# THE OBSERVATORY

Vol. 135 | 2015 FEBRUARY | No. 1244

## MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2014 May 9 at $17^h 00^m$
in the Geological Society Lecture Theatre, Burlington House

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

*The President.* The meeting this afternoon will include a presentation and discussion on a very exciting new project. We heard earlier about the sad loss of Colin Pillinger. Colin, I think, would have approved of 'Astonishing Astronomy and Glorious Geophysics'. Before we proceed to the presentation, I would like to invite you all to stand for a few moments in memory of a great servant to astronomy and planetary science. Thank you very much.

The legacy of the Society as we approach our 200th birthday in a few years' time is something we are thinking about carefully. In light of this, we plan to devote some of the reserves of the Society to something we might loosely term a grand vision for outreach. This fulfils both the Society's responsibility as a charity and also considerations about taking forward astronomy and geophysics into the future. The project is provisionally called 'Astonishing Astronomy and Glorious Geophysics'. It's currently being led by Steve Miller but unfortunately he is unavoidably out of the country today. Although we went to great lengths to engineer his presence remotely through Skype, I'm afraid that wasn't possible. I'd like to invite our Deputy Executive Secretary, Robert Massey, to give the presentation on his behalf.

*Dr. R. Massey*. [The speaker described the proposed initiative; further materials and information are available on the RAS website, at www.ras.org.uk/200. The following introduction is taken from a paper circulated at the meeting:

"In 2020, the Royal Astronomical Society will celebrate 200 years of serving its scientific community and the wider public beyond. Our sciences have always attracted the crowds, from the early days of the travelling showmen, through magazines, newspapers, and books, to the media of radio, film, and television. Crowd-sourcing activities, blogs, tweets, and other new media outreach activities show just how inspirational and popular astronomy and geophysics can be. In the years leading up to the RAS Bicentennial, the Royal Astronomical Society will show its deep-seated commitment to the popularization of astronomy and geophysics with a major investment of one million pounds from its reserves in a programme of outreach and engagement projects.

Astonishing Astronomy and Glorious Geophysics is intended to provide the focus for this activity. It will support projects, coming from the grass roots upwards, that extend the reach and appeal of the Society into new areas of society. It specifically aims to reach audiences not always easy to engage with our, or any, sciences. It seeks to form new partnerships with organizations that have had little to do with the Society in the past, whilst mobilizing the extensive network of existing partners that we have built up over the last two centuries. At its foundation, it will draw on the Society's own committed and enthusiastic membership, making use of their talents and their individual and local networks.

Above all, projects will leave a legacy of embedding astronomy and geophysics amongst our fellow citizens and the wider community that will ensure our sciences retain their appeal, inspire young people and old alike, and set the RAS on course for the next 200 years as an outward-looking society that actively supports and underpins its sciences."]

*The President*. Any questions?

*Dr. R. Catchpole*. I just wondered how this overlaps with what STFC has been doing for years?

*Dr. Massey*. We are looking at different communities from those reached by STFC to some extent. They have a different set of criteria. We are also talking with Robin Clegg and his colleagues; we are working with them as well.

*Dr. R. Clegg*. I would just like to say as a Fellow that I support the initiative very strongly and I think that it's a good use of the reserve's money. To make just a couple of points, and I'd be glad to work with you on these: one is to say, I think that working with communities previously unengaged in science and technology will be seriously hard work; finding the community partners and local organizations will be hard but we can do it. Secondly, just to query the title: will it work for the audiences and partners that we want to reach?

*Dr. Massey*. Obviously we have in mind to find a snappy and succinct title. If somebody has a brilliant title for something that encompasses both our sciences I'm sure we'll be interested. [The programme is now called 'RAS200: Sky and Earth'. — Ed.] On your first point, we did talk about exactly those considerations and the idea is that as well as working with large national organizations, we will look at those communities right down to the level of local councils.

*Mr. J. C. Taylor*. As the person who founded the Hanwell Community Observatory 15 years ago I am extremely interested in this. I have two questions: the honorary auditor earlier commented on the 19% female membership in our Society — have you built into your thinking yet any attempt to redress the gender imbalance in astronomy?

*Dr. Massey*. The answer is yes, we have, and we have looked at the partners that would help us with that kind of work. It's not just gender diversity, it's ethnic diversity too. For that reason we are talking to faith groups and so on.

*Mr. Taylor*. My second question is what about engagement with the amateur community?

*Dr. Massey*. That's certainly been part of our discussion as well. It's really about people who can help us deliver the vision, perhaps coming to the stakeholder day and working out how to work with other partners.

*Dr. D. McNally*. Will you also be trying to include the burgeoning number of dark-sky reserves?

*Dr. Massey*. Yes, clearly those are good venues. I've done some work myself in West Yorkshire, for example. We are well connected through people like Steve Owens who was our coordinator in 2009, and also through Dan Hillier, who looks after that work for STFC.

*Professor A. Chapman*. This is of course an historical event — the 200th anniversary. There is an enormous interest in our past, culturally and in other respects. I wondered if there was any planned historical component? This is often a crucial way of getting people, who might be a little frightened of science, more into it, as they are interested in the history.

*Dr. Massey*. I think that's a great idea and if a group comes up with a proposal around that we would like to look at it.

*The President*. Thank you very much, Robert. [Applause.]

I think people are very excited by the recent announcement about the detection of B-modes by *BICEP2*. We are about to hear a little more about that from Dr. Stephen Feeney of Imperial College — '*BICEP2*'s B-mode detection: have we seen (or jumped) the smoking gun of inflation?'

*Dr. S. Feeney*. Unless you live at the North Pole, you will have heard a great deal about a paper presented by the *BICEP2* team about B-mode polarization. If you live at the South Pole, you will probably have heard more than most, but more on that later. At the time of my talk, 53 days after its posting on the arXiv, the paper had received over 300 citations; some three months later, the count is nearing 600. So what's all the fuss about? I'll try to explain what they're looking for, why and how they're looking for it, and what they've found.

Let's start at (nearly) the beginning. After the Big Bang, the Universe was a plasma of photons, protons, and electrons, with the photons and electrons tightly coupled by scattering. As the Universe expanded, its temperature dropped until it was cool enough for the electrons and protons to combine into hydrogen. With no free electrons left to scatter off, the photons were free to travel (more-or-less) unmolested throughout the Universe. And travel they did, red-shifting all the while, to arrive in our telescopes today as the cosmic microwave background (CMB).

Measurements of the intensity of the CMB provide a great insight into our Universe. The discovery of the CMB by Penzias and Wilson dealt a fatal blow to the Steady State theory of our Universe. Later missions, such as the *COBE*, *WMAP*, and *Planck* satellites, revealed that the CMB temperature is the same across the sky to 1 part in 100 000 (implying a phase of exponential expansion — 'inflation' — in the very early Universe; more on that later), and have measured the tiny fluctuations in temperature (which are also predicted by inflation) to determine the makeup of our Universe: how much dark matter, dark energy, and normal matter there is.

That is not all we can extract from the CMB though! The CMB is partially linearly polarized, and the particular patterns of polarization imprinted upon it contain even more precious information about our Universe. To understand why the CMB is polarized, one must imagine an electron at the time the photons last scattered off it. As light is a transverse wave, when an unpolarized ray of light hits an electron and changes direction the electric field can't oscillate in the new direction of travel: the light therefore becomes partially polarized. If the electron sees an isotropic radiation field, that is, if it sees the same temperature radiation coming at it from every angle, this effect averages out. If, however, the electron sees different-temperature radiation coming at it from different angles — and, in particular, if the extrema in radiation temperature are separated by 90 degrees: a quadrupole — then there is net polarization.

Do we expect electrons in the last scattering surface to see quadrupolar radiation? The answer is yes, if some physical process sets up perturbations (or waves) in either the contents of the Universe or the Universe itself. Consider a density wave in the early Universe: a plane wave where the peaks and troughs correspond to extrema in radiation temperature (and, indeed, dark and normal matter density: these are the small perturbations that eventually grow into the clusters and filaments of galaxies we see today). An electron in, say, a trough will see different temperature radiation coming from the directions of the peaks compared to along the trough. Hey presto: a quadrupole! Another potential source is gravitational waves. These waves squeeze the fabric of space–time in one direction and stretch it in the direction perpendicular, blue- and red-shifting radiation to create a quadrupolar variation. We can distinguish the two types of waves by looking at the patterns of polarization they produce in the CMB. The CMB polarization can be broken down into two fields, namely (curl-free) E-mode patterns and (divergence-free) B-mode patterns. Crucially, density waves do not produce B modes, but gravitational waves do.

Detecting B modes in the CMB is therefore evidence for gravitational waves, but why should we expect gravitational waves to be present in the early Universe? Because of inflation. Inflation's accelerated expansion is so violent that space–time itself is stressed, producing a characteristic spectrum of gravitational waves some $10^{-32}$ seconds after the Big Bang! These waves, in turn, produce CMB B modes whose angular scale peaks at about one degree on the sky. This is the so-called "smoking gun" of inflation: though other theories can explain the CMB's overall uniform temperature and tiny fluctuations, nothing else predicts this distinctive B-mode signal.

There is, of course, a catch: the B modes' amplitude can be very small indeed. The CMB polarization signal is already some four orders of magnitude weaker than the temperature signal, but the B modes are further suppressed: the lower the energy at which inflation took place, the lower the B modes' amplitude. This amplitude is parameterized by the quantity $r$, which defines the relative strengths of the density and gravitational waves. If $r$ is around 10% the B-mode power spectrum is approximately $10^5$ times smaller than the temperature, requiring exquisite experimental control to measure. It gets worse: theoretically $r$ can be arbitrarily small, easily small enough to produce B modes beyond detection.

