0·006
$L_1/(L_1+L_2)_V$	0·6771 ± 0·0007	0·5924 ± 0·0005	0·5866 ± 0·0005
$L_1/(L_1+L_2)_B$	0·703 ± 0·008	0·623 ± 0·007	0·615 ± 0·007
JDo (days)	2454018·85206 ± 0·00014	2454018·85200 ± 0·00014	2454018·85203 ± 0·00013
Period (days)	0·375685 ± 0·000008	0·375683 ± 0·000008	0·375680 ± 0·000007
r_1, r_2 (pole)	0·404 ± 0·004, 0·333 ± 0·004	0·368 ± 0·004, 0·388 ± 0·004	0·371 ± 0·005, 0·371 ± 0·005
r_1, r_2 (side)	0·430 ± 0·005, 0·351 ± 0·005	0·388 ± 0·005, 0·389 ± 0·005	0·392 ± 0·006, 0·392 ± 0·006
r_1, r_2 (back)	0·465 ± 0·007, 0·391 ± 0·009	0·426 ± 0·008, 0·426 ± 0·008	0·432 ± 0·010, 0·432 ± 0·010
		Starspot parameters	
Location	Secondary Component	Secondary Component	Primary Component
Colatitude (°)	113 ± 2	136 ± 2	130 ± 3
Longitude (°)	36 ± 5	37 ± 2	46 ± 2
Spot Radius (°)	94 ± 1	94 ± 1	97 ± 1
Temp. Factor	1·050 ± 0·001 (T_{spot} = 5590K)	1·049 ± 0·001 (T_{spot} = 5283K)	0·97 ± 0·001(T_{spot} =5576K)
Sum(W*Res**2)	8·617	8·432	8·860

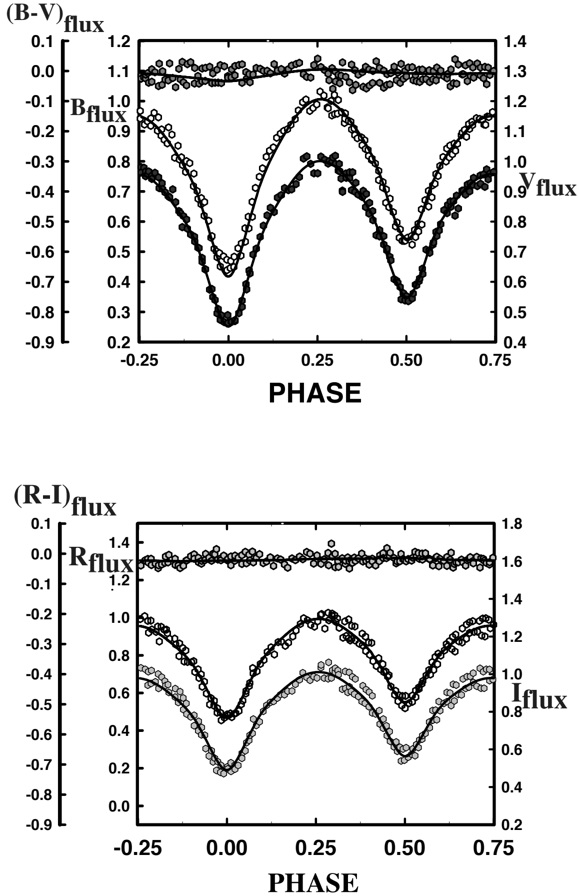

FIG. 4

B, V, R, and I normalized flux curves overlain by the best, $q = 1 \cdot 0$, solution.

Discussion

We note that this large area of slightly elevated temperature, *i.e.*, a *super-luminous region,* is fairly unusual. An earlier example of this effect was determined for the W UMa binary CE Leo[12]. In that case, the spot radius was 45°. It was also super-luminous, with low T-Factor = 1·035. In near-contact, semi-detached systems, such as BE Cep[13] and RR Lep[14], a hot spot may be due to a gas stream leaving the L_1 point of the star that fills its critical surface and striking the surface of the gainer. However, such spots are usually small and intense. Large, super-luminous regions on contact systems may be explained by the flow of matter in

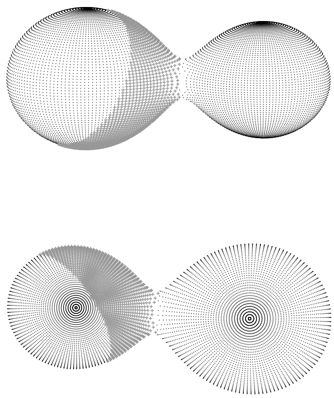

FIG. 5

Roche-lobe surfaces of the initial, $q = 0 \cdot 65$, mass-ratio solution at phase $0 \cdot 74$; the upper figure shows the model in the equatorial plane while the lower one shows the pole-on view.

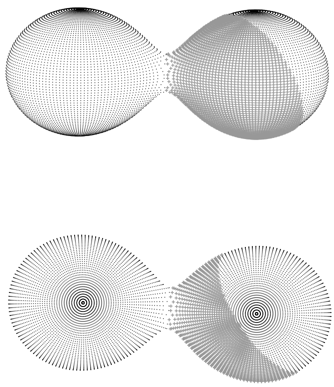

FIG. 6

Roche-lobe surfaces of our best, $q = 1 \cdot 0$, mass-ratio solution at phase $0 \cdot 74$; the upper figure shows the model in the equatorial plane while the lower one shows the pole-on view.

transit through the 'neck' of the Roche lobes accelerating toward the other component causing an acoustic shock wave, thus heating the photosphere[14]. Another source of hot regions on solar-type binaries is magnetic in nature, arising from white-light faculae. These may dominate the surfaces of short-period, chromospherically active binaries[15]. They may actually be even more prevalent than the dark-spot activity usually modelled. In the case of magnetic surface phenomena, the reader should not think that we are dealing with an actual single spot of these dimensions. Owing to the low level of temperature disparity with the surface, and the fact that one spot is used to model the non-uniformity, it is probably a *region* with a slightly elevated *average* temperature. In other words, it may consist of many white and dark magnetic spots, but the white-light faculae prevail. But, whatever the cause, we note that our differential-corrections solutions seem to favour a hemisphere-wide super-luminous region.

We note that radial-velocity curves are needed to obtain true absolute mass values. In addition, this system should be patrolled for the next ten years to monitor the period behaviour of the system. Finally, more light curves are needed to model the time evolution of the super-luminous region.

Acknowledgements

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 203: HD 117063, HD 117123, HD 117139, AND HD 117673

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Orbits are given for four spectroscopic binaries in the North-Galactic-Pole field. They are about the ninth magnitude apart from HD 117673, which is near $7^{m}\cdot 5$; their orbits have periods of 443, 470, 183, and 1361 days, and eccentricities of 0·11, 0·60, 0·84, and 0·27, respectively. They are all single-lined, with very modest mass functions. HD 117063 is a main-sequence star a little earlier than the Sun. HD 117123 has been classified as K3 V, but its parallax requires it to be of at least the luminosity of a giant and *DDO* photometry indicates a type of K1 III. Such photometry suggests that HD 117139 is a G9 III star; at that luminosity its proper motion represents an improbably large transverse velocity, although it should be noted that its mean radial velocity is also quite high (–50 km s^{-1}). Its very eccentric orbit has a period extremely close to half a year and involves a very sudden decline through its whole range of radial velocity in just a few days at the beginning of March every year (and another at a time of year when the star is not really accessible to observation). HD 117673 is a late-K or early-M giant that shows small photometric variations of a character typical of such objects, and has received the variable-star designation CP CVn.

Introduction

Several previous papers in this series have presented orbits for binaries identified in the comprehensive North-Galactic-Pole (NGP) radial-velocity and photometric survey published[1] in 1997 by Yoss & Griffin, and this is another contribution of that ilk. It gives orbits for four stars whose right ascensions (and hence *HD* numbers) are very close together; they are near the following margin of the NGP field, at declinations of approximately 20, 34, 17, and 36 degrees, respectively. The two at lower declinations are in the eastern part of Coma Berenices, between α Com and η Boo; the other two are in Canes Venatici far from any bright star, and those two only, among the four stars treated here, were observed by *Hipparcos*.

There is very little — in the case of HD 117063, the faintest, *nothing* — to be gleaned from the *Simbad* bibliographies of the four stars, making it the more unfortunate that the survey paper[1] is not retrievable from them. The information given in that paper on the stars concerned is reproduced here in Table I.

Photometry of HD 117123 was also carried out by Häggkvist & Oja[2], with the results $V = 9^{m}\cdot 18$, $(B-V) = 1^{m}\cdot 10$, $(U-B) = 1^{m}\cdot 12$. HD 117123 was classified, along with more than 6000 other NGP stars, by Tchipashvili[3] from

TABLE I

NGP Survey[1] *results for the four stars*

Star	*V*	*(B−V)*	*Type*	M_V	*z*
	m	*m*		*m*	*pc*
HD 117063	9·67	0·53	F9 V	+4·2	122
HD 117123	9·16	1·10	K1 III	+1·6	320
HD 117139	9·18	0·95	G9 III	+1·9	278
HD 117673	7·58	1·54	K4 III	+1·6	153

objective-prism spectra obtained at a reciprocal dispersion of 166 Å mm^{-1} at Hγ with an 8° prism on the Moscow 70-cm reflector. The type given was K3 V, but it conflicts with the *Hipparcos*[4] parallax, which is only $0''\cdot00028 \pm 0''\cdot00126$. The corresponding 1-$\sigma$ lower limits are 650 pc to the distance, about $9^{\rm m}$ to the distance modulus, and about $0^{\rm m}$ to the absolute magnitude. Not only is the dwarf classification definitely excluded, but even the absolute magnitude of $+1^{\rm m}\cdot6$ obtained from *DDO*-style[5] photometry (Table I) sits uncomfortably with the parallax. It seems likely, from the discussion by Keenan & Barnbaum[6], that pre-*Hipparcos* calibrations of the absolute magnitudes of giant stars were something like a whole magnitude too faint, and if that really applies to the NGP results exemplified in Table I above (as it probably does) then the discrepancy is reduced to an acceptable level. A mean radial velocity was noted for HD 117123 — and also one for HD 117673 — in a table mentioned by Famaey *et al.*[7], but it was based only on the present writer's own data which, to the extent that they are held in the data base of *Coravel* observations in Geneva, were utilized (with the writer's permission) by Famaey *et al.* for the purpose of their table.

The only paper that seems to have much relevance to HD 117139 is that by Soubiran *et al.*[8], which refers to a table which gives a radial velocity of −53·42 km s^{-1} (but no date, so it cannot be utilized here). It also lists estimates of $1^{\rm m}\cdot741$ and 303·6 pc for the absolute magnitude and *z*-distance, respectively, which appear to be specified to much greater precision than their actual accuracy warrants and so are not significantly different from the corresponding values shown in Table I above. HD 117673 is considerably brighter than the other three stars treated in the present paper; it was observed photometrically by Häggkvist & Oja[3], who found $V = 7^{\rm m}\cdot54$, $(B-V) = 1^{\rm m}\cdot56$, and considerably later by Oja[9] alone, with the results $V = 7^{\rm m}\cdot60$, $(B-V) = 1^{\rm m}\cdot54$, $(U-B) = 1^{\rm m}\cdot75$. The discrepancy between the V magnitudes ought to be significant, but evidently was not seen to be sufficiently compelling to precipitate the gazetting of HD 117673 as a variable star until *Hipparcos*[4], too, saw modest variations of several hundredths of a magnitude (illustrated in the graph in vol. **12**, p. C94; see no. 65953) and arranged for the star to receive[10] the designation CP CVn. The type of variability is listed as 'LB:'; the LB type is defined in the most recent edition of the *General Catalogue of Variable Stars*[11] as "slow irregular variables of late spectral types". *Hipparcos* also noted the star as "suspected non-single"; its duplicity could not be confirmed at a single try[12] by speckle interferometry at the McDonald 82-inch reflector, and Platais *et al.*[13] have proposed that the reason why many *Hipparcos* 'suspected binaries' cannot be confirmed is that the reduction of the *Hipparcos* observations of very red stars was confounded by serious errors in the adopted values of the infrared colour index $(V-I)$. They give for HD 117673 a $(V-I)$ of $2^{\rm m}\cdot28$, whereas *Hipparcos* used a value of $1^{\rm m}\cdot68$ estimated from the $(B-V)$ colour index.

Radial velocities and orbits

Apart from the one un-dated measurement of HD 117139 by Soubiran *et al.*[8], there seem not to be any published radial velocities for any of the four stars. The first measurement of each of the stars in the context of the Cambridge NGP survey was made with the original photoelectric radial-velocity spectrometer[14] in the early 1970s. Owing to the scale of the observing programme in relation to the amount of observing time that could be devoted to its execution, a second measurement of any particular star was typically made only after the order of a decade; even then, through there being no discordance between the first two measures (HD 117123) or delays in reduction (HD 117673) or even obstinate refusal on the part of the star to confirm its own variability (HD 117139), it was a long time before the stars were established on the spectroscopic-binary programme and observed routinely. That became the case for the respective stars, in *HD* order, in 1988, 1992, 1987, and 1989, since which times they have been followed reasonably systematically.

In retrospect the obduracy of HD 117139 is as instructive as it is amusing. The orbit has a period remarkably close (within eight hours) to six months, and an extreme eccentricity which manifests itself as a very sudden drop of the radial velocity in just a few days (in the early years it was at the end of February, now in the first few days of March) through its whole range of about 18 km s^{-1}. The velocity quickly recovers to near its mean value and then changes only slowly until near the next periastron passage, which occurs in the early autumn when the star is not accessible to observation. There was a highly significant discordance between the first two observations, made in 1971 February just before the periastron passage and in 1980 May when the velocity was in the quiescent régime. Single observations were then made in each ensuing season in an effort to confirm the discordance, but in six consecutive seasons they happened to be made rather near the same date and showed no further significant change! Twice during those years the original observation was re-read from the chart record and re-reduced, but nothing could be found wrong with it. Ultimately, in 1987, a more determined effort that started in January began to outline what was really happening, and from then on it was mostly a matter of hoping for good weather on the critical dates.

Six radial-velocity spectrometers have been used in the observations; they are identified, and references given to descriptions of them where available, in the census of measurements set out in Table II.

TABLE II

Sources of radial-velocity measurements of the four stars

Source	*Ref.*	*HD 117063*	*HD 117123*	*HD 117139*	*HD 117673*	*Totals*
Cambridge (old)	14	5	1	19	7	32
Palomar	15	—	1	—	—	1
DAO	16	3	1	5	4	13
OHP	17	22	23	24	26	95
ESO	—	1	—	2	1	4
Cambridge (new)	—	30	49	49	40	168
Totals		61	75	99	78	313

TABLE III

Radial-velocity observations of HD 117063

Except as noted, the sources of the observations are as follows:
1987–1996 — OHP Coravel (weighted 1/2 in orbital solution);
1997–2008 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
1973 Mar. 30·14**	41771·14	+7·4	0·364	−2·2
1987 Mar. 1·07	46855·07	−0·3	11·829	+1·1
1988 Feb. 1·53†	47192·53	+7·3	12·591	+0·6
Mar. 13·14	233·14	+3·7	·682	0·0
1989 Mar. 27·09	47612·09	+7·6	13·537	−0·4
28·93	613·93	+6·6	·541	−1·3
Apr. 30·01	646·01	+5·8	·613	−0·2
May 30·97*	676·97	+3·7	·683	0·0
1990 Jan. 27·16	47918·16	+8·6	14·227	+1·6
Feb. 12·39‡	934·39	+8·3	·264	+0·2
Mar. 29·05*	979·05	+8·8	·364	−0·8
May 1·01*	48012·01	+7·5	·439	−2·0
Dec. 27·26*	252·26	−2·7	·981	−0·2
1991 Jan. 28·19	48284·19	−0·4	15·053	−0·1
1992 Feb. 27·49†	48679·49	−3·6	15·944	−0·6
Apr. 24·07	736·07	+0·1	16·072	−0·4
June 25·98	798·98	+6·1	·214	−0·5
Dec. 19·23	975·23	+6·0	·611	−0·1
1993 Feb. 11·20	49029·20	+2·3	16·733	+0·4
18·15	036·15	+1·6	·749	+0·3
Mar. 18·15	064·15	−0·6	·812	+0·3
July 7·96	175·96	+0·7	17·064	+0·5
1994 Jan. 8·19	49360·19	+9·9	17·479	+0·9
Feb. 21·15	404·15	+6·5	·578	−0·5
May 2·06	474·06	+0·5	·736	−1·3
1995 June 6·02	49874·02	+4·7	18·638	−0·5
1996 Mar. 31·10	50173·10	+8·1	19·313	−1·0
1997 Mar. 27·05	50534·05	+3·3	20·127	+0·3
Apr. 1·12	539·12	+3·7	·138	+0·2
8·05	546·05	+4·0	·154	−0·2
14·98	552·98	+4·3	·169	−0·6
25·06§	563·06	+5·6	·192	−0·2
May 1·03	569·03	+6·4	·206	+0·1
7·04	575·04	+6·4	·219	−0·4
July 27·85§	656·85	+10·3	·404	+0·7
1998 July 9·95§	51003·95	+5·6	21·187	0·0
1999 July 10·29†	51369·29	−2·7	22·011	−0·9
2000 Jan. 9·26	51552·26	+9·7	22·423	+0·1
Mar. 25·12	628·12	+6·6	·594	0·0

TABLE III (*concluded*)

Date (UT)			*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O−C)* *km s⁻¹*
2000	Apr.	7·13	51641·13	+5·6	22·624	−0·1
2001	Jan.	7·29	51916·29	+7·4	23·244	−0·2
	Mar.	3·20	971·20	+10·5	·368	+0·9
2002	Apr.	4·12	52368·12	+8·6	24·263	+0·5
	May	4·08	398·08	+8·3	·331	−1·0
	June	1·02	426·02	+9·4	·394	−0·2
2003	Mar.	3·16	52701·16	−1·4	25·014	+0·3
	June	14·97	804·97	+7·6	·248	−0·1
2004	Mar.	30·12	53094·12	−3·3	25·901	−0·4
	May	7·04	132·04	−1·9	·986	+0·5
	June	16·99	172·99	+0·4	26·078	−0·4
		27·92	183·92	+2·4	·103	+0·5
2005	Mar.	23·16	53452·16	+3·2	26·708	+0·4
	Apr.	22·02	482·02	+0·4	·775	+0·1
	May	23·01	513·01	−2·1	·845	−0·2
2006	Mar.	1·15	53795·15	+9·8	27·482	+0·8
2007	Mar.	2·17	54161·17	+9·5	28·307	+0·5
		22·14	181·14	+9·1	·352	−0·4
	Apr.	30·01	220·01	+9·6	·440	+0·1
	May	8·02	228·02	+9·4	·458	+0·1
		30·01	250·01	+8·3	·507	−0·3
2008	Feb.	16·21	54512·21	+1·7	29·099	0·0

* Observed with original spectrometer; weight 1/8.
** " by G. A. Radford.
† Observed with DAO 48-inch telescope; weight 1/2.
‡ Observed with ESO *Coravel*; weight 1/2.
§ Observed with OHP *Coravel*; weight 1/2.