Enter *BICEP2*. *BICEP2* is an extremely sensitive microwave telescope situated at the South Pole. Why is it there? In the words of John Kovac (one of *BICEP2*'s principal investigators), "The South Pole is the closest you can get to space and still be on the ground. It's one of the driest and clearest locations on Earth." Placing the telescope on the ground means you can calibrate, fix, and upgrade your telescope easily (well, as easily as you can do anything when it's –50° C). Placing it at the South Pole means there's little atmosphere between you and space, and what little atmosphere there is, is (somewhat counter-intuitively) well behaved. Furthermore, at the South Pole they're able to observe a 'clean' patch of the CMB (note the quotes) — *i.e.*, part of our Galaxy where its foreground emissions are low — all year round.

After three seasons of observations, the *BICEP2* team have beaten down the noise in their CMB patch to an astonishing 87 nano-Kelvin per square degree, and peaking through the remaining noise is found the tell-tale patterns of CMB B modes. Converting their maps into power spectra, they find $r = 0{\cdot}2$ at the $7\sigma$ level — an extraordinarily significant detection! Thanks to their beautiful experimental design and ground-based nature, they are able to conduct a huge range of checks for systematic errors in their instrument and analysis pipeline, and thus can be confident that the signal is 'on the sky'.

Should we therefore be getting very excited? Have we found the smoking gun of inflation? Can we get carried away about the fortuitously large value of $r$; the potential to subject inflation to further analysis by measuring not only the amplitude of the signal but how it varies with scale; or the fact that *Planck* has, supposedly, already ruled out this value of $r$ (as gravitational waves also boost the temperature power spectrum)? Not yet, unfortunately, as, though the signal is most likely on the sky, there is not enough proof that it is primordial in nature and not due to foregrounds such as polarized dust emission.

The main issue is that *BICEP2* has observed the sky only at one frequency. This frequency was chosen as the foregrounds there were *predicted* to be small, but the predictions are not based on observations of polarized foregrounds. Until the polarized foregrounds are themselves measured we can't be sure that the B modes are due to gravitational waves. Happily, the foregrounds can be picked out from the CMB as their amplitudes change differently as a function of frequency, but we have yet to make those observations. To confirm that the B modes are primordial we therefore need to observe the sky at multiple frequencies, and ideally with different experiments (to make doubly sure there aren't any systematic errors in the analysis) and in different regions of the sky (to make sure we're not looking at a weird bit of Universe!). I hope we won't have long to wait — a plethora of upcoming CMB experiments on the ground, in the air, and in space hope to have something to say on the matter starting from this autumn, but until then we must be patient, and remember that extraordinary claims require extraordinary proof.

*The President*. That was an extremely clear and interesting talk. We have some time for questions or comments.

*Rev. G. Barber*. Would you like to comment on the report that there's a Galactic dust lane that appears to go through the field of view of *BICEP2* and could also contribute to the polarization?

*Dr. Feeney*. Yes, that was flagged in a paper a couple of weeks ago. That loop of sky has been identified through radio observations as having anomalous temperature emission. It goes right through *BICEP2*'s region of sky. The paper was concentrating on a different loop and they were obviously working on it when the *BICEP2* work was published. They immediately flagged their concern but it does need a lot more work in order to determine whether or not it is just a temperature feature or if it has a significant effect on the polarization. It's concerning that there's something that goes straight through the middle of the *BICEP2* patch but we need follow-up data to determine the full effects.

*Mr. C. Arena*. If the value of $r$ found from this experiment is confirmed, people could put a number of constraints on the possible models of inflation. Would that leave just a few models of inflation?

*Dr. Feeney*. I think theory finds a way. [Laughter.] You might kill off a few models but there will always be more — there is always wiggle room. Essentially what I'm saying is that there is a finite amount of information that we can extract about the inflationary potential. I think the really interesting part is if the tension with *Planck* is real, because then you need more than just a simple model to explain it.

*Professor D. Lynden-Bell*. Is there any correlation between the temperature map and the polarization map?

*Dr. Feeney*. There is correlation between the temperature and the E-polarization but not between temperature and B-polarization; or at least there shouldn't be.

*Professor Lynden-Bell*. I know there shouldn't be, but *is* there?

*Dr. Feeney*. I believe that the way they have used the *T* and B leads to it not being in any of the maps. You can use this as a check for systematics.

*Dr. S. Serjeant*. Can you say anything about the jack-knife tests that they've done?

*Dr. Feeney*. Yes, they have done a whole bunch of jack-knife tests. The jack-knife is just taking combinations of your data where you get rid of the signal; nothing enormously anomalous has been flagged in those. Some people say that they are suspiciously good, but that's more of a subjective statement. They have done a whole sweep of systematic checks that look more or less okay.

*Dr. S. Mitton*. That was an excellent talk and I'd like to go through it again. Is there anybody here who can say when it's likely to be on the RAS website?

*Dr. Massey*. We expect that by the autumn we'll be putting these up routinely.

*Dr. Catchpole*. We know that we're going to wait until October for the *Planck* results. Is anybody likely to come out with results before then?

*Dr. Feeney*. There was an article in *Nature* recently where one of the lead authors of *SPTpol* put his head on the line and said maybe something would be out in the summer. It's clearly in a lot of people's interest to get this out but it's also obvious that we want to do it right. There are two competing forces there.

*The President*. Perhaps we can all thank Stephen again. [Applause.]

I have a few announcements before the meeting closes. I'm pleased to make the announcement for the 2013 thesis prizes. The Michael Penston Prize has been awarded to Dr. Joseph Elliston of Queen Mary University of London for his thesis entitled 'Observable predictions of generalised inflationary scenarios'. The runner-up is Dr. Emma Chapman of University College London. The Keith Runcorn Prize has been award to Dr. Richard Walters, originally at the University of Oxford and now at the University of Leeds, for his thesis entitled 'Geodetic observation and modelling of continental deformation in Iran and Turkey'. The runner-up is Dr. Alex Chartier, originally at the University of Bath and now at Johns Hopkins University.

May I remind you of the drinks reception in the RAS library immediately following this meeting. The next A&G meeting will be on Friday, 2014 October 10.

# A BRIGHT GIANT AND A GIANT DISCOVERED IN THE BINARY V1375 ORIONIS

*By N. Hauck*
*Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne e. V. (BAV)*

*and*

*R. F. Griffin*
*Cambridge Observatories*

The bright eclipsing system V1375 Ori (HD 36457) has been investigated by differential photometry followed by spectroscopy. Modelling of the photometric data in the light of the distance known from the parallax revealed a bright giant (early K type) accompanied by a hotter component that appears to be a normal (probably F-type) giant. Radial-velocity measurements have shown an eccentric orbit having a line of apsides that is extraordinarily accurately aligned with our line of sight. The joint light-curve–radial-velocity solution delivers radii and masses of both components at nearly 1% accuracy: 41·6 $R_{\odot}$ and a surprisingly low 2·5 $M_{\odot}$ for the bright giant, and 5·8 $R_{\odot}$ and 2·2 $M_{\odot}$ for the normal giant.

A solution is given for the binary system V1375 Ori (HD 36457), located in Orion, about half-way between δ Ori (the right-hand star in the Belt, for northern observers) and the Orion Nebula, and almost bright enough to qualify for the *Bright Star Catalogue*. Though brighter than the seventh magnitude, it had escaped detection as an eclipsing binary until its discovery in the *Hipparcos* 'epoch photometry'; that discovery was evidently regarded as something of a *coup*, as the star features in a small list of "probable eclipsing binaries" in the initial semi-popular *exposé*[1] of the *Hipparcos* project[2] by its leader, Perryman. It was found to be faint on three occasions by *Hipparcos*, and was correctly presumed to be an eclipsing system. The variable-star designation V1375 Ori was assigned to it[3], with the type tentatively given as "E:", *i.e.*, 'eclipsing'. The basic information about the eclipses has been provided by Otero[4], especially a first period of 146·33 days; the out-of-eclipse *V* magnitude is given as $6^{m}\cdot66$. The spectrum of the primary star, G5 in the *Henry Draper Catalogue*[5], has been re-classified much more recently by Houk & Swift[6] as K0/1 III. Nothing has been said in the literature about the nature of the secondary star.

The object features in a recent paper by Tetzlaff *et al.*[7] which presents *A catalogue of young runaway Hipparcos stars within 3 kpc from the Sun*; it is not noted there as being a binary system, but its mass is given as 6·6 $M_{\odot}$ and its 'MK spectral type' is listed as G5 — which is the *HD* type, while the real MK type given by Houk & Swift[6] is ignored; so the veracity of the items that we can check does not augur well for the reliability of the age of 55 million years that is also given for the system. Its 'runaway' nature is not obvious from any large space motion, either in the radial or transverse direction, its annual proper motion being only about 0″·004.

The first author evaluated existing photometry for V1375 Ori in the *V* pass-band from *ASAS–3*[8] and *Hipparcos*[2] in the light of the distance given by the revised[9]

*Hipparcos* parallax measurement, which is 474 pc with 1-σ limits of 361–690 pc. The corresponding distance modulus is about $8{\cdot}4^{+0{\cdot}8}_{-0{\cdot}6}$ magnitudes, yielding with the *Hipparcos*-derived *V* magnitude of $6^{m}{\cdot}71$ an $M_V$ of about $-1^{m}{\cdot}7$ with the same (considerable) 1-σ uncertainty. The $(B-V)$ colour index, transformed in *Simbad* from *Tycho* photometry, is $1^{m}{\cdot}32$, somewhat redder than would ordinarily correspond to the spectral type; from a distance of half a kiloparsec in the Orion region, there could well be appreciable reddening, implying also an increase in the luminosity derived from the apparent magnitude, as quantified below. It was therefore clear that the normal giant of the MK classification[6] had to be replaced by a larger 'bright giant' (luminosity class II).

Clarifying new photometry has been collected in pass-bands *B* and *U* with an internet-controlled 17-inch CDK-designed reflecting telescope[10] with a CCD camera in Mayhill, New Mexico, USA. To reduce scintillation noise from such a bright system all new photometric data in *B* have been averaged from seven images each. Exposure times have been 5s and 180s in *B* and *U*, respectively. The comparison star was HD 36710, located 32′ from the variable, and the check star was HD 36696, 27′ away.

A $T_{\rm eff}$ of 4500 ± 200 K has been derived for the primary star from Fig. 3.12 of Kaler[11], who gives spectral-type $-T_{\rm eff}-$luminosity-class relationships. Moreover, the same $T_{\rm eff}$ has been derived by Oudmaijer[12] from the IR flux distribution known from the *IRAS* mission. The identification of the primary minimum as a total eclipse allowed the calculation of the interstellar absorption $A_V$ from the difference between the $(B-V)$ colour index of $1^{m}{\cdot}41$ observed at primary minimum (when the cool star is observed alone) and the theoretical value of $1^{m}{\cdot}19$ obtained from Table III of Flower[13] for 4500 K. An $A_V$ of $0^{m}{\cdot}69$ has been adopted on the basis of the implied colour excess of $0^{m}{\cdot}22$ multiplied by the *R* factor of 3·14 recommended by Schultz *et al.*[14].

Upon the recommendation of the first author, and recognizing the interest of HD 36457 as well as the lack of a spectroscopic orbit for it, the co-author placed it on the radial-velocity observing programme of the Cambridge *Coravel* in 2013 October and had the opportunity to see it round just one 146-day orbital cycle before the close of the observing season. It proved to be quite a pleasure to observe, being bright and giving radial-velocity traces with a very fine dip, about 30% of the 'continuum' deep. It is unusual for the co-author to present an orbit on the basis of only one season's observations, although it is very common for an orbit to be observed only for one cycle when the cycle length is many years. The only reasons to observe a short-period star for a long time are to improve the precision of the orbital period (but in the present case that had already been done for us photometrically), and to improve the uniformity of the phase distribution of the observations (but that is not too bad as it stands). In an observing season that, despite reports of flooding and other weather-related problems in England, was unusually good, velocities were obtained for HD 36457 on 53 nights.

No details have been reported in the literature about the secondary star, and the co-author somehow failed for a long time to trouble himself sufficiently over that issue. A secondary that was too faint, and/or of too early a type to cross-correlate with the K2 mask in the *Coravel* spectrometer, would not register in the radial-velocity traces. A wide scan made with a short integration at one of the early observations did not reveal the weak secondary, and thereafter the secondary dip was beyond the range of the scan except when it was blended with the primary dip — in which case the trace could appear to be sloped between the sections of apparent continuum on either side of the dip, but any

TABLE I

*Radial-velocity observations of V1375 Orionis (HD 36457)*

*All the observations were made with the Cambridge Coravel*

| *Date (UT)* | *MJD* | *Velocity* Prim. $km\,s^{-1}$ | *Velocity* Sec. $km\,s^{-1}$ | *Phase* | *(O – C)* Prim. $km\,s^{-1}$ | *(O – C)* Sec. $km\,s^{-1}$ |
|---|---|---|---|---|---|---|
| 2013 Oct. 17·17 | 56582·17 | +61·4 | — | 0·236 | –0·1 | — |
| 24·17 | 589·17 | +57·6 | — | ·284 | 0·0 | — |
| 29·14 | 594·14 | +54·6 | — | ·318 | +0·5 | — |
| 30·19 | 595·19 | +53·3 | — | ·325 | 0·0 | — |
| Nov. 8·13 | 604·13 | +46·1 | — | ·387 | +0·3 | — |
| 9·11 | 605·11 | +45·2 | — | ·393 | +0·2 | — |
| 13·12 | 609·12 | +41·5 | — | ·421 | +0·2 | — |
| 15·11 | 611·11 | +39·4 | — | ·434 | –0·1 | — |
| 19·11 | 615·11 | +35·1 | — | ·462 | –0·7 | — |
| 20·05 | 616·05 | +34·3 | — | ·468 | –0·6 | — |
| 30·09 | 626·09 | +25·4 | — | ·537 | –0·2 | — |
| Dec. 5·05 | 631·05 | +20·9 | — | ·571 | –0·1 | — |
| 20·03 | 646·03 | +8·4 | — | ·673 | +0·3 | — |
| 22·99 | 648·99 | +6·1 | — | ·693 | +0·2 | — |
| 27·98 | 653·98 | +2·8 | — | ·727 | +0·2 | — |
| 28·95 | 654·95 | +2·2 | — | ·734 | +0·2 | — |
| 2014 Jan. 5·00 | 56662·00 | –1·3 | — | 0·782 | –0·2 | — |
| 9·98 | 666·98 | –1·7 | — | ·816 | +0·1 | — |
| 11·93 | 668·93 | –1·4 | — | ·829 | +0·2 | — |
| 17·95 | 674·95 | +0·6 | — | ·871 | –0·2 | — |
| 19·92 | 676·92 | +2·1 | — | ·884 | –0·3 | — |
| 20·88 | 677·88 | +2·9 | — | ·891 | –0·4 | — |
| 26·98 | 683·98 | +11·1 | — | ·932 | –0·1 | — |
| 27·87 | 684·87 | +12·9 | — | ·938 | +0·2 | — |
| Feb. 1·81 | 689·81 | +22·3 | — | ·972 | +0·2 | — |
| 2·89 | 690·89 | +24·7 | — | ·980 | +0·3 | — |
| 3·88 | 691·88 | +26·6 | — | ·986 | +0·1 | — |
| 4·82 | 692·82 | +28·6 | — | ·993 | 0·0 | — |
| 5·95 | 693·95 | +30·8 | — | 1·000 | –0·2 | — |
| 9·90 | 697·90 | +39·3 | — | ·027 | –0·2 | — |
| 11·86 | 699·86 | +43·6 | — | ·041 | +0·2 | — |
| 12·85 | 700·85 | +45·5 | +13·7 | ·048 | +0·2 | –0·6 |
| 13·86 | 701·86 | +47·1 | +12·9 | ·055 | 0·0 | +0·6 |
| 15·90 | 703·90 | +50·5 | +8·8 | ·068 | –0·1 | +0·4 |
| 18·84 | 706·84 | +55·2 | — | ·089 | +0·3 | — |
| 20·82 | 708·82 | +57·3 | +1·0 | ·102 | +0·1 | 0·0 |
| 21·83 | 709·83 | +58·3 | +0·1 | ·109 | 0·0 | +0·3 |
| 22·88 | 710·88 | +59·0 | –1·1 | ·116 | –0·2 | +0·1 |
| 25·81 | 713·81 | +61·4 | –2·6 | ·136 | +0·1 | +1·0 |
| 26·80 | 714·80 | +61·7 | –3·3 | ·143 | –0·2 | +0·9 |
| 27·83 | 715·83 | +62·2 | –5·1 | ·150 | –0·1 | –0·4 |
| Mar. 1·84 | 717·84 | +62·7 | –5·6 | ·164 | –0·2 | –0·3 |
| 3·80 | 719·80 | +63·1 | –6·3 | ·177 | –0·1 | –0·6 |
| 4·82 | 720·82 | +63·4 | –5·4 | ·184 | +0·2 | +0·3 |
| 7·83 | 723·83 | +62·8 | –4·0 | ·205 | –0·1 | +1·4 |
| 8·85 | 724·85 | +62·5 | –4·8 | ·212 | –0·2 | +0·3 |
| 11·83 | 727·83 | +61·7 | –4·5 | ·232 | 0·0 | –0·5 |
| 12·84 | 728·84 | +61·3 | –4·2 | ·239 | 0·0 | –0·6 |
| 13·80 | 729·80 | +60·9 | –4·0 | ·246 | 0·0 | –0·9 |
| 15·80 | 731·80 | +60·3 | –2·5 | ·259 | +0·5 | –0·6 |
| 16·81 | 732·81 | +59·2 | –1·6 | ·266 | –0·1 | –0·3 |
| 19·81 | 735·81 | +57·5 | +0·7 | ·287 | +0·1 | –0·1 |
| 21·81 | 737·81 | +55·9 | +2·1 | ·300 | –0·1 | –0·2 |

such slope was taken out in the routine course of the reduction procedure. It was not until the second observed conjunction that the secondary forced itself upon the observer's attention by the unacceptable inequality of the supposed 'continuum' heights on the two sides of the dip, and thereafter it (as well as the primary) has been assiduously observed. A double-lined trace showing the very unequal dips appears here as Fig. 1. The absurd phase distribution of the 21 velocities that are now available for the secondary does not actually much impair the determination of the orbital elements, since they largely depend upon the considerably more accurate velocities obtained for the primary star; the quantity for which the secondary's velocities most need to be relied upon is the amplitude of the velocity variations of the secondary component itself.

All the radial velocities are set out in Table I; they have been solved with a weighting of 0·15 for the secondary to bring the variances for the two components approximately into equality. The period has been imposed from the first author's photometry. The resulting orbit is plotted in Fig. 2 and the elements are given in Table II.