TABLE IV

Radial-velocity observations of HD 117123

Except as noted, the sources of the observations are as follows:
1989–1996 — OHP Coravel (weighted 1/2 in orbital solution);
1997–2008 — Cambridge Coravel (weight 1)

Date (UT)			*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O−C)* *km s⁻¹*
1972	Apr.	8·07*	41415·07	−37·9	0·608	+0·3
1978	May	23·41†	43651·41	−38·4	5·368	−0·6
1989	Apr.	30·05	47646·05	−43·1	13·872	+0·6
1992	Feb.	27·49‡	48679·49	−46·1	16·072	−0·1
	Apr.	24·07	736·07	−38·7	·193	+0·9
	June	25·98	798·98	−38·4	·327	−0·4
	Dec.	19·23	975·23	−39·0	·702	+0·1

TABLE IV (*continued*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
1993 Feb. 11·18	49029·18	–41·7	16·817	–0·3
18·16	036·16	–41·9	·832	0·0
Mar. 18·15	064·15	–44·8	·891	+0·1
25·07	071·07	–46·4	·906	–0·4
July 6·92	174·92	–41·7	17·127	+0·1
Sept. 12·79	242·79	–39·0	·271	–0·6
1994 Jan. 8·19	49360·19	–37·8	17·521	0·0
Feb. 21·15	404·15	–38·3	·615	0·0
May 2·06	474·06	–40·7	·764	–0·6
Aug. 2·91	566·91	–53·5	·961	–0·6
1995 Jan. 3·25	49720·25	–38·9	18·288	–0·6
June 3·03	871·03	–38·8	·609	–0·6
Dec. 27·22	50078·22	–49·9	19·050	–0·9
1996 Jan. 1·23	50083·23	–47·5	19·061	–0·1
Mar. 31·10	173·10	–37·9	·252	+0·7
1997 Feb. 8·17	50487·17	–47·6	19·921	–0·2
Mar. 1·14	508·14	–53·3	·965	+0·2
6·12	513·12	–54·8	·976	+0·3
27·04	534·04	–54·5	20·020	–0·1
29·11	536·11	–53·5	·025	+0·1
31·11	538·11	–52·7	·029	+0·1
Apr. 3·94	541·94	–51·2	·037	0·0
8·05	546·05	–49·6	·046	+0·1
11·12	549·12	–48·6	·052	0·0
14·98	552·98	–47·5	·061	–0·1
18·08	556·08	–46·1	·067	+0·5
25·06§	563·06	–44·8	·082	+0·1
May 1·03	569·03	–44·0	·095	–0·2
10·04	578·04	–43·0	·114	–0·5
July 18·90§	647·90	–38·4	·263	+0·1
Dec. 24·23§	806·23	–37·7	·600	+0·5
1998 July 7·94§	51001·94	–54·9	21·016	+0·1
2000 Jan. 9·26	51552·26	–39·4	22·188	+0·3
Mar. 25·13	628·13	–37·7	·349	+0·2
Apr. 7·13	641·13	–38·1	·377	–0·3
May 31·00	695·00	–38·8	·492	–1·0
July 17·91	742·91	–38·4	·594	–0·2
Aug. 29·83	785·83	–39·2	·685	–0·3
Dec. 3·27	881·27	–44·9	·888	–0·2
2001 Jan. 7·30	51916·30	–52·8	22·963	+0·3
14·25	923·25	–55·8	·978	–0·4
Mar. 3·20	971·20	–45·5	23·080	–0·3
July 4·96	52094·96	–37·3	·343	+0·6
2002 Feb. 24·16	52329·16	–42·4	23·842	–0·1
Mar. 28·10	361·10	–46·4	·910	0·0
Apr. 4·12	368·12	–47·9	·925	–0·1
17·02	381·02	–51·4	·952	+0·1
24·04	388·04	–54·0	·967	–0·2
May 4·07	52398·07	–56·6	23·989	–0·1
16·01	410·01	–55·4	24·014	0·0
29·02	423·02	–50·0	·042	+0·4

TABLE IV (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2002 June 23·98	52448·98	−43·8	24·097	−0·2
2003 Mar. 16·14	52714·14	−38·6	24·661	+0·1
May 16·02	775·02	−40·3	·791	+0·4
2004 Mar. 1·16	53065·16	−37·8	25·409	−0·1
Apr. 3·12	098·12	−37·7	·479	0·0
May 7·05	132·05	−37·7	·551	+0·2
June 12·96	168·96	−38·2	·630	+0·2
Sept. 7·82	255·82	−40·9	·815	+0·4
2005 Mar. 23·16	53452·16	−39·1	26·232	−0·2
2006 Mar. 1·15	53795·15	−52·9	26·963	+0·2
Apr. 6·08	831·08	−50·9	27·039	0·0
May 29·95	884·95	−40·1	·154	+0·6
2007 Mar. 2·18	54161·18	−39·5	27·742	+0·2
May 30·98	250·98	−48·5	·933	+0·3
June 1·98	252·98	−49·6	·937	−0·3
4·97	255·97	−50·1	·944	+0·1
2008 Feb. 2·22	54498·22	−37·3	28·459	+0·4

* Observed with original spectrometer; weight 1/4.
† Observed with Palomar 200-inch telescope; weight 1/2.
‡ Observed with DAO 48-inch telescope; weight 1/2.
§ Observed with OHP *Coravel*; weight 1/2.

TABLE V

Radial-velocity observations of HD 117139

Except as noted, the sources of the observations are as follows:
1971–1991 — original Cambridge spectrometer (weighted 1/4 in orbital solution);
1992–1996 — OHP Coravel; 1997–2008 — Cambridge Coravel (both weight 1)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
1971 Feb. 21·18	41003·18	−43·3	0·983	+1·4
1980 May 15·97	44374·97	−50·0	19·430	+0·4
1981 May 5·03	44729·03	−50·8	21·367	+0·2
1982 May 29·91	45118·91	−49·9	23·500	−0·1
1983 May 17·02	45471·02	−49·4	25·427	+1·0
1984 Apr. 28·04	45818·04	−50·5	27·325	+0·9
1985 June 1·95	46217·95	−49·7	29·513	0·0
1986 Apr. 11·04*	46531·04	−52·1	31·226	+0·5
May 13·97	563·97	−49·9	·406	+0·7

TABLE V (*continued*)

Date (UT)			MJD	Velocity km s⁻¹	Phase	(O – C) km s⁻¹
1987	Jan.	31·21	46826·21	–47·2	32·841	–0·8
	Feb.	21·19	847·19	–43·1	·956	+1·0
	Mar.	3·13*	857·13	–62·1	33·010	–0·4
	May	7·98	922·98	–50·2	·371	+0·7
	June	3·96	949·96	–49·3	·518	+0·3
1988	Jan.	31·49†	47191·49	–46·6	34·840	–0·2
	Mar.	12·11*	232·11	–57·4	35·062	–0·3
		17·04*	237·04	–56·1	·089	–0·3
	Apr.	14·01	265·01	–52·3	·242	+0·1
	May	19·96R	300·96	–47·9	·439	+2·4
	June	6·93	318·93	–49·9	·537	–0·4
1989	Feb.	24·28‡	47581·28	–44·3	36·972	–0·4
	Mar.	25·14*	610·14	–54·5	37·130	–0·1
		28·04*	613·04	–54·3	·146	–0·2
	Apr.	28·07*	644·07	–51·1	·316	+0·4
	May	3·00*	649·00	–51·9	·343	–0·7
1990	Jan.	27·10*	47918·10	–47·0	38·815	–0·2
	Feb.	12·40‡	934·40	–45·2	·904	+0·1
	Mar.	29·06	979·06	–53·3	39·148	+0·7
	Apr.	5·02	986·02	–53·9	·187	–0·7
1991	Jan.	26·19*	48282·19	–46·9	40·807	0·0
	May	10·01	386·01	–50·7	41·375	+0·2
	June	13·97	420·97	–48·6	·566	+0·6
1992	Feb.	26·47†	48678·47	–44·6	42·975	–0·6
		27·37†	679·37	–44·8	·980	–0·5
		28·31†	680·31	–45·0	·985	+0·1
	Mar.	2·51†	683·51	–59·5	43·003	–1·0
	Apr.	30·08	742·08	–50·8	·323	+0·6
	June	26·99	799·99	–48·4	·640	+0·2
	Dec.	19·23	975·23	–49·4	44·599	–0·4
1993	Feb.	11·20	49029·20	–45·4	44·894	+0·1
		18·16	036·16	–45·0	·932	–0·3
	Mar.	19·14	065·14	–55·9	45·091	–0·2
	July	7·97	175·97	–48·2	·697	–0·1
1994	Jan.	8·19	49360·19	–48·0	46·705	0·0
	Feb.	21·16	404·16	–44·3	·945	0·0
	May	2·07	474·07	–51·3	47·328	+0·1
1995	Jan.	5·24	49722·24	–48·4	48·686	–0·2
	June	5·89	873·89	–50·3	49·515	–0·6
1996	Mar.	31·10	50173·10	–54·4	51·152	–0·5
1997	Mar.	1·14	50508·14	–44·9	52·985	+0·3
		1·24	508·24	–45·3	·986	0·0
		3·10	510·10	–51·4	·996	0·0
		6·12	513·12	–61·9	53·012	–0·1
	Apr.	30·99	568·99	–51·5	·318	0·0
1998	July	7·94*	51001·94	–48·6	55·687	–0·4

TABLE V (*concluded*)

Date (UT)			*MJD*	*Velocity* km s^{-1}	*Phase*	*(O−C)* km s^{-1}
2000	Jan.	9·27	51552·27	−47·8	58·698	+0·3
	Mar.	1·11	604·11	−44·3	·981	+0·2
		2·03	605·03	−44·5	·986	+1·0
		3·99	606·99	−52·8	·997	−0·2
		4·24	607·24	−54·2	·998	0·0
		5·03	608·03	−58·2	59·003	+0·5
		7·09	610·09	−62·1	·014	−0·4
	May	1·00	665·00	−51·4	·314	+0·1
	June	17·96	712·96	−49·5	·577	−0·4
2001	Mar.	2·14	51970·14	−44·3	60·984	+0·6
		3·12	971·12	−46·9	·989	−0·4
		4·99	972·99	−54·9	61·000	+0·5
		5·22	973·22	−56·6	61·001	+0·1
		8·06	976·06	−61·7	·016	−0·2
		9·05	977·05	−60·8	·022	+0·1
		11·13	979·13	−58·9	·033	+0·6
		12·09	980·09	−58·7	·038	+0·2
		14·09	982·09	−57·6	·049	+0·4
2002	Mar.	1·11	52334·11	−43·5	62·975	+0·5
		2·17	335·17	−45·0	·981	−0·6
		28·11	361·11	−54·0	63·123	+0·6
2003	Mar.	1·17	52699·17	−43·7	64·972	+0·3
		3·17	701·17	−45·4	·983	−0·6
	May	16·03	775·03	−50·9	65·388	−0·1
	June	14·97	804·97	−49·8	·551	−0·4
2004	Jan.	17·25	53021·25	−47·5	66·735	+0·2
	May	7·05	132·05	−51·3	67·341	−0·1
		21·98	146·98	−50·5	·422	0·0
		30·99	155·99	−50·4	·472	−0·4
2005	Jan.	22·25	53392·25	−47·3	68·764	+0·1
	Mar.	25·10	454·10	−55·2	69·103	+0·1
	Apr.	22·02	482·02	−51·9	·256	+0·3
	June	26·94	547·94	−48·4	·616	+0·4
2006	Mar.	4·95	53798·95	−47·5	70·989	−0·9
		6·16	800·16	−51·9	·996	−0·4
	Apr.	6·09	831·09	−54·0	71·165	−0·4
		9·08	834·08	−53·7	·182	−0·4
	June	11·96	897·96	−49·7	·531	−0·2
2007	Feb.	4·23	54135·23	−46·2	72·829	+0·4
	Apr.	16·04	206·04	−52·6	73·217	+0·2
		30·01	220·01	−51·3	·293	+0·5
2008	Mar.	5·15	54530·15	−46·2	74·990	+0·6
		6·13	531·13	−50·8	·995	−0·1
		7·95	532·95	−59·9	75·005	+0·4

* Observed with OHP *Coravel*; weight 1.
† Observed with DAO 48-inch telescope; wt. ½.
‡ Observed with ESO *Coravel*; weight 1.
R Rejected observation.

TABLE VI

Radial-velocity observations of HD 117673

Except as noted, the sources of the observations are as follows:
1988–1998 — OHP Coravel (weighted 1/2 in orbital solution);
1999–2007 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
1972 Mar. 28·10*	41404·10	+2·6	0·662	−0·2
1984 May 11·98*	45831·98	−3·1	3·916	+0·1
1988 Feb. 1·54†	47192·54	−2·7	4·915	+0·5
Mar. 13·14	233·14	−3·9	·945	+0·2
1989 Mar. 27·10	47612·10	+1·2	5·224	+0·1
Apr. 29·08	645·08	+2·2	·248	+0·6
June 1·96*	678·96	+1·7	·273	−0·4
1990 Jan. 27·17	47918·17	+3·7	5·449	0·0
Feb. 14·39‡	936·39	+3·2	·462	−0·5
Mar. 29·08*	979·08	+4·2	·493	+0·5
Apr. 29·04*	48010·04	+3·6	·516	−0·1
Dec. 27·77*	252·77	+2·5	·694	+0·1
1991 Jan. 28·20	48284·20	+1·7	5·718	−0·4
May 22·98*	398·98	−0·1	·802	−0·4
Dec. 19·24	609·24	−4·9	·956	−0·6
1992 Feb. 27·49†	48679·49	−5·0	6·008	−0·3
Apr. 24·08	736·08	−3·9	·050	+0·2
June 20·97	793·97	−2·8	·092	0·0
Aug. 15·85	849·85	−1·7	·133	−0·3
Dec. 19·24	975·24	+0·5	·225	−0·7
1993 Feb. 15·21	49033·21	+1·7	6·268	−0·3
Mar. 19·15	065·15	+2·6	·291	+0·2
July 7·97	175·97	+3·4	·373	+0·1
Sept. 12·79	242·79	+3·9	·422	+0·3
1994 Jan. 8·20	49360·20	+3·5	6·508	−0·2
Feb. 21·16	404·16	+4·5	·540	+0·8
May 2·08	474·08	+3·6	·592	+0·2
Aug. 2·91	566·91	+2·4	·660	−0·5
Dec. 28·26	714·26	+1·3	·768	+0·2
1995 Jan. 8·25	49725·25	+0·7	6·776	−0·3
June 3·03	871·03	−2·5	·884	−0·4
Dec. 27·22	50078·22	−5·0	7·036	−0·6
1996 Mar. 31·10	50173·10	−2·1	7·106	+0·2
1997 Feb. 8·19§	50487·19	+2·8	7·336	−0·1
Mar. 29·13§	536·13	+2·7	·372	−0·6
Apr. 30·98§	568·98	+3·2	·396	−0·2
July 19·94	648·94	+3·0	·455	−0·7
1998 May 4·08	50937·08	+2·9	7·667	+0·1
July 7·94	51001·94	+2·6	·715	+0·5
1999 Apr. 9·44†	51277·44	−3·7	7·917	−0·4
July 9·33†	368·33	−5·0	·984	−0·3

TABLE VI (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2000 Jan. 9·27	51552·27	−1·9	8·119	0·0
Mar. 25·13	628·13	0·0	·175	+0·1
Apr. 6·06	640·06	−0·3	·183	−0·4
May 13·96	677·96	+1·0	·211	+0·2
2001 Jan. 11·30	51920·30	+3·4	8·389	0·0
Mar. 5·20	973·20	+3·7	·428	+0·1
May 12·02	52041·02	+4·2	·478	+0·5
Aug. 1·88	122·88	+3·6	·538	−0·1
Dec. 20·24	263·24	+3·1	·641	0·0
2002 Jan. 18·23	52292·23	+2·3	8·663	−0·5
Mar. 28·11	361·11	+2·3	·713	+0·1
May 17·03	411·03	+1·2	·750	−0·3
July 3·94	458·94	+0·6	·785	−0·1
Aug. 6·88	492·88	+0·3	·810	+0·2
Sept 1·83	518·83	−0·5	·829	−0·1
Oct. 3·77	550·77	−1·4	·853	−0·3
28·23	575·23	−1·9	·871	−0·2
2003 Mar. 3·18	52701·18	−3·9	8·963	+0·5
May 16·05	775·05	−4·5	9·017	+0·2
July 15·90	835·90	−3·7	·062	0·0
Aug. 16·85	867·85	−3·1	·086	−0·1
Sept. 14·79	896·79	−2·3	·107	0·0
2004 Mar. 2·19	53066·19	+1·2	9·231	−0·1
Apr. 23·08	118·08	+2·6	·269	+0·6
June 12·97	168·97	+2·9	·307	+0·3
Dec. 27·30	366·30	+3·4	·452	−0·3
2005 Apr. 22·05	53482·05	+4·1	9·537	+0·4
May 23·04	513·04	+3·5	·560	−0·1
June 22·97	543·97	+3·6	·582	+0·1
July 16·90	567·90	+3·3	·600	−0·1
Aug. 15·87	597·87	+3·4	·622	+0·2
2006 Feb. 16·17	53782·17	+1·7	9·757	+0·3
Apr. 26·04	851·04	+0·6	·808	+0·4
June 3·97	889·97	−0·3	·837	+0·3
July 2·94	918·94	−1·3	·858	0·0
2007 June 27·94	54278·94	−1·6	10·122	+0·2
July 29·89	310·89	−0·8	·146	+0·2

* Observed with original spectrometer; weight 1/2.
† Observed with DAO 48-inch telescope; weight 1/2.
‡ Observed with ESO *Coravel*; weight 1/2.
§ Observed with Cambridge *Coravel*; weight 1.