TABLE II

*Spectroscopic orbital elements for the binary V1375 Orionis (HD 36457)*

| | | | | | |
|---|---|---|---|---|---|
| $P$ | = | 146·301 days (fixed) | $(T)_1$ | = | MJD 56254·98 ± 0·15 |
| $\gamma$ | = | +30·68 ± 0·04 km s$^{-1}$ | $a_1 \sin i$ | = | 63·97 ± 0·10 Gm |
| $K_1$ | = | 32·51 ± 0·05 km s$^{-1}$ | $a_2 \sin i$ | = | 71·51 ± 0·33 Gm |
| $K_2$ | = | 36·34 ± 0·17 km s$^{-1}$ | $f(m_1)$ | = | 0·4886 ± 0·0023 $M_\odot$ |
| $q$ | = | 1·118 ± 0·005 (= $m_1/m_2$) | $f(m_2)$ | = | 0·682 ± 0·010 $M_\odot$ |
| $e$ | = | 0·2076 ± 0·0014 | $m_1 \sin^3 i$ | = | 2·450 ± 0·026 $M_\odot$ |
| $\omega$ | = | 270·3 ± 0·4 degrees | $m_2 \sin^3 i$ | = | 2·191 ± 0·013 $M_\odot$ |

R.m.s. residual (unit weight) = 0·23 km s$^{-1}$

The simple fact that the system exhibits eclipses demonstrates that the orbital inclination must not be far from 90°, and therefore the quantities $\sin i$ and even $\sin^3 i$ may be taken as unity to a first approximation.

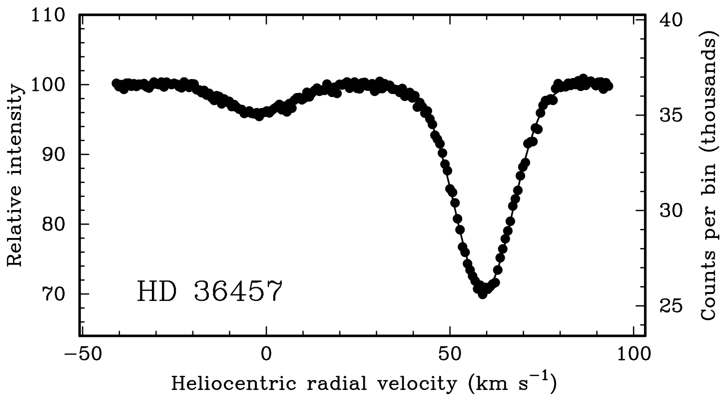


FIG. 1

Radial-velocity trace of HD 36457, obtained with the Cambridge *Coravel* on 2014 February 22.

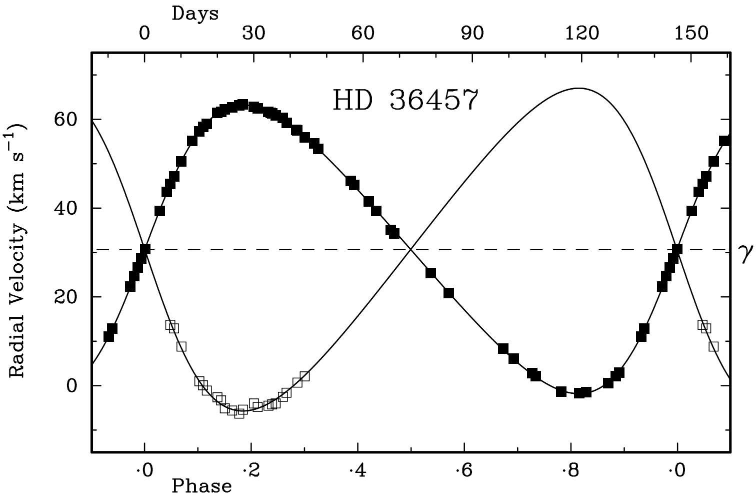


FIG. 2

The observed radial velocities of HD 36457 plotted as a function of phase, with the velocity curves corresponding to the adopted orbital elements drawn through them. Filled symbols represent velocities of the primary component, open ones the secondary, which was recognized only upon its emergence from blending with the primary after the conjunction near phase zero.

An extraordinary feature of the orbital elements is the closeness of the longitude of periastron to 270°, which implies that (despite the considerable orbital eccentricity) the conjunctions are exactly 180° of orbital phase apart. The timings would not reveal the non-circularity of the orbit, although the difference in the durations of the eclipses might do so. Another interesting feature is the smallness of the disparity in the masses of the components, which is only about 10%. The high luminosity of the system, and the generous depth of the dip given in radial-velocity traces by the primary, practically guarantee that that star has reached in its evolution more or less the top of the giant branch of the H–R diagram. The secondary is likely also to be on that sequence, but considerably lower down on it, since it is only a little less massive than the primary and must also be a late-type star (otherwise it would not register in the *Coravel* traces). The mean equivalent widths of the two dips in the radial-velocity traces are 5·8 and 0·80 km s$^{-1}$, a ratio of about 7·2 or in stellar-magnitude terms about $2^{m}$·15. As a star climbs the giant branch its spectrum becomes progressively later in type; dip depths increase towards later types in the range likely to be of relevance, so the actual difference between the magnitudes of the components — if indeed they are of the general nature that is being suggested here — would be considerably smaller, perhaps $1^{m}$·5. Such an *ex cathedra* guess or assertion may seem less than scientific, but the complexities and uncertainties involved in modelling an isochrone and assessing the equivalent widths of the dips to be expected for stars at different points along it are such as to make such an exercise liable to be unproductive.

The first author has taken the orbital elements listed above together with the radial-velocity data and used them as input for the *Binary Maker 3* (*BM3*) software[15]. By simultaneous fitting of those data with 45 new data from differential photometry in the $B$ pass-band and 43 old *ASAS*/*Hipparcos* data in $V$, a convincing joint light-curve–radial-velocity solution for a single set of physical parameters has been found. The light-curves computed from the final solution are shown in Figs. 3 and 4. In a first step a single data point from *Hipparcos* was successfully aligned with three new data points in the $B$ pass-band. All four points are located in the ingress phase of the primary minimum and have residuals of less than 1 milli-magnitude from the computed light curve. The long time axis of more than 26 years allowed a precise determination of the orbital period. The longitude of periastron changed slightly, from 270°·3 ± 0°·4 to 270°·0 ± 0°·4. The joint value of $\omega$ of 270°·15 ± 0°·25 is consistent with the photometric epoch that was determined from a recent primary minimum which was only 0·07 days before the co-author's calculated periastron time $T$ shown in Table II above. The chance of finding an eccentric orbit to have an $\omega$ within 0°·15 of 270° or 90° is obviously 0°·6/360, *i.e.*, only 1 in 600. The r.m.s. deviations of the data points from the computed light-curves are 4 and 9 milli-magnitudes in $V$ and $B$, respectively. The data obtained in $U$ are not shown; however, they are consistent with the final solution, and have been useful for adjusting the $T_{\rm eff}$ of the secondary component. The magnitudes of the primary star are observed directly during total eclipse; those of the secondary can be inferred from the light loss during eclipse with respect to the mean out-of-eclipse magnitudes. The results from photometry and the joint light-curve–spectroscopic solution are presented in Tables III and IV.

TABLE III

*Parameters of the binary system V1375 Ori (HD 36457)*

| | | | |
|---|---|---|---|
| Epoch mid primary minimum (HMJD) | 56254·91 ± 0·04 | Eccentricity $e$ | 0·2076 ± 0·0014 |
| Period $P$ (days) | 146·301 ± 0·003 | Longitude of periastron $\omega$ | 270·15 ± 0·25 |
| Mean maximum light $V/B$ | 6m·66/8m·00 | Inclination $i$ (degrees) | 84·4 ± 0·3 |
| Depth primary minimum $V/B/U$ | 0m·15/0m· 22/0m·32 | Semi-major axis $a_1$ (Gm) | 64·28 ± 0·11 |
| Depth secondary minimum $V/B$ | 0m·025/0m·025 | Semi-major axis $a_2$ (Gm) | 71·85 ± 0·33 |
| Duration of primary minimum (days) | 8·19 | Semi-major axis $a$ (AU) | 0·9100 ± 0·0024 |
| Duration of total eclipse (days) | 5·56 | Semi-major axis $a$ ($R_\odot$) | 195·5 ± 0·5 |
| Duration of secondary minimum (days) | 11·12 | Distance (pc) | 363 ± 34 |

TABLE IV

*Parameters of the components of the binary system V1375 Ori (HD 36457)*

| *Parameter* | *Primary* | *Secondary* |
|---|---|---|
| Spectral type | K0/1 II | F4 III (estimated) |
| $T_{\rm eff}$ (K) | 4500 ± 200 | 6350 ± 300 |
| Mean radius ($R_\odot$) | 41·6 ± 0·5 | 5·85 ± 0·07 |
| Bolometric luminosity (log $L_\odot$) | 2·80 ± 0·08 | 1·70 ± 0·09 |
| Absolute magnitude ($M_V$) | –1·68 ± 0·19 | +0·49 ± 0·20 |
| Apparent $V$ magnitude ($m_V$) | 6·81 ± 0·02 | 8·88 ± 0·02 |
| Apparent $B$ magnitude ($m_B$) | 8·22 ± 0·02 | 9·84 ± 0·02 |
| Mass ($M_\odot$) | 2·485 ± 0·027 | 2·223 ± 0·032 |

The distance implied by our results is 363 ± 34 pc, which is just inside the 1-σ range derived from the *Hipparcos* parallax.

The components' $\Delta m_V$ of 1m·62 shown in Table IV is in satisfactory accord with the 1m·5 that was roughly estimated from the relative areas of the 'dips' in the radial-velocity traces. The $(B - V)$ colour index of the secondary component is seen from the subtracted magnitudes in Table IV to be 0m·96, or 0m·74 when

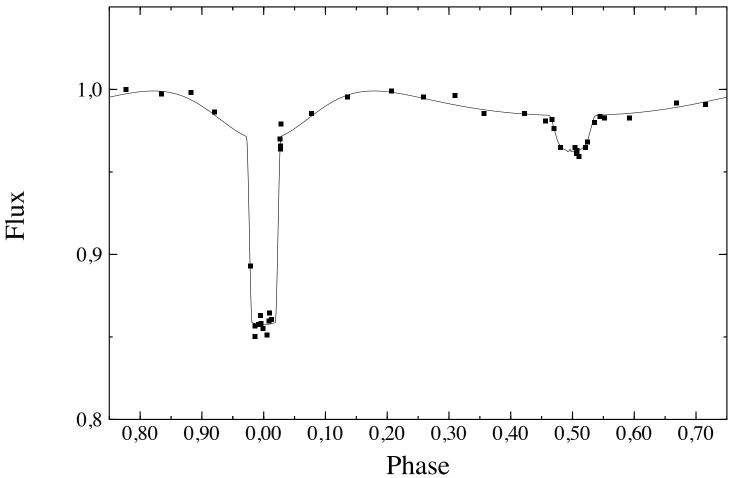


FIG. 3

Computed light-curve and *ASAS*/*Hipparcos* data for HD 36457 in pass-band *V* (550 nm).