As usual in this series of papers, the OHP and ESO measurements, which had been reduced initially on the post-2000 Geneva zero-point[18], have been increased by 0·8 km s^{-1} before being entered in the journals of radial-velocity measurements, which appear here as Tables III–VI. The Geneva reduction process includes empirically determined adjustments which are related to colour index; they are applied without the user being aware of them. Analogous but not necessarily identical ones are needed for the Cambridge *Coravel* observations.

It seems likely that enough experience of them will have accumulated that it will soon be possible to adopt a relationship between colour index and adjustment and apply it to all reductions routinely and not say any more about it in each individual paper. We are not quite at that point yet, but inspections of trial orbital solutions have suggested what adjustments should be applied to the velocities of the stars treated here. They are $-0 \cdot 6$ km s^{-1} for HD 117063, $-0 \cdot 2$ for HD 117123, zero for HD 117139, and $+0 \cdot 2$ km s^{-1} for HD 117673, and are very much in line with amounts independently determined for previously discussed binaries of similar colour indices. No changes have been made to the velocities from the old Cambridge spectrometer or from Palomar or the DAO.

Observations made with the Cambridge *Coravel* have been assigned unit weight in the solutions of the orbits. The other sources have in most cases been weighted ½, but in the case of HD 117139 the OHP and ESO observations have been given unit weight; and the 'original Cambridge' observations have been weighted ¼ for HD 117123 and HD 117139 and only ⅛ for HD 117063. On that basis the measurements have yielded the orbital solutions plotted in Figs. 1–4 and the elements shown in Table VII.

TABLE VII

Orbital elements for the four stars

Element	*HD 117063*	*HD 117123*	*HD 117139*	*HD 117673*
P (days)	443·40 ± 0·24	469·74 ± 0·07	182·7800 ± 0·0027	1360·9 ± 1·5
T (MJD)	51365 ± 11	51464·0 ± 0·4	50876·40 ± 0·05	51390 ± 10
γ (km s^{-1})	+3·90 ± 0·08	−41·55 ± 0·05	−50·28 ± 0·05	+0·64 ± 0·04
K (km s^{-1})	6·34 ± 0·12	9·53 ± 0·08	8·92 ± 0·08	4·25 ± 0·07
e	0·111 ± 0·017	0·602 ± 0·005	0·8395 ± 0·0027	0·273 ± 0·012
ω (degrees)	212 ± 9	186·7 ± 0·7	110·0 ± 0·7	181·3 ± 2·8
$a_1 \sin i$ (Gm)	38·4 ± 0·7	49·2 ± 0·5	12·19 ± 0·14	76·5 ± 1·2
$f(m)$ ($M_{\odot}$)	0·0115 ± 0·0007	0·0215 ± 0·0006	0·00216 ± 0·00008	0·0097 ± 0·0005
R.m.s. residual (wt. 1) (km s^{-1})	0·46	0·31	0·37	0·27

Discussion

Table VII shows that all the mass functions are very small, so the idea that any of the stars might prove to be double-lined receives no encouragement. Specially generous and suitably centred integrations were made at OHP to look for secondary dips near the nodal passages of HD 117063 on 1997 July 27 and HD 117123 on 1995 June 3, but nothing of significance was seen.

According to the *DDO* photometry published in the NGP survey[1], HD 117063 is a main-sequence star a little earlier than the Sun. That is reinforced both by its colour index and by the nature of the dips seen in radial-velocity traces, which have hardly half the area that would be expected for a K star. That, together with the relative faintness of the star, easily accounts for the residuals being larger than most of those found in recent papers in this series. The dips are somewhat widened, no doubt by modest axial rotation of the star; mean values of the projected rotational velocity are found by the OHP and Cambridge *Coravel*s as $5 \cdot 4 \pm 1 \cdot 0$ and $6 \cdot 9 \pm 0 \cdot 8$ km s^{-1}, respectively. The velocity curve looks rather like a sine wave to the eye, but the eccentricity is 6·5 times its own standard deviation and is therefore very certainly non-zero.

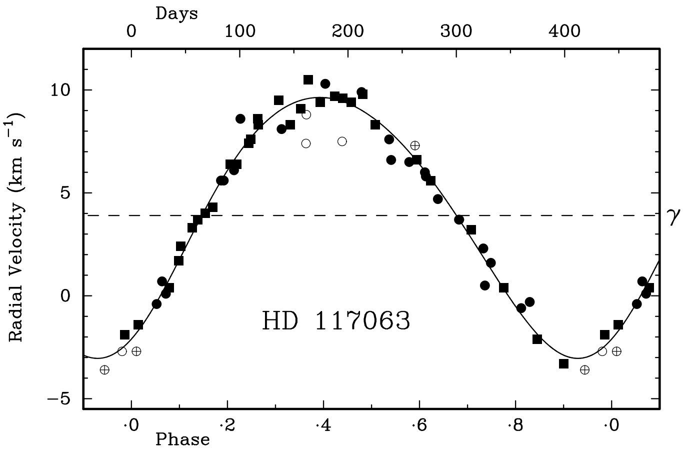

FIG. 1

The observed radial velocities of HD 117063 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Filled symbols represent *Coravel* observations, circles for OHP (and also for one ESO velocity) and squares for Cambridge. Plain open circles indicate measurements made with the original radial-velocity spectrometer at Cambridge; open circles with crosses in them identify DAO measures. In the solution of the orbit the Cambridge *Coravel* velocities were given full weight and the 'original Cambridge' ones 1/8; the other sources were all weighted 1/2.

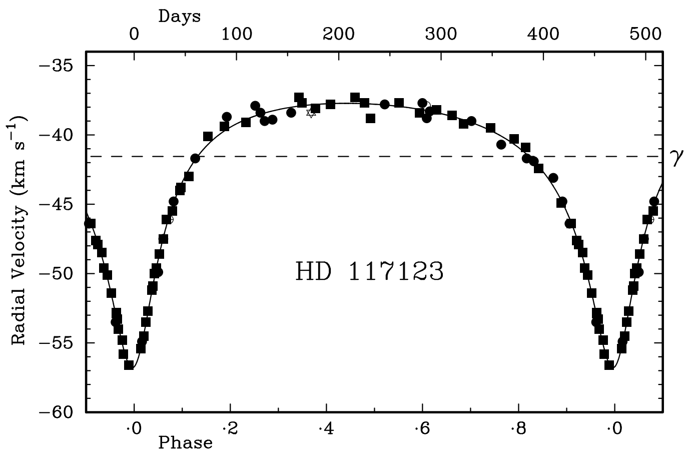

FIG. 2

As Fig. 1, but for HD 117123. The meanings of the symbols and weighting of the different sources is the same except that the 'original Cambridge' measure is weighted 1/4, and here there is in addition one Palomar measure, plotted as an open star and given weight 1/2.

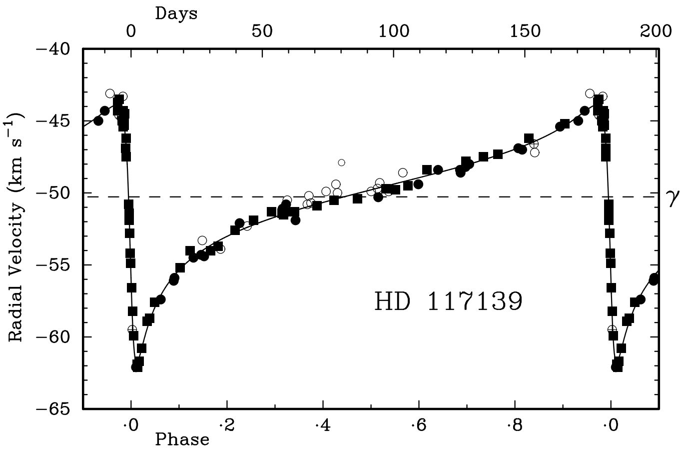

FIG. 3

As Fig. 2, but for HD 117139, and in this case the OHP and ESO velocities were given full weight. One 'original Cambridge' measure that gave a residual well over three times the r.m.s. value was rejected from the solution and is plotted as the small circle at about Day 80.

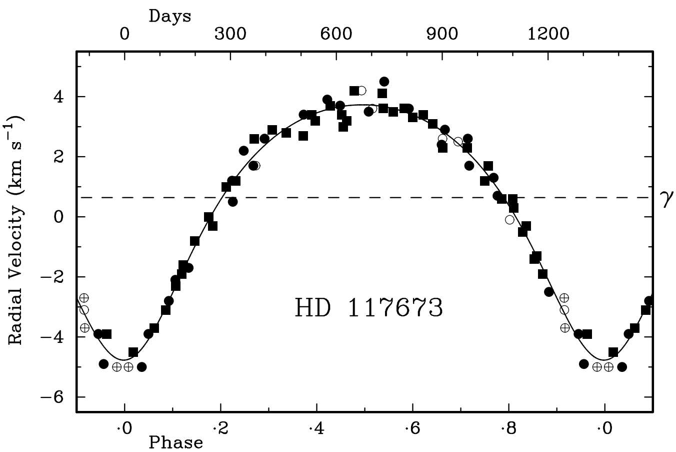

FIG. 4

As Fig. 2, but for HD 117673; here all sources were attributed half-weight except for the Cambridge *Coravel* measures, which received full weight.

HD 117123 is seen to have a quite eccentric orbit which is very well covered by the observations. The colour index is entirely consistent with the K1 III type deduced[1] from *DDO* photometry, but (as mentioned in the introductory section above) the parallax is indeterminately small and suggests that the luminosity could well be higher than that of a normal giant. The proper motion, too, is practically nil and would be very consonant with a high luminosity. We can make no further progress on that point at present.

The obvious noteworthy features of HD 117139 are the extreme eccentricity of its orbit and the closeness of its period to half a year. The period is determined with a standard error of about four minutes. Owing to its high precision, allied with the rather high γ-velocity, the 'true' period, measured in the rest-frame of the system, is about 45 minutes (11 standard deviations) longer than the observed one, at 182·8106 days. The dates of the periastron passages migrate around the year only very slowly, taking 1160 ± 20 years to make a complete circuit, although for practical purposes (if any) the interval is only half as great because there are two periastron passages each year. Since the star is conveniently placed for observation for about half the year, all phases of the orbit will remain observable throughout the cycle of migration. The type of G9 III indicated by *DDO* photometry is consonant with the colour index, but the similarly derived luminosity is somewhat low for luminosity class III. At the indicated distance of about 285 pc, the annual proper motion of very nearly 1/8 of a second of arc represents an extravagant transverse velocity of about 170 km s^{-1}. If we arbitrarily decreed that 50 km s^{-1} was as large a transverse velocity as could readily be countenanced (making it equal to the radial velocity, which is certainly on the large side for a star in the NGP field), that would require the distance to be reduced by a factor of 3·4 and the modulus by $2^m\cdot66$, to give an absolute magnitude of about $4^m\cdot6$, not much brighter than corresponds to a dwarf of the same temperature type. There is no additional information that we can bring to bear in an effort to adjudicate on the matter, unless it be the parallax indicated by the initial reduction of *Tycho*, which though known to be very shaky is actually negative and so certainly does not help to argue for any downward correction to the photometric distance. As matters stand, there is no reason apart from prejudice to object to the properties of HD 117139 as derived from observation.

HD 117673 has been shown[9,4] to exhibit small photometric variations such as tend to characterize giant stars a little later than the K4 III suggested by the *DDO* photometry — in fact the *HD* type of M0 would sit more agreeably with the variability. The parallax is very small, only three times its own standard error, at $0''\cdot00253 \pm 0''\cdot00086$, giving a distance modulus of the order of eight magnitudes and thus an absolute magnitude probably brighter than zero and almost surely brighter than the $+1^m\cdot6$ given in the survey[1]. The dips in radial-velocity traces are distinctly broadened; if the broadening is attributable solely to axial rotation, the implied $v \sin i$ values are 5·7 ± 0·4 km s^{-1} according to the OHP *Coravel* and 6·9 ± 0·2 km s^{-1} according to the Cambridge one. The Cambridge results have been extremely reproducible, but the formal standard error of the mean is not to be taken literally as an externally valid estimate, and the assumption that all of the excess broadening of the lines is due to rotation must also be borne in mind.

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THE RELUCTANT PARSEC AND THE OVERLOOKED LIGHT-YEAR

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The appropriate measure with which to express the distances to the stars (and the greater Universe) is one of those units that took many years to be unanimously agreed upon. Here we trace the origin and seemingly slow acceptance of the distance unit represented by the parsec.

No less august a body than the International Astronomical Union (IAU) declares the parsec (pc) to be the preferred non-SI unit of measure when describing interstellar distances[1]. The light-year (ly) measure of distance, however, is given rather short shrift, "The unit known as the light-year is appropriate to popular expositions on astronomy and is sometimes used in scientific papers as an indicator of distance"[1]. Such comments seem rather divisive, although it appears that the light-year has long been viewed in a somewhat second-class manner. We find, for example, in Volume 2 of the widely read textbook *Astronomy*, by Russell, Dugan & Stewart (published in 1938) the following statements concerning the unit in which stellar distances are measured, "the one used in scientific work is the parsec", to which is added the qualifier that the light-year is used "in more popular discussions".

Even a cursory reading of the astronomical literature reveals that the unit of the light-year existed long before that of the parsec. Sir John Herschel, for example, in his highly read *Outlines of Astronomy*, first published in 1870, notes with respect to stellar distances that, "the only mode we have of conceiving such intervals at all is by the time which it would require light to traverse them". In addition, Herschel notes that, "a parallactic unit of distance from our system of 20 billions of miles, and with a 3¼ years journey of light, may save … ourselves the necessity of covering our pages with such enormous numbers, when speaking of stars whose parallax has actually been ascertained with some approach of certainty". Such sentiments culminated in Charles Young's definition, given in his *A Text Book of General Astronomy*, published in 1899, "A star with a parallax of 1 [arc second] is at a distance of 3·26 *light years*".

No star has a parallax greater than $P = 0{\cdot}7723$ arc seconds (which corresponds to that deduced for Proxima Centauri[2]), so, one might ask, what is so special about a distance unit corresponding to an angle of parallax of 1 second of arc. Of the stars in the solar neighbourhood only four[2] (two of which form the binary of α Centauri — we take the trinary membership of Proxima Centauri to be presently unproven) have a parallax that might reasonably be expressed as being of order unity, while in excess of 100 stars have parallaxes of order one tenth of an arc second. So, why not introduce a unit of distance based upon a parallax angle of 0·1 arc seconds? Well, of course, such things are really arbitrary. That being said, in 1902 Jacobus Kapteyn[3–5] used a unit distance equivalent to a parallax of 0·1 arc seconds in his definition of absolute magnitude (this distance unit is still used to this very day).

The adoption of 1 second of arc as the angular unit of measure with respect to stellar parallax observations appears to be based upon a statement made by James Bradley (1693–1762). Bradley is predominantly remembered for his highly accurate observations of the star γ Draconis and the first measurement of stellar aberration (amounting to 40 arc seconds) and nutation (amounting to 18 arc seconds). In his 1727 letter to Edmund Halley (later published in the *Philosophical Transactions of the Royal Society*[6]) Bradley comments, "it must be granted that the parallax of the fixed stars is much smaller than hath been hitherto supposed … I am of the opinion, that if it were 1 [arc second] I should have perceived it". Again, we find in Herschel's 1870 *Outlines* the comment, "hitherto we have spoken of a parallax of 1 [arc second] as a mere limit below which that of any star yet examined assuredly, or at least very probably falls, and it is not without a certain convenience to regard this amount of parallax as a sort of unit of reference". Herschel's comments are placed into some form of perspective when it is realized that he was writing thirty years after the first set of publications announcing the successful measurement of stellar parallaxes by Friedrich Bessel, Thomas Henderson, and Friedrich Struve[7].

The impetus to fix a unit of distance based upon stellar parallax measurements, but not cast in terms of the light-year, resulted from a growing interest in the analysis of stellar proper motions. Kapteyn pioneered the study of star streaming in the late 1890s, and the statistical analysis of stellar proper motions became an increasingly important topic during the first several decades of the 20th Century. In England, over the time interval of interest, the research field concerned with large-scale stellar motions was dominated by Frank Dyson, Herbert Hall Turner, and Arthur Stanley Eddington.

Astronomer Royal Dyson can be credited with first use of the term parsec in an actual scientific article, the paper seeing print in the *Monthly Notices* for 1913 March 14. A footnote within that paper[8] reads, "There is need for a name for this unit of distance [corresponding to a parallax of one second of arc]. Mr. Charlier has suggested *Siriomete*r, but if the violence to the Greek language can be overlooked, the word *Astron* might be adopted. Professor Turner suggests *Parsec*, which may be taken as an abbreviated form of a distance corresponding to a parallax of one second". In the May 9th issue of the *Monthly Notices*, Carl Charlier comments in another footnote[9], "I have used the term *Siriometer* for denoting a distance equal to a million times the diameter of the Sun from the Earth. I find from *The Observatory* that the Astronomer Royal has objected to this term that it 'suggests a machine for measuring'. I agree with him herein. But having used this term now nearly two years in my lectures [*i.e.*, he coined the term *circa* 1911], I have found that this suggestion, which I had naturally made myself, is easily obliterated" — in other words, Charlier is not moved by the Astronomer Royal's objections. The word *siriometer* takes its heritage from the star gauges of William Herschel. Indeed, writing in the *Philosophical Transactions of the Royal Society* for 1785, Herschel explains, "the stars of the first magnitude being in all probability the nearest, will furnish us with a step to begin our scale; setting off, therefore, with a distance of Sirius or Arcturus, for instance as unity..."[10]. We now know that Herschel's magnitude argument concerning distance is incorrect, but using modern-day values, Sirius has a measured parallax of 379·2 mas, and it is accordingly $5 \cdot 4 \times 10^5$ AU distant. In terms of Charlier's units, the distance to Sirius is 0·54 *siriometers*.

Charlier makes the comment in his 1913 paper that Dyson disliked the word *siriometer*, and the question arises as to where he acquired his information. The answer to this lies in the 1913 April issue of *The Observatory* in which the discussion at the Royal Astronomical Society meeting for March 14th is transcribed[11]. At that meeting both Dyson and Eddington presented review papers on the topic of the statistical analysis of proper motions and star streaming. It is in the discussion following Dyson's paper that we learn from Turner that "I had the privilege of seeing it in MS., suggesting a short name for that unit which represents the distance of a star with parallax one second of arc. I have myself found that unit much more convenient than the light year, which is about one-third of it; but it has at present a very long name. The Astronomer Royal has made the suggestion that it shall be called *Astron*, and I hope that that or some similar suggestion be adopted. It will not be the least valuable part of the paper if he succeeds in giving us a short name instead of that long one. But I urge that he consider carefully which name he puts forward. The only disadvantage about *Astron* is that it might look like *Astronomical unit*. *Macron* might find favour. The opportunity is an important one, for it might be difficult to go back on a word when he once adopts it". The response by Dyson to Turner's comments run as follows: "Referring to the name I put in the footnote, one feels that the use of light-years has been introduced for lecture purposes, not for operations when your lecture is working with the stars. The name of *Siriometer* has been suggested in this connection. I do not like that; it suggests a machine for measuring. I thought of *macron*, and then thought that the meaning of *micron* might lead to confusion; so I suggested *Astron*. I do not know whether it appeals to people or not". There is no further discussion recorded, however, as to whether other people at the meeting did, or did not like the various terms being proffered. Eddington soon adopted the word parsec and its definition as given by Turner, and we find him expressing the distances to globular clusters with this unit in a paper he presented at the 1913 November 14 meeting of the RAS[12].

Within the discussion between Dyson and Turner we once again find the light-year being dismissed as a serious contender for the unit of distance measure, and discover Dyson's preference for the term *astron*. The March 14th RAS discussion is clearly the source from which Charlier gained his information about Dyson's dislike for the *siriometer*, but true to his comments made in 1913 May, he saw no need to stop using his term. Indeed, we find Charlier continuing to use the *siriometer* in the papers that he published through to 1917. We note specifically that the conversion of 1 *siriometer* ≡ 5 parsecs is given in a review paper published by Charlier in the 1917 November issue of *The Observatory*[13].

An additional unit of distance based upon a parallax measurement was defined by Hugo Seeliger, Director of the Munich Observatory in 1909. His unit of distance, the *siriusweite* (literally the *Sirius distance*) was defined according to one *siriusweite* being the distance at which the parallax is 0·2 seconds of arc[14]. Hence we have 1 *siriusweite* = 5 parsecs = 1 *siriometer* = 16·3 light-years.

On 1914 April 24, Dyson delivered the Friday Evening Discourse at the Royal Institution, and chose to talk on the subject of star streaming. Interestingly, rather than push for his "preferred" unit of the *astron* he adopted the parsec with the explanation that it is "a composite word suggested to me by Prof. Turner. With this unit, a distance of 100 in the diagram [his figure 4] denotes 20 million times the distance of the sun from the earth"[15]. We next find Dyson discussing stellar distances and parallax measurements[16] in the Halley Lecture at Oxford University on 1915 May 20. Within this talk, however, he makes no mention of the *astron* or the parsec, but expresses distances in terms of the Astronomical Unit. Interestingly, Dyson makes reference to Bradley's historical statement[8] that if γ Draconis had moved by so much as one second of arc he would have detected it — here was a golden opportunity, deliberately ignored, presumably, to introduce the parsec or *astron*. Dyson also used the Astronomical Unit to describe stellar distances in a 1917 review paper directly relating to the study of stellar distances[17]. Indeed, we find no specific reference to the unit of the parsec or *astron* in any of Dyson's papers published after 1914 — his death being recorded in 1939. Likewise, Turner appears to have felt no strong attachment to the term he coined. Indeed, in his 1919 January 31 talk at the Royal Institution[18], on 'Giant Suns', we find Turner expressing stellar distances in units of the light-year — Turner died in 1930, spending the majority of his time after *circa* 1920 working on seismography and the study of earthquakes.

Across the Atlantic, far from the meeting rooms of the Royal Astronomical Society, American astronomers predominantly used the light-year to express stellar distances. In a 1917 publication[19], for example, we find Harlow Shapley describing the distance to the globular cluster M 3 in light years, but its diameter in Astronomical Units. Just a year later, however, Shapley uses both the light-year and the parsec to express distances to globular clusters[20]. He feels, however, that it is necessary to add a footnote to explain that a parsec is a distance corresponding to a parallax of one second of arc — no other historical reference to the unit being provided. Edwin Hubble, in contrast, doesn't appear to have used the parsec prior to *circa* 1922. In his paper *A General Study of Diffuse Galactic Nebulae*[21], Hubble explains rather loosely, and again with the aid of a footnote, that a distance of 300 light-years is of order 100 parsecs (the actual conversion is about 92 pc). By 1925 Hubble had switched to using the parsec, but still felt that it was necessary to add a light-year conversion. Writing, for example, in *The Observatory* on *Cepheids in Spiral Nebulae*[22], he includes a footnote to indicate that 285 000 parsecs is equivalent to a distance of 930 000 light-years.

During the first several decades of the 20th Century, Kapteyn was one of Europe's leading theorists on the statistical study of stellar proper motions and star streaming. Indeed, in 1902 Kapteyn introduced the term absolute magnitude[3–5], and based this measure on a distance corresponding to a parallax of 0·1 seconds of arc. He continued to use this '10 parsec equivalent' unit measure until 1920. We know that Kapteyn switched preferential units in this year since he writes[23] in the *Astrophysical Journal* for 1920 July, "different units of distance have been used by different astronomers. That most widely used at present is the parsec. For the sake of uniformity we have resolved henceforth not only to use this unit but also to use the name, which is very convenient (though very ugly)". Remarkably, Kapteyn also proposes to re-define the absolute magnitude in terms of a standard distance of 1 pc rather than 10 pc. This latter suggestion (understandably) appears to have had no popular support. While Kapteyn suggests that the parsec is being widely used, there is very little evidence for this within the works published by the leading exponents in the field of stellar dynamics.

The first official sanctioning of the parsec as the preferred unit of measure for stellar distances was announced, appropriately enough, at the first General Assembly of the International Astronomical Union, held in Rome in early May of 1922. We are not privy to the details of the discussions held[24], but it is known that Dyson, Turner, and Shapley were at the meeting. The IAU resolution recommended that distances should be cast in terms of the parsec, but allowed for the continuation of Kapteyn's 10-parsec unit of distance when determining absolute magnitude. The decision by the IAU was not universally welcomed or acted upon. Indeed, in 1925, three years after the IAU meeting in Rome, Karl Malmquist described the new recommendation as being, "wholly unnecessary and moreover, inconvenient, and this is another reason not to consider this decision [by the IAU] as the definite one"[25]. In his article Malmquist argues that, "in reality there are only two units to choose between — namely the *siriometer* and the *parsec*". Interestingly, Malmquist makes no mention of the light-year as a possible unit of distance measure. It is a little surprising, perhaps, to find the *siriometer* as the main apparent rival to the parsec, but Malmquist argues, "as a length is most naturally defined through another length it would be most suitable to define the new unit as equal to 10^6 planetary units [*i.e.*, a million AU]"[25]. It is the distance-defining-a-distance feature of the *siriometer* (rather than a distance being defined *via* an angle, as in the case of the parsec) that Malmquist most likes, and he chastises Dyson for his earlier objections to the *siriometer*'s use[8] since it is "*not the name, but the definition that must be final*" [Malmquist's italics]. Malmquist ends his paper with a plea for further discussion, presumably within the open astronomical literature, but within the columns of *The Observatory*, at least, there is no further debate, and the unit of the *siriometer* (along with the *siriusweite*, *astron*, and *macron*) slipped quietly into the storeroom of astronomical history.

Ultimately, perhaps it is simply usage that enables a specific word to become the accepted norm: the more it is seen in print, the more it is used. Historically speaking, one can understand the reasons why the light-year might not have been favoured as the unit for measuring stellar distances. Firstly, the speed of light was, prior to recent times, subject to frequent experimental revision, and second, what year interval is to be used? — there are at least six to choose from[2]. While the light-year is a derived unit (based upon a measure of light speed and a specified time interval), the parsec is based upon an actual astronomical measure, the parallax, and the fundamental (that is directly measurable) Astronomical Unit, which certainly gives the parsec an edge over the light-year with respect to being a fundamental astronomical unit of measure. This all being said, historical precedent certainly favours the light-year, since we find in the letter from Bessel to Sir John Herschel, written from Konigsberg on 1838 October 23, describing the successful measurement of the parallax to 61 Cygni the following comment, "the distance of the star 61 Cygni from the Sun [is] 657700 mean distances of the earth from the Sun: light employs 10·3 years to traverse this distance"[26]. From the very first, therefore, the light-year has been employed as one of the measures of stellar distance.

There is a tendency in present-day popular-astronomy writing to make statements about the exact instance when a specific event happened. There are many problems in adopting this approach to writing history, not least from the fact that science and scientists rarely ever work in an isolated, step-function-like fashion. In the case of the word *parsec* and its adoption as a unit of distance measure, there is no specific instance when it was first universally adopted. Certainly, the word first appeared in print in the March issue of *The Observatory* for 1913, but the term and its definition were not officially sanctioned or generally accepted for at least a further ten to fifteen years, and even then some astronomers simply chose to ignore the IAU definition. Likewise the originator of the word *parsec*, Turner, felt no great compunction to promote its adoption. Indeed, Turner didn't even use the word in his own publications. Likewise, Dyson, who first used the parsec unit in a scientific publication professed that he preferred another name — the *astron*, although once again he failed to use this term in any of his actual publications. The word *parsec* appears to have become nearly universally adopted within main-stream astronomical literature by *circa* 1930. Interestingly (perhaps inextricably), the divide whereby the light-year is adopted as the measure of stellar distance in 'popular' literature still lingers to this very day.

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CORRESPONDENCE

To the Editors of 'The Observatory'

Compiling Biographical Encyclopediae of Astronomers

As mentioned in a review recently published in these pages[1], *The Biographical Encyclopedia of Astronomers* (hereafter *BEA*) edited by Hockey *et al.*[2] is a substantial work. As a compiler myself, for more than three decades, of directories, dictionaries, and on-line databases of organizations and individuals (see, *e.g.*, ref. 3 and the references quoted therein), I can only praise Hockey and his team for that impressive compendium. Here are, however, a few comments as suggestions for a possible second edition.

First of all, I ran a comparison with an exhaustive list of 82 German and French astronomers based at Strasbourg Observatory during the 19th and 20th Centuries[4]. Out of these, 47 satisfy the *BEA* inclusion criteria, but only ten (21%) appear in it. Among the high-profile ones missing are two of the three German Directors (Julius Bauschinger and Ernst Becker, the latter with the longest German directorship, 22 years — *cf.* refs. 5 & 6), Gilbert Rougier[7] (later to become Director in Bordeaux), and the renowned astro-optician André Couder[7]. Pierre Lacroute (with the longest overall directorship, 36 years, and the father of the revolutionary astrometric satellite *Hipparcos*) appears with only two lines, although an obituary[8] and a dedicated paper[9] were available as sources. Other well-known people are missing such as Walter Wislicenus[10] (founder of the *Astronomischer Jahresbericht*, later to become *Astronomy & Astrophysics Abstracts*), and Paul Muller[11], world-wide specialist on double stars.

This surprisingly low rate of inclusion (considering the broad definition of astronomers adopted by the *BEA* compilers — *cf.* ref. 2, p. *vii*) led me to run another independent comparison. The Royal Academy of Belgium is publishing a national biography (*cf.* ref. 12) gathering together notices on high-profile personalities from the country, including so far 58 astronomers satisfying the *BEA* inclusion criteria. Out of these, only 13 (22%) appear in the *BEA*, a result consistent with the previous one. Thus there seems to be plenty of room for additional inclusions, at least from European countries, in a possible second edition of the *BEA*.

Actually, what is the geographical distribution of the *BEA* entries? To investigate this, I keyed in all names, plus years of birth and death, and calculated the mid-life years. The countries of death were retained as being, in most cases, representative of the places where the professional activities had developed. After removing from the *BEA* listings those few people still alive and those whose temporal data were too vague, I ended up with a sample of 1317 entries, sizeable enough for significant statistics.

Table I lists the 24 most populated countries, with England, Scotland, Northern Ireland, and Wales gathered together under 'United Kingdom', contrary to the *BEA* where that 'country' never appears throughout the two volumes — an amazing inconsistency with what is done for other countries (Germany, Italy, Spain, *etc.*) and with what is claimed on *BEA*'s page *xlvii*. UK is the modern country to which England and the other above entities belong.

Note that I have in principle nothing against working with regions instead of countries, but then this should be done throughout the world and, first of all, for Spain and Germany whose regions have nowadays certainly achieved the largest degree of political autonomy. There are other points regarding the usage

TABLE I

Overall geographical distribution of the BEA entries
(24 most populated countries)

USA	288	Belgium	16
UK	227	Denmark	15
Germany	152	Ireland	15
France	148	South Africa	15
Italy	86	Spain	14
Russia	37	Australia	13
Netherlands	28	Canada	13
Sweden	25	China	13
Greece	22	Japan	13
Iran	19	Poland	13
Austria	18	Switzerland	13
Turkey	18	Egypt	12

TABLE II

Distribution of the BEA sample over the centuries
(based on mid-life years)

Centuries	−5th to 9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
Numbers	45	30	8	12	23	14	23	67	118	138	404	435

TABLE III

Cross-distribution of the BEA sample
over the five most populated countries and the five last centuries

Country	*16th Century (67 astron.)*	*17th Century (118 astron.)*	*18th Century (138 astron.)*	*19th Century (404 astron.)*	*20th Century (435 astron.)*
USA	0	1	5	185	197
UK	12	26	35	89	55
Germany	15	13	18	63	32
France	6	22	37	51	20
Italy	12	21	10	23	3

of country names in the *BEA* that could be commented upon. For instance, it would be much more informative to say that Hans Bethe was born in "Strasbourg (Germany, now France), 2 July 1906" than what is currently recorded; it is the key to that scientist's itinerary. Such 'details' are the price to be paid for full exactitude when putting together historico-international compilations, be it only to show that one masters fully European history with its changes of borders.

An historical breakdown of the *BEA* entries is given in Table II (from mid-life years). It shows a sharp increase in the 19th and 20th Centuries. Should one conclude, by crossing Tables I & II, that the *BEA* is biassed towards Anglo-American astronomers from the 19th and 20th Centuries? Such a hasty conclusion is tempered by Table III giving a cross-distribution over the five most populated countries (in terms of *BEA* astronomers) and the five last centuries.

The trend towards US astronomy over the most recent centuries (*via* a reinforcement by European astronomers in the 19th Century) is obvious, but the under-representation of European astronomers illustrated at the beginning of this note remains an issue. A legitimate question from a statistical stand is: was this induced by the deliberate selection of American editors only?[13] The participation of Europeans in the *BEA* Editorial Board would have probably reduced some of the sample biasses.

Europeans could have helped in other areas too. For instance, an acute *hyphenitis* has struck the way many first names are spelled in the *BEA*. In this part of the world, people are given several first names at birth, a tradition linked to religious godfather/motherhood. But only one first name is used in practice and is often underlined in CVs and official documents (or the secondary ones put between brackets). A hyphen builds a solid entity between two first names. 'Jean-Pierre' or 'André-Marie' is not the same as 'Jean Pierre' or 'André Marie'. The first gentleman has to be greeted by "Hello, Jean-Pierre", not with "Hello, Jean" or "Hello, Pierre". In view of this, the plethora of hyphens used in first names for quite a number of *BEA* entries can only appear as a nonsense. It is unthinkable that French astronomer Pouillet, for instance, would have been hailed by his pals as "Hello, Claude-Servais-Mathias-Marie-Rolland, how are you doing today?" The usual first name of Belgian astronomer Houzeau de Lehaie is Jean-Charles, not Jean-Charles-Hippolyte-Joseph. Many further examples could be given.