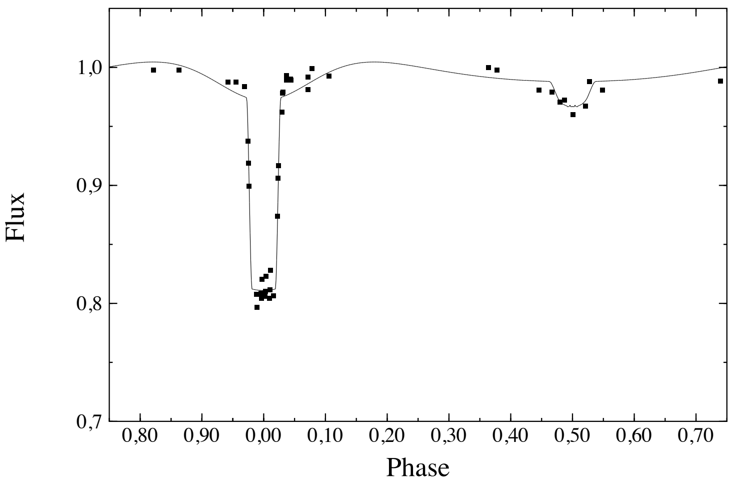


FIG. 4

Computed light-curve and new data for HD 36457 in pass-band *B* (440 nm).

corrected for the colour excess of $0^{m}\cdot22$ derived above. That would indicate for the secondary a significantly lower $T_{\mathrm{eff}}$ (about 5440 K according to Table 3 of Flower[13]) than we show in Table IV. The discrepancy might be explicable in terms of dust surrounding and reddening the secondary component. However, our calculated $(B-V)$ colour index of the secondary star appears quite normal against, *e.g.*, HD 36973 (spectral type F3 III, $(B-V)$ $0^{m}\cdot965$, distance 140 pc) or HD 136346 (spectral type F3 V, $(B - V)$ 0$^{m}$·79, distance 140 pc) (data taken from Anderson & Francis[16]). Hence the introduction of such an additional feature into our model of the binary system might be unnecessary.

Surprisingly, the mass (2·5 $M_{\odot}$) of the bright giant is significantly less than the 4–5 $M_{\odot}$ expected for our derived $T_{eff}$ and luminosity at a normal solar metallicity of $Z = 0{\cdot}014$, according to the modern 'Geneva group' models of Ekström *et al.*[17]. At the same time, the mass is higher than the 1·7–2·0 $M_{\odot}$ for $Z = 0{\cdot}002$ predicted by similar stellar models by Georgy *et al.*[18]. Hence an intermediate sub-solar metallicity might be able to explain our result, but a direct determination of the metallicity of the bright giant would be necessary to clarify the situation. Interesting in this regard is the fact that another seemingly under-massive bright giant (3·14 ± 0·17 $M_{\odot}$ for a G6 II of similar luminosity to V1375 Ori, having a normal [Fe/H] value of –0·04) has already been found in HR 2554 (V415 Car) by Brown *et al.*[19].

Fortunately, in our binary the secondary component is a useful indicator of the age of the system. According to the Geneva model of Ekström *et al.*[17] for solar metallicity ($Z = 0{\cdot}014$), we can expect for the actual secondary mass of about 2·2 $M_{\odot}$ and modelled $T_{eff}$ of 6350 K an age somewhere in the middle of the range 690–1320 Myr given for masses of 2·5 and 2·0 $M_{\odot}$, respectively. On the other hand, for our primary component the model ends at the end of the early asymptotic giant branch (AGB) at a maximum age of 700 Myr for a minimal initial mass of 2·5 $M_{\odot}$. Thereafter, it should follow the expected evolutionary track after the early AGB, *i.e.*, a further increase in luminosity followed by an increase in $T_{eff}$. Hence our old bright giant should then, having the same age as the secondary star, be more or less consistent with the extrapolation of that stellar model at a normal solar metallicity of $Z = 0{\cdot}014$.

*Acknowledgements*

This research has made use of the *Simbad* and *Vizier* databases operated at the Centre de Données Astronomiques, Strasbourg, France. The database of the *All-Sky Automated Survey* (*ASAS–3*) has also been used. We are grateful to an anonymous referee for helpful comments.

## *References*

(1) M. A. C. Perryman, *Sky & Tel.*, **97**, no. 6, 40, 1999.
(2) *The Hipparcos and Tycho Catalogues* (ESA SP–1200) (ESA, Noordwijk), 1997.
(3) E. V. Kazarovets *et al.*, *IBVS*, no. 4659, 1999.
(4) S. A. Otero, *IBVS*, no. 5532, 2004.
(5) A. J. Cannon & E. C. Pickering, *HA*, **92**, 123, 1918.
(6) N. Houk & C. Swift, *Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 5, Declinations –12°·0 to +5°·0* (Univ. of Michigan, Ann Arbor), 1999, p. 59.
(7) N. Tetzlaff, R. Neuhauser & M. M. Holme, *MNRAS*, **410**, 190, 2011.
(8) G. Pojmanski, *Acta Astr.*, **52**, 397, 2002.
(9) F. van Leeuwen, *Hipparcos, the new reduction of the raw data* (Springer, Dordrecht), 2007.
(10) www.itelescope.net
(11) J. B. Kaler, *Stars and Their Spectra* (CUP), 2011, p. 97.
(12) R. D. Oudmaijer *et al.*, *A&AS*, **96**, 625, 1992.
(13) P. J. Flower, *ApJ*, **469**, 355, 1996.
(14) G. V. Schultz *et al.*, *A&A*, **43**, 133, 1975.
(15) D. H. Bradstreet & D. P. Steelman, *Bull.AAS*, **34**, 1224, 2002.
(16) E. Anderson & C. Francis, *Astr. Lett.*, **38**, 331, 2012.
(17) S. Ekström *et al.*, *A&A*, **537**, A146, 2012.
(18) C. Georgy *et al.*, *A&A*, **558**, A103, 2013.
(19) A. Brown *et al.*, *AJ*, **122**, 392, 2001.

# SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

## PAPER 240: BD +59° 224, HD 9592, HD 10171, HD 11738, AND ν CETI

*By R. F. Griffin*
*Cambridge Observatories*

Orbits are presented for five stars that are all within little more than an hour of right ascension in the sky. After the very limited literature on BD +59° 224, which is at a far higher declination than the other four, had proposed spectral types ranging from O to K5 and even to that of a planetary nebula, Gray & Skiff demonstrated that it really has a composite spectrum, about K4·5 Ib + B3 V, quite similar to that of ζ Aur (but without eclipses as far as is known). Here it is shown to have an orbit with a period close to 5 years, an eccentricity of about 0·35, and a mass function of about 0·5 $M_\odot$ — large, but not large enough to encourage an expectation of eclipses. (The corresponding figures for ζ Aur itself are 2⅔ years, 0·39, and 1 $M_\odot$.) HD 9592, a star observed by the writer some 40 years ago in the 'Clube Selected Areas' programme but not then identified as a binary, and with almost no other literature, is shown to have a low-eccentricity orbit with a period very close to 1000 days. A very similar history applies also to HD 10171, except that in *its* case *Simbad* does not even retrieve the writer's own paper; the orbital period is 640 days and the eccentricity 0·38. HD 11738 was not on the original 'Clube' programme but was added in 2002 in a still-unpublished supplement to it; its orbit has a period close to 3 years and an eccentricity a little over 0·5. ν Ceti has an orbit with a period just short of two years, an eccentricity of 0·27, and a very small mass function. The periods of +59° 224, HD 11738, and ν Ceti are close to integral numbers of years; the harm caused by the inevitable gaps in the phase coverage of their orbits is, however, largely just cosmetic. ν Ceti has a $9^m$ main-sequence companion 8″ away. Efforts to measure its radial velocity have been compromised by scattered light from the adjacent much-brighter primary; all that can be said is that its radial velocity is similar to that of the primary and that no real variability is apparent.

### *Introduction*

This paper refers to five stars that are all in the same part of the sky as regards right ascension. One of them, BD +59° 224, is in Area 8 of the 'Kapteyn Selected Areas'[1], and three belong in Area 11 of the 'Clube Selected Areas'[2] — although one of them does not feature in that paper because it was added to the programme as part of a relatively recent and as-yet-unpublished supplement.

The three Area-11 stars are all near the ninth magnitude (that magnitude, and an *HD* type of K0, were the selection criteria for stars within the designated Areas). $\nu$ Ceti is a $5^{m}$ star not far outside Area 11. BD +59° 224 is at much higher declination (as its designation demonstrates) and is about a magnitude fainter; its interest arises from its spectroscopic similarity to $\zeta$ Aur, although it lacks the defining characteristic of the eclipses in that object. The *BD* star, HD 11738, and $\nu$ Ceti share a troublesome proximity of their orbital periods to small integral numbers of years, so their velocity curves exhibit phase gaps where no observations can be made for many years; the deficiency is, however, largely cosmetic — the orbits themselves are quite well determined, and the principal benefit of filling in the gaps would be that the long time taken for its accomplishment would, merely as a corollary, lead to substantial reduction in the standard errors of the orbital periods.