As in any other cataloguing activity, precision and consistency in directories are paramount. Hence the particles *da*, *de*, *di*, *du*, *la*, *le*, *van*, *von*, *etc*., should have received the same treatment as *d'* or *D'* and should have come ahead of the names. In the part of the world from which he originated, nobody would search for Gérard de Vaucouleurs under 'Vaucouleurs', but under 'de Vaucouleurs'. If different policies are followed, pointers from alternative classifications should always be provided, including in the indices. Note that case can be important: lower-case *de* (or *d'*) is generally an indication of nobility, which is not so for the upper-case *De* (nor *D'*). By the way, *Graf* (as in 'Hahn, Graf Friedrich von') means *Count* in German. Titles should not be mentioned, unless one decides to include all of them. But then, good luck with such a policy!

I wish also the *BEA* compilers had decided consistently whether to use the English wording of names or the original one. Again, cross-pointers should always be added here. Strange linguistic mixtures must be avoided. Thus the English–German contraption for Hildegard of Bingen-am-Rhine should appear as (in German) Hildegard von Bingen-am-Rhein and/or as (in English) Hildegard of Bingen-on-Rhine. Bernard of Le Treille is 'Franglais', probably echoed from the *Dictionary of Scientific Biography*. Do not hesitate to insert additional cross-pointers such as 'Guillaume de Conches' for William of Conches and 'Guillaume de Saint-Cloud' for William of Saint-Cloud, otherwise those gentlemen are untraceable under their original names, particularly for their fellow countrymen.

To end this letter on a different tone, I tried to answer a fashionable query: are astronomers living longer? The overall distribution for the sample at hand is given in Table IV (from the full years lived). It shows a maximum in the sixties–seventies, with a significant number of astronomers reaching their eighties and nineties.

As life expectation has increased in the past couple of centuries, it was interesting to investigate whether this would be reflected here. Table V (again from the number of full years lived and with the century of mid-life as reference) definitely shows such a trend. In the 16th Century, the number of astronomers dying in their fifties, sixties, and seventies is roughly the same, with a maximum becoming increasingly pronounced in the seventies during the 17th, 18th, and 19th Centuries. In the 20th Century, that maximum has shifted to the eighties, with a

TABLE IV

Global distribution of ages
(full years lived)

Age intervals	⩽ 20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	⩾ 101
Number	0	5	37	94	158	301	391	261	69	1

TABLE V

Distribution of ages for recent centuries
(full years lived, centuries of mid-life years)

Age intervals	*16th Cent.*	*17th Cent.*	*18th Cent.*	*19th Cent.*	*20th Cent.*
⩽ 20	0	0	0	0	0
21–30	0	3	1	0	0
31–40	2	10	7	9	6
41–50	9	19	10	32	9
51–60	18	16	19	46	24
61–70	16	27	37	105	75
71–80	18	30	43	131	129
81–90	4	13	17	72	140
91–100	0	0	4	9	51
⩾ 101	0	0	0	0	1

significant overflow in the nineties. Detailed data are unfortunately missing from other scientific communities for comparison.

I am very grateful to Harry Blom (Springer) for providing me with a copy of *BEA* and to Françoise Thomas (Royal Academy of Belgium) for communicating a comprehensive table of contents of all their *Biographie Nationale* and *Nouvelle Biographie Nationale* volumes.

Yours faithfully,
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REVIEWS

Skywatching in the Ancient World: New Perspectives in Cultural Astronomy, edited by Clive Ruggles & Gary Urton (University Press of Colorado, Boulder), 2007. Pp. 392, 23·5 × 16 cm. Price £52·50/$65 (hardbound; ISBN 978 0 87081 887 5)

Normal astronomers look out, and concentrate on the celestial bodies. They typically spend their time trying to understand the physics and chemistry of the origin and evolution of galaxies, stars, and planets. Cultural astronomers, however, turn towards the Earth and investigate the influences that the happenings in the sky have on the daily lives of humanity. These effects are numerous. On the one hand there are the practical applications, where the sky is used to help people tell the time, navigate on journeys, and choose the best occasions to go and hunt, gather wild food, and sow and harvest. There are also the more esoteric aspects of cultural astronomy where cosmic happenings form the basis of urban planning, monument construction, celebration organization, making myths, establishing folk-law, and developing religion, as well as influencing literature, music, and art.

Professor Anthony Aveni is an American academic who has spent his life studying the overlaps between astronomy, anthropology, and archaeology, especially in early Mesoamerican culture. In autumn 2003 a symposium was held in his honour at Colgate University, Hamilton, New York (Aveni's own university). The book under review is the resulting *festschrift*.

The essays concentrate on the interdisciplinary approach. Much is made of the interpretation of the hieroglyphs in a series of famous codices (Borgia, Borbonicus, Dresden, Fejérváry-Mayer, and Madrid), these being compiled a century or so before the Spanish invasion of Mesoamerica. Early calendars and their correlations are studied in detail with special reference to the synodic periods of the Moon and Venus and the tropical zenithal passages of the Sun. Lucky astro-archaeologists report on their trips to Hawaii to investigate the orientation of ancient temples. Less-fortunate ones concentrate on the orientation of English churches. The last paper homes in on the relationship between magic, science, and astronomy, and the influence of the cosmos on modern wizard-ware.

All in all the eleven papers present us with an intriguing, detailed, and well-referenced insight into the fascinations of cultural astronomy. The fact that this subject is both challenging and welcoming shines from every page. After reading this book I am even more encouraged in the quest to solve the mystery of Stonehenge. — DAVID W. HUGHES.

Stonehenge, by Rosemary Hill (Profile Books, London), 2008. Pp. 242, 21 × 14 cm. Price £15·99 (hardbound; ISBN 978 1 86197 865 3).

From the start Rosemary Hill makes it clear she is not going to solve the mystery of Stonehenge. This is not really a book about Stonehenge itself, but how it has been interpreted or understood through history. There is a basic description of the site as an introduction, or reminder, before getting on to the different interpretations. It is interesting that an astronomical alignment at Stonehenge was suggested at an early date by the first of the great antiquarians to consider the stones, John Aubrey in 1665. The Rev. William Stukeley pointed out the alignment on the midsummer sunrise in 1740. This alignment was developed by Dr. John Smith in his book *Choir Gaur* of 1771: Smith believed Stonehenge to be an observatory–temple aligned on both the summer and winter solstices; he named the 'Heel Stone' and gave it special significance in the alignment. He also believed the outer circle of stones represented the solar year and the inner circle the lunar month. Smith was followed by the Rev. Edward Duke, who, in his splendidly titled *Druidical Temples of the County of Wiltshire* (1846), named the four 'Station Stones' and supported the case for its astronomical use.

It would give the wrong impression of this book if I over-emphasized the astronomical interpretations covered. There is much about the Druids and a long chapter on the architectural influence of Stonehenge, from Inigo Jones to Milton Keynes. There is also its interpretation in poetry, by Blake and Wordsworth, and in art by Turner and Constable. We discover that Stonehenge has had a very wide influence on British culture.

With the Victorians, new sciences were applied to Stonehenge, archaeology was invented, and geology extended the timescale of pre-history. Charles Darwin investigated the stones as an example of the formation of vegetable mould over time. The Victorians also applied their technology to the study of Stonehenge: E. P. Loftus Brock photographed the sunrise over the Heel Stone and John Herschel drew the stones with a *camera lucida*. Norman Lockyer continued the astronomical interest in Stonehenge with his book *Stonehenge and Other British Stone Monuments: Astronomically Considered* (1906).

Much more was claimed for astronomy in the 1960s and '70s when astronomers Gerald Hawkins and Fred Hoyle claimed Stonehenge was an observatory. They found multiple astronomical alignments for Stonehenge and claimed it could be used as an eclipse predictor, nothing short of a computer in stone. This book goes some way to account for the response of archaeologists to this. Compared to astronomy, archaeology was a relatively new science, and many archaeologists lacked astronomical understanding. More importantly, the astronomical claims for Stonehenge (by implication the product of an advanced civilization) threatened the orthodox belief in progress as a gradual development of civilization. However, this synthesis of astronomy and archaeology in the new field of archaeoastronomy led to a better understanding of the astronomy of ancient cultures. Astronomical interpretations of Stonehenge are now quite acceptable and Hill's own interpretation of Stonehenge is of a temple visited at the solstices.

In recent years problems of preservation, access, traffic, and land ownership have left us with a World Heritage site surrounded by busy roads and a visitor centre with few admirers. The book takes us right up to 2008 April with the recent archaeology and contains useful information for anyone planning a visit. There is a comprehensive bibliographical chapter to review the printed sources.

This book places on record the astronomical interest in Stonehenge and is a useful introduction to its wider cultural significance. — MARK HURN.

François Arago, un savant généreux — Physique et astronomie au XIX^{e} siècle, by James Lequeux (EDP Sciences & Observatoire de Paris, Paris), 2008. Pp. 524, 16 × 24 cm. Price €35 (about £28) (paperback, ISBN (EDP) 978 2 86883 999 2 & (Obs. de Paris) 978 2 901057 56 7).

This abundantly illustrated volume is much more than a mere biography of François Arago (1786–1853), French scientist and politician. In a fluid style, James Lequeux not only masterfully details Arago's life and achievements, but also carefully explains their ins and outs. Through Arago and the major rôle he played in France at both scientific and political levels, the reader is led through a fresco gathering together the historical events and the dramatic scientific evolution of the time. Lequeux's underlying work is impressive and results in a remarkably well-documented volume.

Arago's life was quite a busy one and it would be audacious to attempt summarizing it here in a few words. Arago took part in an adventurous measurement of a meridian arc in Spain (preliminary to the standardization of the metric system). He became a member of the French Academy of Sciences, a professor at the prestigious École Polytechnique, a Director of Paris Observatory and the Bureau des Longitudes, a member of the Chambre des Députés (parliament), a Minister of Navy, Colonies and War, *etc*. He was instrumental in the abolition of slavery in the French colonies.

His scientific contributions dealt with the solar chromosphere, chromatic polarization, speed of sound, refraction in gaseous volumes, electromagnetism, *etc*. A list of the chapter headings gives a good idea of the broad scope covered by Lequeux's book: 'Introduction'; 'French scientific life in Arago's time'; 'Arago's life'; 'The nature of light'; 'The speed of light'; 'The birth of electromagnetism'; 'Measuring the Earth'; 'Arago and Paris Observatory'; 'Arago as an astronomer'; 'Arago as a geophysicist and a meteorologist'; 'Towards applied physics'; 'The promoter of sciences and techniques'; and 'Arago's legacy'. Several appendices ('Arago's life and works'; 'Arago's photometry'; 'Instructions on geophysics') followed by notes (seventeen pages), a bibliography, and an index conclude the book.

Lequeux extensively details experiments and instruments, often with the help of insets. In the most fitting way to understand properly somebody's life, Lequeux shows how Arago's activities articulate within a fascinating epoch that has seen several changes of régime in France, as well as a scientific context including the birth of optics, photography, electricity, thermodynamics, *etc*. Arago was a splendid orator, therefore a great teacher, and an accomplished popularizer. Lequeux also describes Arago's human surroundings, in the first rank of which was his family — leading some critics to coin the word *aragocracy*.

My only difficulty with this book has been of a technical nature. The publishers opted for large outside margins used on many pages for illustrations and legends. By contrast, the inside margins appear a bit too narrow and I had recurrently to fight with the binding to be able to read conveniently the end of the lines on the left-hand pages and the beginnings of those of the right-hand pages. All illustrations are in black and white, something that is quite understandable for historical reproductions, but, at today's relative cheapness of colour reproduction, its use for some explanatory graphs and diagrams would have made a more appealing volume. Some readers would probably also make good use of a more detailed index, including, for instance, secondary headers and titles of insets — a suggestion for a possible second edition. But those reservations do not remove anything substantial from a masterpiece that should remain a model for forthcoming contextual biographies of scientists. It ought to be quickly translated into English too. — ANDRÉ HECK.

La méridienne de France et l'aventure de sa prolongation jusqu'aux Baléares, by Pierre Bayart, with a foreword by Jean-Claude Pecker (L'Harmattan, Paris), 2007. Pp. 250, 13·5 × 21·5 cm. Price €21·50 (about £17) (paperback; ISBN 978 2 296 03874 5).

This book can be read as an historical novel. It tells the adventurous expedition of a group of astronomers to the Balearic Islands and the Spanish eastern coast in order to measure, in 1806–1808 and in the context of the metric system definition, a Mediterranean extension to the Paris meridian crossing France down from Dunkirk. The team leader was French astronomer Jean-Baptiste Biot (1774–1862) accompanied by the young François Arago (1786–1853), José Chaix (1766–1809) from Madrid Observatory, and Galician mathematician–geodetician José Rodríguez González (1770–1824). Biot had noticed Arago at Paris Observatory. Chaix had already worked with Pierre Méchain (1744–1804) in earlier (1803) meridian measurements in Catalonia. Rodríguez had been Biot's student at the Collège de France. Under instructions from their government, Spanish officers and sailors escorted the scientists. The historical background was troubled: Napoleon's battles in Eastern Europe and his meddling in Portuguese and Spanish politics; and the sea was also unsafe in the area, mainly because of Algerian corsairs.

To my knowledge, this is the first book chronicling the daily life of that expedition. It includes numerous authentic excerpts of letters and records of the time. In addition, extensive research has obviously been conducted by the author on the local context. But the reader is sometimes swamped by occasional plethorae of details not directly related to the main story — a pitfall awaiting some historians keen to stuff in the smallest results of their investigations without necessarily sorting out their relative importance to the book's backbone. Secondary elements are of definite interest *per se*, but their presentation as additional footnotes or insets would have made the reading flow more smoothly. A few annexes complete the book, as well as a glossary of names and a few bibliographical pointers.

Some publishing amateurism has to be reported: surprising white spaces at the end of some pages (apparently conditioned by illustrations, but standard text-editing systems can do much better than that nowadays) or isolated question marks at the beginning of lines (instead of closing the previous ones). Additional copy editing was definitely needed before releasing the material to the press.

Beware also of some shortcuts. The adoption of the Greenwich meridian as the longitude reference was much more complex than what is said in the opening pages. Minutes and press reports from the 1884 October Washington conference reveal bickering and bitter bargaining between France on one side and Britain plus the United States on the other, with Spain acting as an intermediary. The

French finally agreed not to object to the Greenwich meridian in exchange for a promise by the Anglo–Americans to adopt the metric system. But more than a century later, world travellers have still to learn how to convert feet and miles to (kilo)metres, pounds to (kilo)grams, and Fahrenheit degrees to Celsius ones. Embarrassing incidents (such as the 1999 failure of a *Mars Orbiter*) still result from confusion between unit systems.

In spite of the shortcomings mentioned above, the book should be seen as a valuable contribution by historians of astronomy, especially through its numerous quotations and excerpts of original texts and letters. But perfectionists be warned: they will not find full bibliographical references for all of these. — André Heck.

Cambridge Illustrated Dictionary of Astronomy, by J. Mitton (Cambridge University Press), 2007. Pp. 397, 23·5 × 16 cm. Price £18·99/$35 (hardbound; ISBN 978 0 521 82364 7).

Since its first edition in 1991, Jacqueline Mitton's *Dictionary of Astronomy* has become an invaluable reference source for many armchair astronomers and amateur skywatchers. This latest incarnation differs from its predecessors in a number of ways, most of them presumably intended to attract a rather wider — and, perhaps younger — readership.

The first obvious difference is the introduction of 300 colour illustrations, most of which are images of celestial objects taken with ground- and space-based telescopes. Also prominent are 20 star maps created by the well-known illustrator, Wil Tirion. Unlike previous versions, the latest edition also includes brief biographical sketches of 70 leading historical figures.

Unfortunately, there are also some significant omissions, most notably a reduction in the number of entries from 3000 in the 2001 dictionary to 1300 in the new, illustrated edition. I must confess that I also miss the appended tables that previously provided useful summaries of the brightest stars, constellations, Solar System objects, and planetary rings.

The book is a pleasure to behold, with excellent reproductions of the colour images and a clear, well-written text. As a former press officer for the Royal Astronomical Society and the author or co-author of numerous other books, Mitton has gained a well-deserved reputation as a respected authority on astronomical topics. For anyone whose bookshelves do not yet include a copy of her *Dictionary of Astronomy*, then this is a good opportunity to remedy the omission. I just wish that this edition had not been abridged quite so much. — Peter Bond.

Atlas Lunarum, 2 DVDs (in English) available from Andreas Phillip, Stellarum, Im Lutzen 21, 73773 Aichwald, Germany (e-mail: stellarum@arcor.de). Price €49·95 + €4·50 (about £40) handling/shipping. (ISBN 978 3 940534 05 7)

This two-DVD set, of the historic lunar atlases of the 19th and 20th Century, is well presented. After placing the first DVD into the drive it immediately displayed a clear, tabulated menu divided into books, atlases with subsections, and readily identifiable maps. Navigation to the various documents and charts contained on the DVD was easy to understand and operate. Like all electronic media, there is a requirement to have the appropriate readers, and this is indicated in the instructions that come with the DVD.

On examination of a range of books and charts, I found most links were operational. Clicking on the link to the first volume by Beer & Madler, for instance, immediately brought up the indexed pages, which were reproductions of the book in PDF format and at a quality that made them easily readable. The accompanying chart demonstrated the achievement in recording lunar features at this point in history. With the benefits of electronic format it is surprisingly easy to compare the accuracy and details within these maps with their modern equivalents. It came as no surprise to discover that these were pretty accurate and reflected how much work must have gone into the production under the difficult circumstances that those early observers had to contend with. Lohrmann's book and charts were similarly of a high quality of reproduction and it was fascinating to see at high magnification the exquisite workmanship employed in producing those maps.

The book by Schmidt was again of high quality but unfortunately on the DVD the links to the charts produced a missing-picture icon, meaning that they were not visible to the reviewer. All other links on the first DVD were functional, whilst DVD 2 had similar layouts and navigation.

The DVDs give a fascinating insight into the history of charting the Moon and constitute an invaluable reference for anyone interested in the historic development of lunar cartography. They would also be ideal for anyone starting out who wishes to compare their first drawings at the telescope with these historical records that were produced in a similar way. — ALAN WELLS.

Beyond UFOs: The Search for Extraterrestrial Life and Its Astonishing Implications for Our Future, by J. Bennett (Princeton University Press, Woodstock), 2008. Pp. 211, 24 × 16·5 cm. Price £15·95/$26·95 (hardbound; ISBN 0 691 13549 5).

Jeremy Bennett has a lifelong passion for exploring the possibilities of extraterrestrial life, and in this book it comes across unbridled. His reviews of planetary science and astrobiology are concise and up-to-date, and he weighs authoritatively the relevant facts and statistics concerning 'life' (which he carefully defines) and the likelihood that it may exist in some form in one or more of the Solar System bodies (which he has carefully researched), and in other planetary systems, wherever they may be. With a refreshing thoroughness he examines every conceivable state of 'life', including microbes that exist in surroundings that are far more extreme than can be tolerated by any more-evolved organism, and urges us to accept his belief that just about any of those forms could be lurking in the lesser-known reaches of the cosmos.

Bennett conveys well the abundant delight which all this brings him and could also hold for us, and his wish that these studies have high priority on every telescope is almost infectious (but not quite). The proposal to detect planets quickly through transit photometry assumes perhaps a little naïvely that many Earth-like planets will be discovered unambiguously if we but acquire the wherewithal, as it overlooks the need to eliminate other possible interpretations such as pulsations or star spots. The suggestion that an international research station on the Moon is our greatest hope of persuading humans to unite in endeavour rather than engage in combat is a worthy one, but is surely not the first of its kind; the Antarctic Treaty declared that Antarctica be used for peaceful purposes only, but does not appear to have heralded the healthy attitudes for which Bennett (and all of us) yearn. But these are only details.

Beyond UFOs is not actually about UFOs at all (but then Daphne Du Maurier's famous novel *Rebecca* isn't about Rebecca, either), nor does it describe actual searches for extraterrestrial life. As Bennett emphasizes, it's about probabilities. It presents no hard evidence, and even dismisses accounts of UFO sightings on the grounds that they cannot be submitted to scientific controls or repeated observation. I was mystified by the "Astonishing Implications" in the subtitle, since the act of searching cannot itself bear any such implications, nor would the recognition of another civilization, either near or far, be very likely to change our attitudes overnight towards one another. There is also a tacit assumption that the evolution of the brain, at least, is sufficiently unique that other civilizations will parallel our own in inquisitiveness, technology, and science, but it overlooks the amazing fact that any duplication of recognizably anthropoidal features would testify to their uniqueness. More than once he promises to describe something, only to let his pen whisk us away to other realms. What he *does* do, though, and with considerable passion, is to present an irresistible plea on behalf of both environmental awareness and international scientific endeavour.

Since I do not subscribe to any particular persuasion regarding the presence or unlikelihood of extraterrestrial *life*, not to mention *intelligence*, I could review this book with a completely open mind. Without question it left me better informed regarding the possibilities, but no nearer the answer to Fermi's Paradox ("Where then are all the evolved civilizations from elsewhere?") than were Fermi's listeners at the time he phrased his famous question. But that didn't trouble me; it was written from the heart, and it was a good read.

Beyond UFOs gives a good impression from the moment you first take it into your hands. It is attractively produced, well written, and very thoroughly proofread. It's an interesting and challenging complement to focussed research, and will be particularly enjoyed by anyone who has an appetite for broad science tinged with morals. — Elizabeth Griffin.

The Solar System Beyond Neptune, edited by M. A. Barucci, H. Boehnhardt, D. P. Cruikshank & A. Morbidelli (University of Arizona Press, Tucson), 2008. Pp. 632, 28·5 × 22 cm. Price $70 (about £35) (hardbound; ISBN 978 0 8165 2755 7).

Historically, the freezing depths of space out beyond Neptune was the Solar System's *terra incognita*. Some even went so far as to postulate that Neptune was right at the edge. But then, in 1930, came the serendipitous discovery of Pluto. The suggestion that Pluto was not alone was made by the Irish astronomer Kenneth E. Edgeworth (in 1938) and the Dutch–American planetary scientist Gerard P. Kuiper (in 1951). Both of them suggested that a host of small comet-like bodies were orbiting out there, and later on it was realized that these were the source of the short-period comets that are captured by Jupiter. This outer belt was named after Kuiper and unfortunately our American colleagues seem to be very reluctant to acknowledge the fact that Edgeworth had actually pipped Kuiper to the post by 13 years.

The insignificance of Pluto was recognized in 1978 when the discovery of its satellite Charon enabled its mass to be calculated. In 1992 Pluto was made to feel even less lonely when 1992 QB_1 was found. Soon other bodies in a 2:3 resonance with Neptune were added to the list, as well as bodies in both a scattered and an extended outer disc. Today over 1000 objects have been found out there in the Edgeworth–Kuiper Belt and it is an ideal time to stand back and review what has been learnt so far.

More than a hundred authors came together to overview the scientific state of play. As is typical of a volume in the *University of Arizona Space Science Series*, the standard of the contributions, the refereeing, the editorial polishing, the referencing, and the reproduction are exemplary. It is clear from this excellent book that the nature of the bodies in the Edgeworth–Kuiper Belt is much better known than their origin.

The first sections of the book concentrate on orbital distributions, surface properties, colours, size distributions, rotational modes, shapes, and compositions. We then venture into less-well-understood territory. Why are there so many binaries? Were collisions important? Were the Edgeworth–Kuiper Belt objects created in that region or have they been pushed out there by planetary migrations and resonance interactions? How has the mass of the Belt changed with time? Have perturbations by passing stars played an important rôle? Does the distribution of Edgeworth–Kuiper Belt objects show that the Solar System has lost some of its outer planets? Are they more closely related to cometary nuclei than to the satellites of the gas giants? Are there any examples of Edgeworth–Kuiper Belt bodies in our meteorite collections? Will the 2015 Pluto flyby by NASA's *New Horizon* space probe answer some of our questions or just propose a host of new ones? Have we discovered enough bodies or will the picture become much clearer when we have logged as many Edgeworth–Kuiper Belt objects as we have Main Belt asteroids? Will the next generation of super-computers solve the orbital-evolution problems? When will the next scientific overview of these bodies be needed? — DAVID W. HUGHES.

Near Earth Objects, Our Celestial Neighbors: Opportunity and Risk (IAU Symposium No 236), edited by A. Milani, G. B. Valsecchi & D. Vokrouhlický (Cambridge University Press), 2007. Pp. 500, 25·5 × 18 cm. Price £62/$117 (hardbound; ISBN 978 0 521 86345 2).

Near-Earth objects (NEOs) are minor bodies (asteroids or comets) that pass within 0·05 AU of the centre of the Earth. Now 0·05 AU is no problem, being about 20 Earth–Moon distances. We should, however, start to sweat when this figure drops to 0·00005 AU. These NEOs do not fly by: they hit.

Three recent events have underlined this potential eventuality. This year we are celebrating the 100th anniversary of the high-altitude Tunguska explosion in Siberia; in 1994 July we saw the fragments of Comet Shoemaker–Levy 9 plunge into the clouds of Jupiter; and in 1991 the cosy relationship between the dinosaur-removing events that occurred at the Cretaceous–Tertiary boundary and the formation of the Chicxulub impact crater in Mexico became hot news. Nations started to spend serious money on NEO research. Organizations with exotic names and acronyms like Spacewatch, NEAT, LONEOS, LINEAR, Pan-STARRS, *LSST*, *DCT*, NEOIC, and KLENOT sprang up. The NEO-discovery rate has rocketed.

Huge efforts are now being made to ensure that accurate orbits are obtained and NEOs do not get lost. Theoretical celestial mechanicians struggle with resonance phenomena and source possibilities. Observational astronomers worry about the comet/asteroid ratio and the possibility that some of the 'asteroids' are actually dormant comets. The relationship between the absolute brightness of the NEO, the possible impact kinetic energy, and the potential crater size is pondered over. The spin modes, shapes, and possible binary natures of NEOs are investigated. And meetings are organized.

The book under review contains the 56 papers generated by the 2006 August 14–18 symposium that was held in Prague. We are presented with a detailed overview of the physics and dynamics of near-Earth objects. The papers are of a very high standard, well refereed and beautifully produced. The subject will be much enhanced by these proceedings, and it is going to be very useful to have these papers all in one book as opposed to being scattered through a host of different journals. Much was also made of the rate of progress in NEO research and it is very clear that the next decade or two will see a vast increase in the inventory. I was a bit surprised about the use of the word 'risk' in the book title. NEOs were treated as remote, benign, inert, astronomical bodies. Little was written about the NEOs' potential for inflicting death, doom, and disaster. Maybe that is the topic of the next meeting. — DAVID W. HUGHES.

The Lunar Exploration Scrapbook: A Pictorial History of Lunar Vehicles, by R. Godwin (Apogee Books, Burlington, Ontario), 2007. Pp. 305, 25·5 × 17·5 cm. Price £16·95/$36·95 (softbound; ISBN 978 1894959 69 8).

Having recently read *Lunar and Planetary Rovers: The Wheels of Apollo and the Quest for Mars*, by A. Young (Springer, 2007), I was pleased to review this related book which charts the plans for the Apollo Applications Program that would have followed on from the initial Apollo missions to the Moon if the programme had not been cancelled after *Apollo 17*. The book is in a 'scrapbook' style, which in general suits the wide variety of areas covered, and has full-colour illustrations on nearly every page. This book describes the vehicles planned for extended lunar exploration after the initial Apollo missions as well as giving a brief history of the actual vehicles used, namely the *Lunar Excursion Module* (*LEM*) and *Lunar Roving Vehicle* (*LRV*), and a history of lunar-exploration concepts. It covers all types of vehicle from modifications to the Apollo capsule, through lunar shelters and mobile laboratories, to lunar flying vehicles and even modifications to the *LEM* to use it as a near-Earth orbiting observatory. A substantial number of the vehicles described were actually built (as prototypes) and tested in the heady days of Apollo when funding wasn't a problem, and photographs of these prototypes, where available, are included in the book. Where such information is not available artist's impressions or line drawings illustrate the concept; however, only summary text is given on most vehicles so details of any one vehicle are not given.

The book contains some real surprises, like a winged version of Apollo that would have landed as a glider following re-entry, and nuclear-powered rover systems for the Moon. However, the major surprise to me — despite Apollo happening within my lifetime — is that many companies and NASA intended the Apollo missions to be just a first step: they intended to go and live and research on the Moon, adapting and modifying elements of Apollo to achieve that goal, predating the current NASA Constellation programme. In fact people will recognize that many of the concepts for lunar exploration highlighted within recent NASA press releases have their origins in work described in this book. It is clear from the book that many of the problems of living and working on the Moon had been thought through in the 1960s, like using lunar regolith as radiation shielding, what combination of vehicles and facilities would be needed for a lunar base, *etc.*

The sad thing to me, having read the book, is that without a loss of political nerve and funding humankind would have been living and working on the Moon in the 1970s, building on the science, technology, and engineering legacy of the Apollo missions, not just thinking of returning to the Moon in around 2019, 50 years after *Apollo 11*. For people interested in history of space exploration and space technology or lunar-exploration plans for the future, the book makes a fascinating read — along with a view of what might have been. — MARK SIMS.

14th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (ASP Conference Series, Vol. 384), edited by G. T. van Belle (Astronomical Society of the Pacific, San Francisco), 2008. Pp. 441 + CD ROM, 23·5 × 15·5 cm. Price $77 (about £38) (hardbound; ISBN 978 1 58381 331 7).

Proceedings of the 'Cool Stars' workshops (hereafter *CS*) are inevitably a somewhat eclectic assortment of research topics, though often with a detectable bias towards the interests of the host organizer. This volume spans subjects such as seismology and magnetism, which are presently studied to mutual advantage in both the Sun and in cool stars, with extensive contributions on the broader issues of star formation, stellar evolution, and extrasolar planets. Many of the contributions depict new ventures, new limits, and new achievements (several are more recent than *CS13* in 2004) and are labelled as "firsts", whether at detecting magnetic fields in starspots and stellar chromospheres or measuring precisely the angular diameters of some 450 main-sequence stars. There is a noticeable tendency to focus on low-mass objects and brown dwarfs, which were not even thought of at the time the *CS* series started in 1980. To that extent, therefore, these proceedings chart the progress of stellar research and where it is currently pointing. Those who specialize in cool giants will have found *CS13* or (coming soon) *CS15* richer in what they want. Nevertheless, stellar astronomers should be happy that series like *CS* maintain their sterling rôle in nurturing a very vibrant community of stellar researchers.

Personally, I am a bit bothered by conference proceedings. Much of what they contain has been, or is very likely to be, written up for a refereed journal, while the essence of a conference is to distil what is thought, known or new, and to talk it over. Unfortunately, most published proceedings do not reflect those thought processes which are the stuff of scientific progress; whatever the content of an actual presentation, the formal contribution gets whittled down into what resembles a published paper, thus (for the reader, at any rate) tending to toss out the baby with the bath-water. In that respect this book is no exception, though it does of course have the saving grace of filtering out all non-cool-stars research. It could have been extremely interesting to record and share (for instance) the reactions to Ayres' claim that we have been getting the solar abundance of oxygen wrong all these years, or to the conclusion of Grupp & Mashonkina that state-of-the-art model atmospheres incorporate an almost irreducible uncertainty in effective temperature of $\pm \sim 75$ K. Instead, the contributions tend to be their pre-conference versions and thus do not reflect that feedback which is a significant element of a conference.

Cool Stars workshops include 'splinter sessions', which are highly-focussed discussions embracing a dozen or so topics of particular interest to enough people, and which are summarized in the proceedings. Most of those splinter sessions appear to have been organized as mini-conferences, though some made more of an effort to promote discussion rather than display. It is my belief that those discussions are intrinsically more valuable, *if published*, than a compendium of one-way communications from authors, since they provide synopses of current thinking in a number of defined topics, and can weigh the global uncertainties more comprehensively. Such a publication would justify better the monetary and environmental costs of bringing together so many people from so far.

As is now fairly widespread practice, poster papers are included in digital form only, in the interests of saving space (money); the publisher includes them in a CD that comes with the book. For presumably the same reason, many of the printed diagrams are reproduced on a scale that makes their details hard to discern, and it would have been useful to be supplied with a magnifying glass too. As is also customary, the contributions are reproduced directly from the authors' submissions, and lack the detailed proof-reading of a refereed paper; the splinter-sessions' accounts are divided between the first person and reported speech, and (even though this workshop was held on US soil) one notices that the adjective 'insightful' came from the keyboard of a British scientist.

The publisher recommends this book for (*inter alia*) graduate students. However, it is not a textbook; its contents assume considerable expertise in the topic in question, and (presumed familiar) acronyms abound. One of the splinter sessions defines a splinter session but not the basic concepts of the science it discusses.

These proceedings of a meeting held in late 2006 took a year to prepare for printing and another six months to emerge in book form, just as the registration for *CS15* (2008) was declared oversubscribed. But though a few of the papers are already dated in some aspects, the whole stands as a lasting contribution to the considerable growth in knowledge, techniques, and wisdom as stellar physics continues its relentless pursuit of understanding. No library should be without this complete series. — ELIZABETH GRIFFIN.

Triggered Star Formation in a Turbulent Interstellar Medium (IAU Symposium No. 237), edited by B. G. Elmegreen & J. Palouš (Cambridge University Press), 2007. Pp. 509, 25·5 × 18 cm. Price £62/$117 (hardbound; ISBN 978 0 521 86346 9).

The 237th IAU symposium was a fairly major event. It was held in Prague in 2006 August and was part of the 26th General Assembly of the IAU. According to the listing given at the front of the volume there were over 520 participants, including most of the key workers in the field of dynamic star formation. This reflects the fact that the nature and physics of star formation is the most actively debated subject in galactic astrophysics. Whilst it seems that sites of individual star formation are essentially quiescent, the interstellar medium is anything but. It is this dynamic, turbulent medium that seeds the star-forming cores. The symposium was largely motivated by the wealth of new observational data, much of which is at extremely high spatial resolution, and significant developments in the detailed computational models such that theory and observations are almost at the stage where direct comparisons can be made.

There are two different approaches to presenting conference proceedings; one is to give over a significant fraction of the volume to seminal contributions from invited speakers. The alternative approach is to allow shorter, less-comprehensive contributions from all of the active participants at the meeting. This book falls into the latter category. There were 14 sessions, covering a huge range of topics, but broadly categorized into: turbulence and the interstellar medium, shells, molecular clouds, clusters, and galaxies. The oral contributions are represented by some 64 papers, each typically 4–8 pages long (including the discussions). In addition, a page is given to each of the 111 poster contributions — basically specifying who is doing what and where the next developments are likely to occur.

What we have in these proceedings is therefore essentially a snapshot of the state of the art. It is, inevitably, something of a curate's egg — in such a wide-ranging compilation there will always be some articles that are more interesting and/or topical than others. But, overall, the level is very high. The shortness of the contributions is perhaps rather frustrating — providing snippets of work in progress — but it is sufficient to whet the appetite, and provides an important reference point for further developments.

Although the subject is rapidly evolving, the broad base of this symposium probably ensures that the proceedings will be an important reference source for some years to come. — JONATHAN RAWLINGS.

Subsurface and Atmospheric Influences on Solar Activity (ASP Conference Series, Vol. 383), edited by R. Howe, R. W. Komm, K. S. Balasubramaniam & G. J. D. Petrie (Astronomical Society of the Pacific, San Francisco), 2008. Pp. 440, 23·5 × 15·5 cm. Price $77 (about £38) (hardbound; ISBN 978 1 58381 329 4).