*BD +59° 224*

The object is far from conspicuous, being about tenth magnitude and in a rich Milky Way field in Cassiopeia, about 1° preceding $\delta$ Cas. The reason that it has come to attention is that it happens to fall within one of the Kapteyn[1] *Selected Areas*, *viz.*, Area 8, centred at an epoch-1875 position of RA $0^{h}$ $58^{m}$ $06^{s}$, declination 60° 06′·1* (currently about $1^{h}$ $06^{m}$·7, 60° 51′). On that account it features in the *Bergedorfer Spektral-Durchmusterung*[3] (*BSD*), where it is designated as no. 8–747; the *BD* identities noted for that star and no. 748 (a visually somewhat fainter star located about 78″ distant in p.a. 133°, but shown as nearly a magnitude brighter and of type B7 in the *BSD*, which gives *photographic* magnitudes) are transposed in the *BSD*, so the star of present interest is incorrectly noted there as +59° 225 and no. 748 as +59° 224.

The history of the spectral classification of BD +59° 224 has been well set out by Gray & Skiff[4], but it seems helpful to recall it briefly here. The spectrum is noted in the *BSD* as "peculiar", and there is a considerable coded footnote to the effect that the spectrum is a composite of F2 + G5 but also shows helium, that the *K* line, H$\delta$, and the *G* band are all weak, and the energy distribution in the spectrum is analogous to that of a G5 star. (That seems like quite a lot to divine from an objective-prism spectrum having a reciprocal dispersion of about 400 Å mm$^{-1}$ at H$\gamma$!) Other objective-prism classifications, also made at very low dispersions, have been, to say the least, discordant. Lee *et al.*[5], observing in the 'visual' region, gave the type simply as K5 (which actually is very plausible, as will become clear below). Brodskaya[6], on the other hand, gave it as O, possibly because the spectrum holds up well towards short wavelengths but she could not see any lines in it. Sjogren[7] obtained photometry as well as objective-prism spectroscopy in *BSD* Area 8; he obtained for no. 747 (for which he followed the *BSD* itself in mis-identifying it as BD +59° 225) the magnitudes $V = 9^{m}{\cdot}846$, $(B - V) = 1^{m}{\cdot}62$, and despite the extraordinary redness described the 'peculiar' spectrum in a footnote as "Planetary Nebula. Spectrum with many emission lines."

In 2004 Gray & Skiff[4] finally elucidated the true character of BD +59° 224 by means of CCD spectra obtained with the modest 0·8-m telescope of the

*There are 206 4°×4° Areas at centres selected according to a "Systematic Plan" at uniform intervals of (epoch-1875) celestial coordinates, together with a further 46 "Special Plan" Areas covering particularly significant fields or objects. Area 8 of the Systematic Plan is in principle centred at RA = $1^{h}$, $\delta$ = 60°, but the Area centres were allowed to move slightly from their nominal positions to make them coincide with the nearest suitable 'guide star', which had to be between the $8^{th}$ and $9^{th}$ photographic magnitudes; in this case the selected guide star is the one now known as HD 6382.

Dark Sky Observatory in North Carolina. The spectra run from *H* & *K* up to the green and have about 500 resolution elements. They largely confirmed the findings of the *BSD* but amplified them in a way that enabled the nature of the system to be understood. In the green the spectrum matches that of ξ Cyg (K4–5 Ib–II[8]), but in the violet the Balmer lines are too strong for that type, *H* & *K* are too weak, and the λ4026-Å line of He I is visible — all going to show that there is a hot companion, which those authors classified as B3 V. So the system is spectroscopically quite analogous to the well-known eclipsing composite-spectrum system ζ Aur[9,10], although no eclipses have been noticed in BD +59° 224. Both the analogy with ζ Aur, and the discussion by Gray & Skiff[4], lead to estimates of about 2 kpc for the distance of BD +59° 224. At that distance the proper motion of about 8 arc-ms per annum, determined by *Tycho* but with none-too-high accuracy, represents a transverse motion of about 75 km s$^{-1}$; that is quite large but will be seen below to be quite similar to the radial velocity and therefore altogether unexceptionable.

The object was placed on the radial-velocity observing programme of the Cambridge *Coravel* in 2005 in direct response to Gray & Skiff's discovery of its composite nature. The radial-velocity spectrometer cross-correlates the spectrum of the star being observed with a late-type spectrum (actually related to that of Arcturus, type K2) imprinted upon a mask within the instrument, so it is sensitive only to the late-type component of a composite spectrum. That has the advantage that no confusion arises from the composite nature of the spectrum or the dilution of the spectrum of the cool component by that of its companion; on the other hand, there is no prospect of determining the radial velocity of the hot star or obtaining the mass ratio from the spectrometer measurements. Altogether 57 radial velocities have been obtained for the K-supergiant star; they are set out in Table I and show the orbit to have a moderate eccentricity (about 0·35) and a period of about five years. The mass function of slightly more than half a solar mass is much smaller than that of ζ Aur (almost 1 $M_\odot$) and does not encourage an expectation of eclipses, especially since the orbit is larger than that of ζ Aur and moreover the relevant conjunction occurs near apastron. If the reasonable assumption is made that the star whose velocity has been measured is the primary (more massive) component*, it follows that both components must have masses more than four times the mass function, *viz.*, more than about 2·2 $M_\odot$; the B3 classification[4] of the hot component implies a mass about four times as great as that, and reinforces pessimism concerning the likelihood of eclipses. The orbit is plotted in Fig. 1, and its elements are presented in the informal table here.

| | | |
|---|---|---|
| $P$ = 1892 ± 5 days | $(T)_1$ = MJD 54996 ± 11 | |
| $\gamma$ = −66·25 ± 0·12 km s$^{-1}$ | $a_1 \sin i$ = 365 ± 4 Gm | |
| $K$ = 14·99 ± 0·17 km s$^{-1}$ | $f(m)$ = 0·541 ± 0·019 $M_\odot$ | |
| $e$ = 0·353 ± 0·010 | | |
| $\omega$ = 82·1 ± 2·3 degrees | R.m.s. residual (wt. 1) = 0·75 km s$^{-1}$ | |

The residuals of the radial velocities are about three times the values typical of the *Coravel* spectrometer. Without necessarily denying that there could be some 'jitter' arising from the star itself, one could accept that the observational errors in this case are larger than usual, because (*a*) the star is fainter than

*It has evolved while its companion is still a B star; the only way it could be less massive would be by substantial mass transfer — unlikely in this system where the periastron separation of the components is probably near 4 AU — or a massive stellar wind, of which no evidence has been noticed.

TABLE I

*Radial-velocity observations of BD +59° 224*

*All the observations were made with the Cambridge Coravel*

| *Date (UT)* | | | *MJD* | *Velocity* km s$^{-1}$ | *Phase* | *(O – C)* km s$^{-1}$ |
|---|---|---|---|---|---|---|
| 2005 | Sept. | 7·12 | 53620·12 | −78·3 | 0·272 | −0·6 |
| | | 17·07 | 630·07 | −77·4 | ·278 | +0·1 |
| | Nov. | 5·05 | 679·05 | −76·7 | ·304 | −0·2 |
| | Dec. | 16·97 | 720·97 | −76·2 | ·326 | −0·7 |
| 2006 | Jan. | 28·79 | 53763·79 | −74·7 | 0·348 | −0·1 |
| | Feb. | 25·82 | 791·82 | −73·1 | ·363 | +0·8 |
| | July | 12·08 | 928·08 | −68·9 | ·435 | +1·7 |
| | Aug. | 11·12 | 958·12 | −68·7 | ·451 | +1·2 |
| | Sept. | 8·11 | 986·11 | −67·9 | ·466 | +1·3 |
| | Oct. | 5·06 | 54013·06 | −68·2 | ·480 | +0·3 |
| | Nov. | 2·04 | 041·04 | −68·4 | ·495 | −0·6 |
| | Dec. | 2·89 | 071·89 | −67·1 | ·511 | −0·1 |
| 2007 | Jan. | 10·83 | 54110·83 | −66·2 | 0·532 | −0·1 |
| | Feb. | 2·81 | 133·81 | −65·5 | ·544 | 0·0 |
| | Aug. | 10·11 | 322·11 | −61·0 | ·644 | −0·5 |
| | Sept. | 11·10 | 354·10 | −59·7 | ·660 | −0·1 |
| | Oct. | 5·04 | 378·04 | −59·8 | ·673 | −0·8 |
| | Nov. | 8·98 | 412·98 | −59·1 | ·692 | −1·1 |
| | Dec. | 12·93 | 446·93 | −58·9 | ·710 | −1·8 |
| 2008 | Jan. | 7·91 | 54472·91 | −57·1 | 0·723 | −0·7 |
| | Feb. | 8·77 | 504·77 | −56·7 | ·740 | −1·2 |
| | Aug. | 13·12 | 691·12 | −50·6 | ·839 | +0·6 |
| | Sept. | 19·06 | 728·06 | −50·0 | ·858 | +0·7 |
| | Oct. | 17·02 | 756·02 | −48·8 | ·873 | +1·8 |
| | Nov. | 23·01 | 793·01 | −51·1 | ·892 | −0·4 |
| | Dec. | 6·96 | 806·96 | −51·3 | ·900 | −0·4 |
| 2009 | Jan. | 2·89 | 54833·89 | −51·3 | 0·914 | +0·1 |
| | | 20·80 | 851·80 | −51·7 | ·924 | +0·3 |
| | Feb. | 3·81 | 865·81 | −52·5 | ·931 | +0·1 |
| | Mar. | 5·81 | 895·81 | −55·5 | ·947 | −1·2 |
| | Aug. | 16·15 | 55059·15 | −70·1 | 1·033 | +0·1 |
| | | 30·07 | 073·07 | −71·5 | ·041 | +0·1 |
| | Sept. | 13·14 | 087·14 | −73·3 | ·048 | −0·4 |
| | Oct. | 9·02 | 113·02 | −74·5 | ·062 | +0·4 |
| | | 25·07 | 129·07 | −75·8 | ·070 | +0·2 |
| | Nov. | 9·02 | 144·02 | −77·3 | ·078 | −0·4 |
| | | 20·97 | 155·97 | −77·8 | ·084 | −0·2 |
| | Dec. | 28·79 | 193·79 | −78·9 | ·104 | +0·2 |
| 2010 | Jan. | 29·82 | 55225·82 | −80·0 | 1·121 | −0·1 |
| | July | 30·11 | 407·11 | −79·1 | ·217 | +0·5 |
| | Aug. | 24·15 | 432·15 | −78·7 | ·230 | +0·5 |
| | Sept. | 17·13 | 456·13 | −80·2 | ·243 | −1·4 |
| | Oct. | 20·07 | 489·07 | −78·7 | ·260 | −0·5 |
| 2011 | Sept. | 13·06 | 55817·06 | −71·4 | 1·434 | −0·7 |
| | Nov. | 27·97 | 892·97 | −69·4 | ·474 | −0·6 |
| 2012 | July | 25·10 | 56133·10 | −61·3 | 1·601 | +1·4 |
| | Aug. | 31·12 | 170·12 | −60·4 | ·621 | +1·3 |