The 24th National Solar Observatory Sacramento Peak Workshop was held in 2007 April and brought together experts studying solar active regions both below and above the solar surface in order to further our understanding of the creation and evolution of solar active regions and solar activity. The articles contained in this volume reflect the wide range of topics discussed at that meeting, including surface and subsurface flows around active regions, flux emergence and cancellation, the evolution of active regions and filaments, MHD waves, and the connection between space weather and solar activity.

This volume provides a nice overview of much of the latest thinking in these areas and the combination of heliospheric and atmospheric observations and theory mean that pretty much all aspects of active regions, from conception through to birth at the solar surface and throughout their lives, are considered. Papers discuss not only the latest observational and theoretical results but also analysis techniques: for instance, how to determine flows and flux from observations, and numerical experiments to model theoretically what is observed. Furthermore, key aspects of solar-active-region behaviour both new and old are mentioned. In particular, there are papers discussing the latest observations from *Hinode*, as well as a series of papers presenting new models of active regions and/or active-region behaviour.

All in all this volume amounts to a very readable collection of papers of interest to anyone wishing to learn more about the origin and evolution of solar (or solar-like stars showing evidence of) activity. — CLARE PARNELL.

Astrophysical Masers and Their Environments (IAU Symposium No. 242), edited by J. M. Chapman & W. A. Baan (Cambridge University Press), 2008. Pp. 533, 25·5 × 18 cm. Price £65/$130 (hardbound; ISBN 978 0 521 87464 9).

These conference proceedings provide a comprehensive description of the application of masers in astrophysics. It is a timely update as new facilities begin to yield new insights. Large-area blind surveys, taking place at Arecibo and Parkes, have come to maser astronomy, and will ultimately cover the whole Galactic Plane. This heralds a new era of systematic study, rather than pointed follow-ups of samples selected at other wavelengths, and complements other multi-wavelength Galactic Plane surveys.

Another new technological breakthrough that features highly in the proceedings is the large number of trigonometrical-parallax measurements at the *VLBA* and the specially-built *VERA* array. This is producing new data on the structure of our Galaxy. Similar observational methods are revealing absolute proper motions of masers that trace the dynamics on unprecedented scales in jets and disc winds in young stellar objects and evolved stars. Multi-epoch VLBI observations of masers in AGN discs continue to deliver precise values for the Hubble constant, free from the usual distance-ladder biasses, as well as insights into AGN physics. Together with the ability to measure magnetic-field strengths and morphology at high angular resolution, the maser work described in this volume continues to provide unique and valuable information on many areas of astrophysics. Many in the field will also remember this volume as a suitable legacy for Jim Cohen, whose great impact on this field underpins much of the work described within its pages. Sadly he died just prior to the conference that celebrated much of what he had achieved. — MELVIN HOARE.

The Second Annual Spitzer Science Center Conference: Infrared Diagnostics of Galaxy Evolution (ASP Conference Series, Vol. 381), edited by R.-R. Chary, H. I. Teplitz & K. Sheth (Astronomical Society of the Pacific, San Francisco), 2008. Pp. 525, 23·5 × 15·5 cm. Price $77 (about £38) (hardbound; ISBN 978 1 58381 325 6).

Volume 381 of an ever-expanding series (there were 20 published in 2007 alone), this one appeared early in 2008, but reports the proceedings of the *Spitzer* meeting held in 2005 November. It thus records a snapshot of *Spitzer*-related research two years into the mission. (A previous *Spitzer* volume, No. 357, appeared in 2006.) The contents are exactly what it says on the cover, with a total of 14 reviews, 45 talks, and 112 poster papers, divided into 12 sections covering all aspects of the use of infrared imaging and spectroscopy in the study of galaxy evolution from $z = 6$ to the present. Although presenting a good summary of relevant work, the lag of over two years between meeting and proceedings means that most of the results are already published or on astro-ph, so I wouldn't rush out to buy a personal copy. One for the library for reference. — STEVE PHILLIPPS.

Galaxies: A Very Short Introduction, by J. Gribbin (Oxford University Press), 2008. Pp. 121, 17·5 × 11 cm. Price £6·99/$9·95 (hardbound; ISBN 978 0 19 923434 9).

According to the 'blurb', the aim of this series is to provide "… a stimulating and accessible way into a new subject." Despite this, my overriding reaction after reading this book was to wonder why the author and publishers had produced it. That is not to say that the book isn't stimulating and accessible. It may well be — but a useful introduction to galaxies? No, not really. My main reason for saying that is the rather important one of its contents. Given that there already exists a *Very Short Introduction to Cosmology*, written by Peter Coles, why did the author of the present work think it was a good idea to expend 40 of his 110 pages explaining the expansion of the Universe, its curvature and mass density, and its ultimate fate. Even in the remainder, it is notable that the index item with by far the most entries (over 50) is 'Black holes'. Cosmology and black holes are indeed fascinating, but surely the author could have resisted the temptation to write another book on them? Maybe the giveaway comes in Chapter 2 — "Since 1931, the aim of all measurements of distances beyond the Milky Way has simply been to calibrate the Hubble constant." And here was I, thinking the galaxies themselves were interesting!

So much for the overview, what of the details? Well, better proof reading might have caught some of the more unfortunate howlers. For instance, we are told that there are "several (at least three) hundred million stars" in the Galaxy, and that the "speed with which a planet moves is inversely proportional to the square of its distance" from the Sun. Or how about 2·7 K being –272·3° C? Throw in, what seemed to me, some rather strange ways of phrasing things, some contradictory statements, and technical errors, and I'm definitely not sure what has really been introduced. All in all, it is rather reminiscent of those science series on television, where you tend to believe what they say until there is one in your own subject area. — STEVE PHILLIPPS.

Galactic Dynamics, 2nd Edition, by J. Binney & S. Tremaine (Princeton University Press, Woodstock), 2008, Pp. 885, 23·5 × 15·5 cm. Price £35/$60 (paperback; ISBN 978 0 691 13027 9).

This is the much-anticipated 2nd edition of Binney & Tremaine's classic textbook on the dynamics of stellar systems. Since its 1st edition in 1987, *Galactic Dynamics* has become the 'bible' for everybody working on the dynamics of galaxies at the postgraduate and research level and has had a significant impact on a whole generation of scientists. Certainly influenced partly by this book, the last two decades have seen many advances in the field, and the 2nd edition is largely a revision to reflect many of these new developments, but also older results which were missing from the 1st edition. Unlike many other further editions of academic textbooks, this is not just an extension of the previous edition: the new materials are not merely added, but the authors have re-written the whole text, also reflecting the change in their own views, and thus provided us with a coherent and well-inter-coordinated text.

This massive book of 885 pages (up from 733 of the 1st edition despite dropping one chapter) will likely be mostly used as a reference, although I found it very useful to read selected sections on topics slightly off my immediate research interests. The book develops the field from the perspective of the theoretical physicist and is quite mathematical and geared towards analytical results, though the treatment of the increasingly important numerical methods has been extended since the 1st edition.

After a brief overview mostly of the relevant observational facts in Chapter 1, Chapter 2 deals with potential theory, *i.e.*, the practical problem of finding the gravitational potential generated by a given mass density. This rather mature field, which reaches back to Newton, is presented in a clear way, including recent progress in methods used for *N*-body simulations. Chapter 3 deals with orbits in galactic potentials and has been significantly rewritten, mostly to close gaps left in the 1st edition, namely numerical orbit-integration methods and perturbation theory. Chapter 4, on equilibria of collisionless systems, has been revised considerably with more emphasis on distribution-function modelling and includes several analytic results which have emerged in the last 20 years. New in this chapter are the treatments of adiabatic compression and deformation of equilibria, and sections on *N*-body modelling and Schwarzschild's orbit-based numerical method and the use of stellar kinematics for inferring the mass distribution of a stellar system.

The discussion on stability of collisionless systems in Chapter 5 has been revised with extended discussions of Landau damping and van Kampen modes as well as a new treatment of perturbation theory using angle-action variables and Kalnajs' matrix method. Chapter 6 about disc dynamics and spiral structure contains some beautiful colour plates, but otherwise is only mildly altered when compared to the

1st edition (sadly, Figure 6·3 seems corrupted in every copy). Compared to the 1st edition, Chapters 7 and 8 have been swapped, with collisions and encounters of stellar systems presented in Chapter 8 and kinetic theory in 7. The latter is the only place in the book discussing the special properties of collisional stellar systems, such as globular clusters and galactic centres, for which gravitational two-body interactions affect the evolution. The chapter gives an excellent and up-to-date overview. Since the 1st edition, the subject of interactions between stellar systems has greatly benefitted from *N*-body simulations and an increase in computer power. This is reflected in Chapter 8, in particular by some nice snapshots from such simulations, though not much new material has been added relative to the 1st edition.

Chapter 9 on galaxy formation replaces Chapter 10 ('Dark matter') of the 1st edition (Chapter 9 of the first edition on chemical evolution has been abandoned since it was only quite loosely connected to the rest of the material and is also well covered in other textbooks), but is completely new, reflecting the significant progress in the past 20 years largely owing to the advent of high-resolution *N*-body simulations of large-scale structure formation. Though perhaps not the highlight of the book, the chapter gives an overview of this rich field, starting with some basic cosmology, *via* linear and non-linear structure formation (including Press–Schechter theory), to *N*-body simulations and the effects of stellar feedback (though the importance of AGN feedback is not well identified).

Each chapter also comes with a number of problems of varying degree of difficulty, mostly requiring some algebraic manipulations. There are over 200 of these, almost twice the number in the 1st edition (several of the new problems are generated by 'recycling' material which has been omitted from the text relative to the 1st edition).

As with the 1st edition, the many appendices are a rich source of knowledge in their own right, and are alone reason enough to have a copy on your shelf. Appendices B & C summarize most of the mathematical background required by anybody conducting research in the subject area, from vector calculus and Fourier series to probability theory and special mathematical functions. Appendix D summarizes in just 13 pages much of classical mechanics at postgraduate level: from Newtonian and Hamiltonian mechanics to canonical transformations and generating functions. Appendix E is new and closes a gap left by the 1st edition in that it presents the orbital elements of the Kepler problem and their relation to angle-action variables. An impressively comprehensive overview of fluid dynamics is given in just 11 pages of Appendix F.

On the negative side, one must mention that some important results are missing (*e.g.*, some spherical potential-density pairs, the augmented density approach, and Cuddeford's spherical distribution functions in Chapter 4) and conversely some out-dated or less relevant material (*e.g.*, the modified Hubble profile) is still included. Another perhaps more serious shortcoming (in common with the 1st edition) is a somewhat sloppy referencing of the original sources: though these are usually quoted somewhere, many results are presented without direct quotation of their original authors.

These minor deficiencies notwithstanding, this is a great book, already evident from the fact that since its 1st edition nobody has attempted to rival it. It is an absolute must for everybody, from PhD students to senior researchers, whose studies touch upon the subject of galaxy dynamics. A great strength of this book, and certainly a reason for the overarching success of its 1st edition, lies in Binney & Tremaine's ability to explain even the most complicated of concepts and arguments in a straightforward and logical way. — WALTER DEHNEN.

L'observation en astrophysique, 3rd Edition, by Pierre Léna, Daniel Rouan, François Lebrun, François Mignard & Didier Pelat, with the collaboration of Laurent Mugnier (EDP Sciences/CNRS Éditions, Paris), 2008. Pp. 742, 15·5 × 23·0 cm. Price £50/€64) (paperback, ISBN 978 2 86883 877 3 (EDP Sciences) & 978 2 271 06744 9 (CNRS Éditions)).

Here is an excellent volume, lying between a textbook and a reference work. It is the third — revised and augmented — edition of a compendium originally triggered by educational activities and centred on tools and methodologies for astrophysical observing. The thread of the book is to be seen in the photon (or the electromagnetic wave) as the main information carrier in astrophysics. Hence collecting, measuring, and quantitatively analysing that information are at the heart of this volume.

Léna has to be praised for producing, roughly every decade and with different collaborators pooling their expertise, a new edition integrating the progress of knowledge as well as the evolution of fields, technologies, and methodologies. Thus in this new edition, adaptive optics, optical interferometry, submillimetric astronomy, exoplanet searches, quest for neutrinos, *etc.*, are tackled, together with more specific data-related fields (signal processing, databases, and so on).

The overall scope of the book is broad and varied, but also detailed, as sketched by the following main headings: 'Fundamentals' (information in astrophysics, terrestrial atmosphere, and space; radiation and photometry; space and time references), 'Collecting information' (telescopes; image shaping and diffraction; radiation receivers; spectral analysis), 'Analysing information' (signal in astronomy; large surveys and virtual observatories). Several appendices and tables conclude the volume ('Fourier transforms'; 'Random variables and processes'; 'Constants and useful values'; 'Space missions'; 'Web links'; 'Acronyms and abbreviations'), as well as a small French–English lexicon, a thematic bibliography, and an index. Exercises are provided. With the exception of a central set of colour pictures, all illustrations and figures are in black and white.

The unavoidable heterogeneity resulting from the many authors is minimal. The legibility of the text, formulae, and graphics is excellent. I spotted only a couple of glitches, possibly remaining from earlier versions. Some of the URLs provided in an appendix will have to be updated (web links remain very volatile indeed), as well as a couple of bibliographical references (*StarGuides* and *StarBriefs 2001* are now *StarGuides* and *StarBriefs Plus* published in 2004). Such 'details', however, do not remove anything substantial from this reference work that should be found on the shelves of every astronomical library. An English version will hopefully soon be available for the benefit of the world-wide community of colleagues and students in astrophysics. — André Heck.

Particle Detectors, 2nd Edition, by C. Grupen & B. Schwartz (Cambridge University Press), 2008. Pp. 651, 25·5 × 18 cm. Price £80/$160 (hardbound; ISBN 978 0 521 84006 4).

The remit of this book is all aspects of particle detectors, specifically those used in nuclear and particle-physics research. It is clearly laid out in text-book style, with a set of problems at the end of each chapter, and solutions at the back. Fully referenced and generously indexed, it also includes five appendices covering fundamental constants, units, relevant material properties, decay schemes, and Monte Carlo generators, which all go to make it a fully rounded reference work.

The initial chapters deal with the theory of particle interactions with matter and thus lead to a discussion of detectors and detector properties. After an historical account of early track detectors the authors deal with modern detectors, which include use of various track techniques, through calorimetry, particle identification, and momentum measurement.

There is ample practical information about real detectors, including the read-out electronics and the effects and remedies for interference and noise, and an eye-opening section on data analysis. This section is worth reading by anyone who has marvelled at the incredibly complex multi-particle track images that we see from CERN and other frontier laboratories. The multistage analysis of a typical high-energy-physics interaction, which involves picking out the relevant information from perhaps 10^8 detector events, and then constructing the sequence of hits and recoils from a whole zoo of particles, puts those easily digested images into their true astonishing context.

Equally fascinating is the section on applications outside particle physics. This includes descriptions of such diverse techniques as medical imaging, radiation treatment, tribology, random-number generation, archaeology, and many more.

Although aimed at graduate students and researchers in particle physics, the text-book-style layout and clear explanations would also make this book valuable to the wider readership of undergraduate physics courses. — Barry Kent.

Numerical Methods in Astrophysics: An Introduction, by P. Bodenheimer, G. P. Laughlin, M. Rózyczka & H.W. Yorke (Taylor & Francis, London), 2007. Pp. 329 + CD ROM, 24·5 × 16 cm. Price £39·99 (hardbound; ISBN 0 750 30883 4).

In recent years, the use of computer simulations and computational techniques has become an almost indispensable tool in theoretical astrophysics. An introduction to the use of numerical techniques is therefore an important aspect in the curriculum of astronomy students. This book fills a gap in the current literature, in providing a general overview of the most important numerical techniques used in astrophysics. The topics covered are wide ranging: from simple partial differential equations to N-body techniques, from Smoothed Particle Hydrodynamics to grid-based hydrodynamics and MHD, from stellar evolution to radiative transfer, encompassing essentially all the methods a theorist might need.

An important characteristic of the book is its emphasis on the physical aspects of the algorithms rather than on the implementation. In fact, the approach used by the authors is to guide the reader to understand the physics behind the various algorithms, rather than simply providing a number of recipes for their implementation. On the other hand, the book is also complemented by a useful CD-ROM, which contains simple examples of codes — which are often the same as those widely used by professionals — implementing the various techniques described.

This book is likely to become an essential reference for undergraduate courses. It is very clearly written and contains a few simple exercises to help the students familiarize themselves with the topic. The book is not intended to give an exhaustive account of all the aspects of the various methods described, and students wishing to get a more advanced knowledge will have to resort to more specialist reviews aimed at describing a single specific technique. Nevertheless, it is highly recommended in order to provide a first introduction to such an important aspect of modern astrophysics. — Giuseppe Lodato.

My Heavens! The Adventures of a Lonely Stargazer Building an Over-the-Top Observatory, by G. Rogers (Springer, Heidelberg), 2008. Pp. 196, 23·5 × 15·5 cm. Price £19·50/$34·95/€26·95 (paperback; ISBN 978 0 387 73781 2).

Gordon Rogers is a well-respected amateur astrophotographer and this book is a personal, perhaps idiosyncratic, account of his journey to better facilities. The author has enough money to indulge his whims and makes no claims to technical expertise, but he has sought advice from a variety of contacts and the main purpose of this book should be to pass on to others what works and what does not. He describes how he worked his way up from a small refractor, an 8-inch Meade, a 16-inch Meade, and finally a 16-inch Ritchey Chrétien, using increasingly more sophisticated, and larger, CCD cameras, software suites, and add-on refractors to mount on the main telescope. During this odyssey he realized the need for a permanent housing and a large part of the book is concerned with the building of his observatory, the decisions that had to be made, and why they were made in the way in which they were. It is here that one starts to see some of the difficulties with the author's self-professed lack of technical expertise. For example, he chose a steel Ash dome, but the local council had insisted that the external finish should be copper. The dome had to be expensively painted with a copper paint. He could have had a fibreglass dome with copper, pre-aged if required, incorporated into the external gel coat. He describes how it was necessary to mount the telescope pillar on three 9-inch-diameter by twenty-seven-feet-deep piles. This massive structure would certainly not be required by most people. Much of the information in this section would be useful to others who hope to construct professional-level observatories with comfortable observing rooms from which to make the observations, but the reader will have to consult several other books before they can make informed decisions with regard to their own site.