TABLE I (*concluded*)

| *Date (UT)* | *MJD* | *Velocity* *km s⁻¹* | *Phase* | *(O–C)* *km s⁻¹* |
|---|---|---|---|---|
| 2013 July 10·09 | 56483·09 | −53·0 | 1·786 | +0·3 |
| Sept. 3·11 | 538·11 | −51·4 | ·815 | +0·6 |
| Nov. 19·93 | 615·93 | −50·3 | ·856 | +0·5 |
| Dec. 22·91 | 648·91 | −51·0 | ·874 | −0·4 |
| 2014 July 31·11 | 56869·11 | −62·3 | 1·990 | −0·9 |
| Aug. 12·13 | 881·13 | −62·9 | ·996 | −0·2 |
| 29·13 | 898·13 | −64·3 | 2·005 | +0·3 |
| Sept. 8·13 | 908·13 | −65·6 | ·011 | +0·1 |
| 25·09 | 925·09 | −67·7 | ·020 | −0·1 |
| Oct. 5·00 | 935·00 | −67·5 | ·025 | +1·1 |

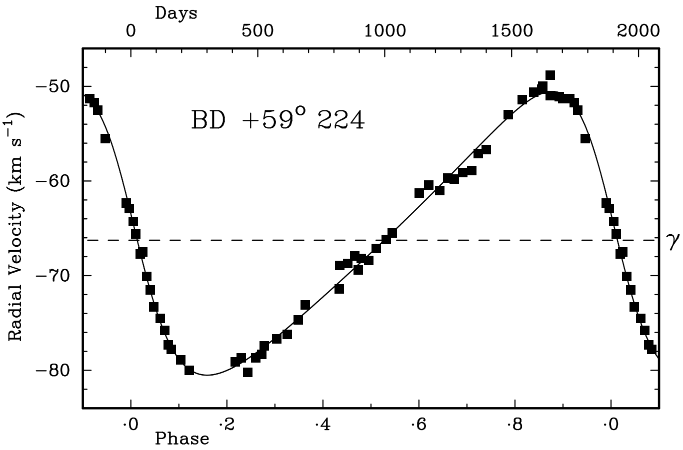


FIG. 1

The observed radial velocities of BD +59° 224 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All of the 57 observations were obtained by the writer with the Cambridge *Coravel*.

most of those treated in this series of papers, and (*b*) it gives cross-correlation 'dips' that are unusually difficult to measure accurately, both because the spectral features of the late-type star are diluted by the quasi-continuum of its hot companion, and because the dips are considerably wider than those of most stars. For stars having luminosities no higher than those of normal giants, the dip widths furnish reliable measures of rotational velocities, but in the cases of high-luminosity objects the spectral lines are broadened by atmospheric velocity fields that are non-committally described as 'turbulence'. The widths of the dips given by BD +59° 224 would correspond to a $v \sin i$ of 10·7 km s$^{-1}$ in the case of a star of more normal luminosity, but in the present case it would be less. In the absence of experience of dip widths of other high-luminosity stars with reliably known rotational velocities (if there are any), the writer can only comment that the 10·7 km s$^{-1}$ value is a little higher than the corresponding figures for such supergiants as are found in ζ Aur and 31 and 32 Cyg, and so may be expected to include at least *some* contribution from real stellar rotation.

*HD 9592*

HD 9592 is by no means a stranger to the writer of this paper, having first been observed by him in the course of the 'Clube Selected Areas' radial-velocity programme[11] in 1972. It is a very red $8^{m}\cdot5$ star, to be found in Area 11 near the following (eastern) margin of Pisces, approximately half-way between the bright stars $\beta$ Ari and $\phi$ Psc. As an aside, it may be recalled that both those stars have distinguished histories in the field of spectroscopic binaries. The former held the record for the highest eccentricity (0·896) of any well-determined spectroscopic orbit[12] until it was superseded by HD 210647, whose orbit, published[13] in Paper 56 of the same series as this paper, in 1984, was the first to have $e > 0\cdot9$. The other one, $\phi$ Psc, is a visual double system whose respective components featured[14,15] in Papers 99 and 100 of this series. The primary is another star with a very eccentric orbit ($e \sim 0\cdot82$) and has a period of more than 20 years; the faint visual secondary, quite difficult to observe (but at the relevant time the writer was privileged to have periodic access to the Palomar 200-inch reflector), proved to have a period that was the shortest that had yet been found in this series, but also created additional interest and difficulty by differing by only about five seconds from the exact value of two sidereal days. The $\nu$ Ceti system, discussed below, has some analogies to $\phi$ Psc.

HD 9592 is perhaps a bit unlucky not to have featured in the *Hipparcos* programme, but it was measured photometrically by *Tycho*, with the results $V = 8^{m}\cdot52$, $(B - V) = 1^{m}\cdot40$. Only two papers mentioning the star are retrieved by *Simbad*. One of them is the present writer's own paper[11] on the Clube Selected Areas. The other is the *PASTEL Catalogue of Stellar Parameters*[16]; the only parameter that appears to be of much interest here is the metal abundance relative to the solar value, [Fe/H], which is given as the improbably high and precise value +0·200 (though with an uncertainty listed as 0·050).

The Clube Selected Areas paper listed only two velocities for HD 9592, made nearly two years apart with the original radial-velocity spectrometer[17] and differing by 2·4 km $s^{-1}$, which with that instrument was not quite enough to warrant an assertion of real variability without additional evidence*. Interest in the northern Clube Areas was re-kindled some years ago after the southern Areas, previously neglected simply through being out of reach of the Cambridge spectrometer, were observed[18] with the Geneva Observatory's *Coravel* at ESO and thereby leap-frogged the northern Areas in terms not only of accuracy but also of numbers of stars (since the surface density of *HD* stars is much greater in the southern hemisphere than in the north). All the northern Areas have been re-observed with the Cambridge *Coravel* in a programme that is as yet unpublished; the Areas were enlarged in order to make the number of stars per Area more comparable with those in the southern hemisphere, and a good many additional spectroscopic binaries have been discovered, not only among the newly added stars but also among those, such as HD 9592, whose variability had escaped attention in the original investigation.

Thus after a lapse of 28 years HD 9592 was restored to the observing programme in 2002. It soon proved to vary in velocity and was transferred to

*Their actual residuals from the orbit found here are only 0·5 and 0·7 km $s^{-1}$, so their mutual discrepancy does in fact appear to be quite significant. If it had not been for misfortune in the relative phasing of the two measurements the variability of velocity would readily have been discovered with the original instrument.