Following the construction of the observatory, the author changed his telescope from a 16-inch Meade to a 16-inch RCOS Ritchey Chrétien on a Paramount. Here the author has been let down by his editors. The author incorrectly states that it was the shift from an equatorial mount which caused him to have to move the telescope mount to the north of the position it had taken on the earlier mount. The fact is that both are equatorial mounts and it was the change from fork mount to a German equatorial mount which required the change of location.

The book then covers the opening night and the types of CCD cameras and software packages which the author has used, details of which will have general use and interest. He describes some of the methods that he uses and the foibles of some of the software packages. Here the author resorts to some of his earlier style. Things go wrong with the software, he (and his wife) lose items, and his explanation for this is that the home suffers from a poltergeist! Not mistakes, overwork, or terminal confusion, which beset the rest of us. No, he has a poltergeist.

Chapter 10 should be the show-piece of the book as it contains many of the images which have made this author's reputation. The captions contain details of telescopes, objects, and the colours of the stars, *etc.* Sadly, the publishers have produced the whole lot in monochrome. The next two chapters are written by Americans who, upon reading about the author's own observatory, sought his advice and then had their own comfortable observatories designed and built. Common to all three observatories is that their owners have the funds to make something to a quality, not a price, and as such they serve as a reference frame against which others can judge their requirements. The final part of the book is a useful compilation of sources of help and instrumentation.

In addition to the errors mentioned above, this reviewer noted the following: the text on p. 34 referring to Figures 5·17 and 5·18 is incorrect although the captions to those figures are correct; on p. 90 one reads that Guy Hurst is editor of *Astronomy Magazine*; it should be *The Astronomer*. There are places where the advice offered, such as having a one-piece mould in which to pour concrete for the pillars of the telescope, is expensive and unnecessary.

Should you buy the book? If you wish to have a comfortable and impressive observatory then here are details of three with which to compare your own aspirations. If you just wish to consider buying some of the cameras or software used then you will be better off going to a user group. From this book you will not be able to judge whether there are inherent faults with some of the packages and their reliability.

The author lets us know that he has a gorgeous wife, an indoor pool containing many 12-lb Koi Carp, an attic containing a fully landscaped model-railway system, that he goes on ocean cruises with his astronomical binoculars, that when out dining and meeting a "man of style" he assumes the man will have a beautiful wife and invites them to dinner, and so on. Perhaps a man with all this really does have a poltergeist with which to complete his home! — NORMAN WALKER.

Venus and Mercury and How to Observe Them, by P. Grego (Springer, Heidelberg), 2008. Pp. 280, 23·5 × 17·5 cm. Price £19·50/$34·95/€26·95 (paperback; ISBN 978 0 387 74285 4).

This volume follows the usual format for books in Springer's *Astronomers' Observing Guides* series: that is, a preliminary survey of present knowledge about the planets concerned, followed by advice on how to observe them with the sort of equipment routinely available to the amateur. Peter Grego gives a workmanlike review of current knowledge of Mercury and Venus, dealing with physical dimensions and properties, orbital characteristics, axial tilt and rotation, as well as surface features and geology. Here one might question the timing of this book's appearance, in that both of the inferior planets are currently the objects of ongoing scrutiny by robotic space vehicles, a scrutiny that adds to our knowledge with each passing month. In some respects the volume is already out-of-date in its inability to take account of the new results from the first fly-by of the *Messenger* probe to Mercury and the ever-growing body of information returned by ESA's *Venus Express* mission. Grego and Springer might have been well advised to defer the preparation of this book by a year or so.

The present reviewer sensed some uncertainty over the intended readership of the volume. On the one hand, it is overtly directed at the amateur observer but, on the other, it devotes some 90 pages to a detailed topographical description of surface features revealed only to spacecraft (and, in the case of Venus, by means of radar, rather than visual imaging). Grego's analysis of the types of geological features to be found on each planet is fine, but his Baedeker-like guide to the minutiae of surface geography beyond the reach of Earth-based observation is surely misplaced.

Grego is more secure in the section of the book devoted to observation of the two planets, but even here there are lacunae. Surely a brief review of the history of observation of Mercury and Venus would have enriched the experience of the contemporary observer? Much more could have been done by way of advice on the use of coloured filters as an adjunct to observation. High-resolution webcam imaging of Venus at near-UV wavelengths is one of the most exciting new areas now open to the amateur observer, but Grego passes over it in fewer than ten lines. Moreover, he makes no mention of the opportunities offered by ESA's Venus Amateur Observing Project, which allows suitably equipped amateurs to contribute ground-based support to the *Venus Express* mission and thus do real science.

While this book is in many respects to be welcomed, in that Mercury and Venus have received scant attention in works aimed at the amateur astronomer (at least when compared with the visually more dramatic planets, Mars, Jupiter, and Saturn), it is nevertheless a flawed and rather disappointing volume. It would also have benefitted from a more thorough proof reading to pick up the typos, inaccuracies, and missing lines that are still to be found in its pages. — BILL LEATHERBARROW.

Jupiter and How to Observe It, by John W. McAnally (Springer, Heidelberg), 2008. Pp. 228, 23·5 × 17·5 cm. Price £19·50/$39·95/€32·95 (paperback; ISBN 978 1 85233 750 6).

Jupiter and How to Observe It is a book with a strange and off-putting cover, but one is relieved upon opening it to discover a good, honest, practical guide written by an amateur astronomer who has been analysing Jupiter data for the Association of Lunar & Planetary Observers for several years. The descriptions of the Jovian system, with details of atmospheric structure, magnetosphere, and satellites (which occupy the first part of the book) are all well done. Curiously, Figure 5·5, of Io, is precisely repeated as Figure 6·2, 16 pages later. In the practical section (the second part) and elsewhere there is a pleasant personal touch, and the author freely offers us his personal observing experiences and tips, including how to take good webcam videos and images, how to process them using REGISTAX, and where to send them so that they may be of scientific use.

In describing the analysis of drift-rates there is too little detail: there is just one drift-chart illustrated for two features only, and the famous JUPOS software is mentioned but its precise use is not illustrated. There are many measures of the length of the Great Red Spot given but the reader who follows them in detail will suffer painfully on page 35, where a good table would have been better. There are 525 references, which at first sight looks impressive, but as over 100 of them are to just one book, *The Giant Planet Jupiter*, by John Rogers, the system of citation seems clumsy. Excepting the spacecraft results in the first part, the illustrations are mostly all colour CCD or webcam images taken by amateurs during the last decade. These are all beautifully reproduced, but there are no good examples of full-disc drawings, giving the mistaken impression that visual work is useless. Our experience in the British Astronomical Association Jupiter Section is that the visual observer, through long familiarity with the telescopic appearance, may be the first to spot some new development, such as a bright spot heralding an SEB revival. Hand-drawn strip-charts do briefly surface, but for single dates and limited time intervals only, and the possibility of combining them chronologically is never discussed. Nor have any of the superb colour images been combined to show how to make whole-planet maps. The recording of albedo details upon the satellites is not discussed, but it is now an almost routine matter with modest apertures and webcams.

The publisher's requirement of the authors of this Springer series only to use quite recent illustrations (and to avoid drawings) has meant that a number of the most spectacular Jovian phenomena, such as SEB fades and revivals, and the circulating current associated with South Tropical Disturbances, are mentioned just in passing. Jovian events may inconveniently recur over intervals longer than a decade! The great comet crash of 1994, a unique observational event, receives just one picture and only one sentence: is 1994 considered to be too long ago? It is not McAnally's fault that his Jupiter is much less changeable than the real planet that I have followed through the eyepiece at every opposition since 1973.

Notwithstanding the above critical remarks, this will prove a very useful book for those new to the giant planet. — RICHARD MCKIM.

Stargazers' Almanac 2009 (Hawthorn Press, Stroud), 2008. Pp. 32, 30 × 42 cm. Price £14·99 (ISBN 978 1 903458 84 6).

Located on my office wall, just to the right of my PC through which passes essentially all of the material that makes up this *Magazine*, the *Stargazer's Almanac* is my first point of reference for checking up on what is going on in the night sky throughout the year. The 2009 edition is now available and makes the ideal Christmas present for anyone with an astronomical interest. Designed for the observer in temperate northerly latitudes, each opening of this calendar shows views towards the north and south in a clear manner with appropriately coloured stars graded in size according to magnitude on a blue background; the principal seasonal constellations are shown, as are planets and things of special interest, such as the Perseid radiant (on the chart open on my wall as I write this review. Unfortunately our typical summer weather has again prevented the meteor shower being seen!).

In addition to full instructions on use of the Almanac, the publishers have continued their excellent support for the BAA's Campaign for Dark Skies with notes on light pollution and what to do about it. A special feature this year describes telescopes and Galileo's first astronomical use of them 400 years ago. Recommended. — DAVID STICKLAND.

THESIS ABSTRACTS

STRONG GRAVITATIONAL LENSING AS A PROBE OF GALAXY STRUCTURE

By Edward Shin

On large scales, and *in vacuo*, light travels along geodesics of spacetime, according to Einstein's General Relativity. Light from distant astronomical sources therefore appears to the observer to be 'bent' by the gravitational fields of intervening matter; in particular, multiple images of a background source may appear around a foreground 'lens' galaxy. This *strong lensing* allows astronomers to study the structure of the foreground galaxy, and statistics of lenses allows estimation of cosmological parameters such as the expansion rate of the Universe.

The most popular mass-distribution models of strong lenses that are used in the literature are simple ones that often do not provide good fits to observational data unless the lens galaxy is elliptical and relatively isolated. This thesis introduces and investigates new lens models applicable to spiral galaxies (which constitute a minority of the strong-lens population but have very different lensing properties to ellipticals) and binary galaxies (a natural starting point in the problem of strong lensing by multiple galaxies, which observations indicate is far from uncommon), and also addresses the question of whether so-called anomalous flux ratios — where the fluxes of lensed images cannot be well fitted by a smooth-lens model even though their positions can — is evidence of substructure in galactic dark-matter haloes.

Specifically, the models are a three-component (disc, bulge, and halo) model for an edge-on disc galaxy, a face-on spiral galaxy with logarithmic spiral arms, and a lens consisting of two isothermal spheres (either singular or cored). An edge-on disc-galaxy lens has a signature 'disc triplet' image configuration, the cross-section of which is sensitive to the mass and sharpness of the disc. As more edge-on disc-galaxy lenses are found in future surveys, strong lensing will help determine the prevalence of maximal discs (*i.e.*, discs whose contribution to the rotation curve in the inner parts of the galaxy dominates that of the dark halo).

Whilst the observed strong lenses that have more than five images are complicated systems with more than one mass component, both the edge-on disc galaxy and the double-isothermal-sphere lens, though comparatively simple, can give rise to exotic high-order multiple imaging, the cross-sections for which can be increased by perturbation from the lens environment, as can the maximum possible number of images. The principal effect of spiral arms, though, is to alter the fluxes of images.

Dark substructure such as satellite subhaloes can also affect image fluxes; indeed, the anomalous flux ratios observed in many four-image lenses are often cited as evidence for the dark-matter-dominated satellites predicted by simulations of hierarchical merging of cold dark matter. It is found here that the fraction of four-image systems in which fluxes are perturbed by satellites is critically dependent on the characteristic length scale of the distribution of satellites around the main lens galaxy, and on the total mass in satellites, whilst being only weakly dependent on the satellite mass function. Conclusions are that satellite dwarf galaxies might cause flux anomalies in enough four-image lenses to match the observations, but that it is unlikely that the largest satellite galaxies — bright enough to be observable — are the predominant cause of flux anomalies, as some have suggested in recent years. — *University of Cambridge; accepted 2008 June.*

A full copy of this thesis can be requested from: e.m.shin@gmail.com

Probing the Milky Way Galaxy Through Thick and Thin (Discs and Halo) with the *COrrelation RAdial VELocities* (*CORAVEL*) and the *RAdial Velocity Experiment (RAVE)* Surveys

By George Seabroke

Within the past decade it is being increasingly recognized that many of the clues to the fundamental problem of galaxy formation in the early Universe are contained in the motions and chemical composition of long-lived stars in our Milky Way galaxy. The growing awareness of the importance of the 'fossil record' in the Milky Way galaxy in constraining galaxy-formation theory is reflected by the increasing number of surveys and missions designed to unravel the formation history of the Galaxy. The *RAdial Velocity Experiment* (*RAVE*) is a spectroscopic survey measuring the radial velocities (RVs) and stellar-atmosphere parameters (temperature, metallicity, and surface gravity) using the *Six Degree Field* on the *UK Schmidt Telescope* at the Anglo-Australian Observatory in Australia. The *RAVE* programme started in 2003, obtaining medium-resolution spectra (median $R \sim 7500$) in the calcium triplet (Ca II) region (8410–8795 Å). To date, *RAVE* has observed more than 200 000 stars. This thesis has made major technical contributions to the *RAVE* project and scientifically exploited its data.

The thesis describes how I built the currently-in-use *RAVE* input catalogue from *DENIS* and *2MASS*. This was a critical contribution to *RAVE* because the original input catalogue was almost exhausted. My new input catalogue contains 959 057 stars and has increased *RAVE*'s observing rate to $\sim$ 90 000 stars per annum. Funding permitting, *RAVE* has enough target stars to run until $\sim$ 2016.

I helped to discover two RV errors: a systematic fibre-to-fibre RV offset and a variable RV zero-point offset. I established a correlation between RV zero-point shift and spectrograph temperature change. This discovery and consequent zero-point recovery reduced the variable systematic RV error from $\sim|5|$ to $\sim|1|$ km s^{-1}, increasing the reliability of the 25 274 RVs in the first public *RAVE* data release and all future releases.

Accurate distances to *RAVE* stars have not yet been derived. Instead, *RAVE* RVs can be selected to approximate Galactic space velocities towards the Galactic cardinal directions. In order to interpret these, I analysed actual Galactic space velocities (U,V,W) from the *CORAVEL* survey. I revisited one of the fundamental aspects of disc-galaxy evolution with the *CORAVEL* dwarfs: the age–velocity dispersion relation. Previous fitting of the age–$\sigma_{U,V,W}$ relations with power laws has led to the interpretation of these as evidence for continuous heating of the disc in all directions throughout its lifetime. I used the *CORAVEL* giants to show that structure in the local velocity-distribution function distorts the in-plane (U and V) velocity distributions away from Gaussian so that a dispersion is not an adequate parametrization of their functions. My new result is that a power law is not required by the data for the age–σ_W relation: disc-heating models that saturate after $\sim 4 \cdot 5$ Gyr are equally consistent with observations.

Efficient vertical phase-mixing near the Galactic plane produces apparently symmetric *CORAVEL W* velocity distributions. I searched for stellar streams infalling onto the local Milky Way disc in the *CORAVEL W* distributions and *RAVE* RVs that are sensitive to $W(b < -45^\circ)$. I found that the local volumes of the solar neighbourhood sampled by the *CORAVEL* and *RAVE* surveys are devoid of any vertically coherent streams containing hundreds of stars. This is sufficiently sensitive to allow my *RAVE* sample to rule out the passing of the tidal stream of the disrupting Sagittarius dwarf galaxy through the solar neighbourhood. There are no vertical streams in the *CORAVEL* giants and *RAVE* samples with stellar densities $> \sim 1 \cdot 6 \times 10^4$ and $1 \cdot 5 \times 10^3$ stars kpc^{-3}, respectively, and therefore no evidence for locally enhanced dark matter. — *University of Cambridge; accepted 2008 July*.

A full copy of this thesis can be requested from: g.m.seabroke@open.ac.uk

NOTES

Sets of Reprints of Papers 101–200 of the Spectroscopic Binary Orbits Series

In 1991, when the first hundred papers in the series was completed, sets of reprints of those papers were offered. Analogously, sets comprising nos. 101–200 are now available. Requests should be addressed to Prof. R. F. Griffin at The Observatories, Madingley Road, Cambridge CB3 0HA, UK, or email rfg@ast.cam.ac.uk. The set includes the synopsis paper which is published in this present issue of *The Observatory* and itself carries an index to the objects whose orbits have been determined.

Duplicate Pages in Some Copies of the October Issue

A few copies of the 2008 October issue (No. 1206) have come to light in which duplicate pages have been found. This Note is to alert subscribers, particularly those who intend to have their copies bound, to check their copies carefully. The remedy is, in general, quite simply to remove those offending pages, which is easy to do with the staple binding. However, if more serious problems are revealed, you are invited to contact the Managing Editor, who will supply a 'good' copy.

Here and There

ANOTHER EUROPEAN BUTTER MOUNTAIN?

… the molecular maps made with the Plateau de Beurre mm-wave array. — *ASP Conference Series*, Vol. **365**, p. 339, 2007.

SO LONDON REALLY IS THE CENTRE OF THE UNIVERSE

… e chi nel 1965 ha individuate il rumore del Big Ben "piu' lontando id qualunque galassia". [… and those who in 1965 detected the noise of the Big Ben "farther than any galaxy".] — *Corriere della Sera*, 2008 May 8, p. 9.

ASTRONOMER HAS THE VAPOURS

[Milne] derived a form of the equation describing how radiation propagates through a stellar gas that also carries his name. — *Biographical Encyclopedia of Astronomers* (Springer, 2007), p. 783.

ANCIENT EGYPTIANS PROBABLY KNEW BETTER?

"Maybe it meant something to ancient Egyptians, but we now understand that it's just the moon passing between the earth and the sun" (caption to picture of the Moon in total eclipse) — *Times2*, p. 3, 2008 February 22.

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.

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(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).

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