TABLE II

*Radial-velocity observations of HD 9592*

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

| *Date (UT)* | *MJD* | *Velocity* *km s*$^{-1}$ | *Phase* | *(O – C)* *km s*$^{-1}$ |
|---|---|---|---|---|
| 1972 Nov. 30·87* | 41651·87 | −6·3 | $\overline{11}$·191 | −0·5 |
| 1974 Aug. 28·05* | 42287·05 | −3·9 | $\overline{11}$·824 | −0·7 |
| 2002 Sept. 29·08 | 52546·08 | −7·9 | 0·058 | −0·2 |
| Nov. 7·00 | 585·00 | −7·6 | ·097 | −0·2 |
| 2003 Sept. 18·09 | 52900·09 | −0·2 | 0·411 | 0·0 |
| Oct. 26·99 | 938·99 | +0·7 | ·450 | +0·2 |
| Nov. 26·95 | 969·95 | +1·0 | ·481 | +0·1 |
| Dec. 28·89 | 53001·89 | +1·3 | ·513 | +0·1 |
| 2004 Jan. 24·84 | 53028·84 | +1·5 | 0·540 | +0·2 |
| Feb. 25·81 | 060·81 | +0·9 | ·571 | −0·5 |
| Aug. 20·13 | 237·13 | −1·1 | ·747 | −0·1 |
| Sept. 14·09 | 262·09 | −1·4 | ·772 | +0·3 |
| Oct. 22·06 | 300·06 | −2·7 | ·810 | +0·1 |
| Nov. 26·93 | 335·93 | −4·1 | ·846 | −0·3 |
| Dec. 17·86 | 356·86 | −4·2 | ·867 | +0·2 |
| 2005 Jan. 12·85 | 53382·85 | −5·1 | 0·893 | +0·1 |
| Feb. 12·83 | 413·83 | −6·2 | ·924 | −0·2 |
| Aug. 7·14 | 589·14 | −7·3 | 1·098 | +0·1 |
| Oct. 26·02 | 669·02 | −6·1 | ·178 | 0·0 |
| Nov. 18·94 | 692·94 | −5·3 | ·202 | +0·2 |
| Dec. 8·92 | 712·92 | −5·0 | ·222 | 0·0 |
| 2006 Jan. 4·76 | 53739·76 | −3·9 | 1·249 | +0·4 |
| Feb. 8·77 | 774·77 | −3·2 | ·284 | +0·1 |
| Mar. 3·79 | 797·79 | −3·1 | ·307 | −0·4 |
| Dec. 16·88 | 54085·88 | +1·2 | ·594 | −0·1 |
| 2007 Jan. 11·77 | 54111·77 | +1·1 | 1·620 | 0·0 |
| Feb. 7·77 | 138·77 | +0·8 | ·647 | −0·1 |
| Mar. 3·80 | 162·80 | +0·8 | ·671 | +0·3 |
| Aug. 7·12 | 319·12 | −3·3 | ·827 | 0·0 |
| Oct. 31·97 | 404·97 | −5·6 | ·912 | +0·1 |
| Dec. 5·95 | 439·95 | −6·5 | ·947 | 0·0 |
| 2008 Jan. 5·89 | 54470·89 | −6·9 | 1·978 | +0·2 |
| Feb. 11·82 | 507·82 | −7·5 | 2·015 | 0·0 |
| Sept. 20·09 | 729·09 | −4·5 | ·236 | +0·1 |
| Oct. 18·99 | 757·99 | −3·8 | ·264 | 0·0 |
| Dec. 9·91 | 809·91 | −2·5 | ·316 | −0·1 |
| 2009 Jan. 2·83 | 54833·83 | −1·8 | 2·340 | 0·0 |
| 20·85 | 851·85 | −1·5 | ·358 | −0·2 |
| Feb. 3·83 | 865·83 | −0·9 | ·372 | +0·1 |
| 21·80 | 883·80 | −0·7 | ·390 | −0·1 |
| Oct. 25·06 | 55129·06 | +0·8 | ·635 | −0·2 |
| Dec. 20·89 | 185·89 | +0·6 | ·691 | +0·4 |
| 2010 Jan. 3·84 | 55199·84 | −0·2 | 2·705 | −0·1 |
| 29·80 | 225·80 | −0·7 | ·731 | 0·0 |
| Oct. 20·10 | 489·10 | −7·1 | ·994 | +0·2 |

TABLE II (*concluded*)

| *Date (UT)* | *MJD* | *Velocity* *km s⁻¹* | *Phase* | *(O – C)* *km s⁻¹* |
|---|---|---|---|---|
| 2012 Jan. 2·77 | 55928·77 | +0·2 | 3·432 | 0·0 |
| 2013 Jan. 9·84 | 56301·84 | −2·8 | 3·804 | −0·2 |
| Feb. 19·78 | 342·78 | −4·0 | ·845 | −0·2 |
| Sept. 3·14 | 538·14 | −7·5 | 4·040 | +0·1 |
| Oct. 7·04 | 572·04 | −7·8 | ·074 | −0·2 |
| Nov. 19·92 | 615·92 | −7·2 | ·118 | 0·0 |
| Dec. 4·91 | 630·91 | −7·0 | ·133 | −0·1 |
| 27·82 | 653·82 | −6·5 | ·156 | 0·0 |

*Observed with original radial-velocity spectrometer[17]; weight 1/10

the binary programme and observed at appropriate intervals. There are now 53 measurements of it, set out in Table II. They have all been accorded the same weight in the solution of the orbit apart from the original pair[11], which were attributed a weight of 0·1 to bring their weighted variance more or less into accord with that of the *Coravel* measurements, which in this case exhibit an r.m.s. residual of only 0·18 km $s^{-1}$, somewhat smaller than usual. That may well be because the cross-correlation 'dips' in the radial-velocity traces are agreeably deep, having a mean 'equivalent width' of about 6·4 km $s^{-1}$, which is nearly the maximum found for stars of types other than supergiants and might be held to support the high metal abundance proposed by *PASTEL*. The orbital elements are shown in Table VII towards the end of this paper, with those of the other stars treated below; the observations and solution are shown in Fig. 2. The most interesting quantities are the period of 1002·5 days (with a standard error of less than one day), and the small but definitely non-zero eccentricity of

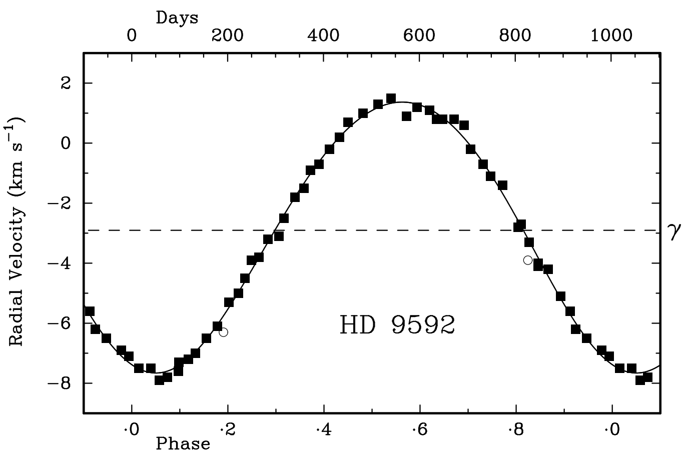


FIG. 2

As Fig. 1, but for HD 9592. In this case, in addition to the 51 Cambridge *Coravel* observations, represented by squares, there are two measurements made with the original radial-velocity spectrometer[17] at Cambridge by the writer more than 40 years ago; they are shown as open circles and were weighted 1/10 in the solution of the orbit.

0·057 ± 0·009. The mass function of less than 0·01 $M_{\odot}$ does not encourage an expectation that the secondary star should be easily observable, and there is no evidence of it in the radial-velocity traces.

The *HD* spectral type of HD 9592 (as of all the Clube stars) is K0, but the colour index indicates that the true type must be later. If HD 9592 is a main-sequence star, it must be so nearby that it cannot be significantly reddened, and its colour index of $1^{m}\cdot40$ corresponds to a very-late-K type with an absolute magnitude of about $8^{m}\cdot5$ and thus a distance modulus close to zero — a distance of 10 pc. It would be surprising, in that case, that its relative proximity has not been picked up previously. The *PASTEL* catalogue lists its log *g*, with characteristically implausible precision, as 4·180 in c.g.s. units, a little less than could be expected for a late-K dwarf but nowhere near the value of about 2 that would correspond to the gravity of a giant of that colour index, whose type would be about K4 III.

The *Tycho 2* proper motion of HD 9592 is given by *Simbad* as $\mu_{\alpha} = +1\cdot0 \pm 1\cdot0$, $\mu_{\delta} = -1\cdot8 \pm 0\cdot9$ arc-milliseconds per year — so it is scarcely significantly different from zero. One millisecond a year at 10 parsecs corresponds to a transverse velocity of 0·047 km $s^{-1}$, and the probability of such a tiny value is so small that (the *PASTEL* log *g* notwithstanding) the idea that the star is on the main sequence can be rejected with high confidence. It would be easier for a normal giant, with a type of about K4 III, an absolute magnitude of about −1, and therefore a distance modulus of about $9^{m}\cdot5$ or a distance of about 800 pc, to have such a small proper motion: 1 ms/year at that distance would represent a transverse velocity of about 4 km $s^{-1}$ — small, certainly, by stellar standards, but not implausibly so, and made perhaps more acceptable by the radial-velocity $\gamma$-velocity of only about −3 km $s^{-1}$.

The Cambridge radial-velocity traces nearly all show 'dips' that are slightly wider than the minimum that is believed to correspond to zero rotational velocity, and rotational velocities are routinely derived from each of them individually. The mean value of $v \sin i$ found for HD 9592 is 2·0 ± 0·25 km $s^{-1}$, but rotational velocities determined just from dip widths are not claimed to have external accuracies better than ±1 km $s^{-1}$, so the figure to be recommended is 2 ± 1 km $s^{-1}$.

### *HD 10171*

This is another star in Clube Area 11, near the following margin of Pisces; it is about 3° north of HD 9592, 4° south-preceding α Tri, and only about 50′ from the $6^{m}$ star HR 484, in p.a. 340°. Once again we are indebted to *Tycho* for the photometry, $V = 9^{m}\cdot00$, $(B-V) = 1^{m}\cdot07$. Seemingly perversely, since HD 10171 is half a magnitude fainter than HD 9592, the former is an *Hipparcos* star whereas the latter is not; the parallax[19] of HD 10171 is, however, negative by almost its own standard error, at −1·39 ± 1·57 arc-milliseconds, indicating that although the star cannot in reality be 'beyond infinity' it must be a long way away, at least the order of a kiloparsec, and therefore must have at least the luminosity of an MK Class-III star; its colour index might then suggest its type to be K0 III.

*Simbad* records only four papers that refer to HD 10171; they do not include the one[11] in which the writer gave its radial velocity, although they do include two[20,21] that refer to large catalogues in which that result is listed. There is one pre-*Hipparcos* paper giving an astrometric position; and there is one[22] giving "Fundamental parameters … of *Hipparcos* stars", which was evidently compiled by such a humourless computer with so little intelligent oversight that the star's distance is listed (as negative, and to six 'significant' figures) as −719·420 pc [*sic*].

TABLE III

*Radial-velocity observations of HD 10171*

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

| *Date (UT)* | *MJD* | *Velocity* *km s⁻¹* | *Phase* | *(O – C)* *km s⁻¹* |
|---|---|---|---|---|
| 1971 Nov. 22·87* | 41277·87 | −32·4 | $\overline{18}$·824 | −1·0 |
| 1974 Aug. 21·11* | 42280·11 | −30·4 | $\overline{16}$·388 | −3·2 |
| 2002 Sept. 29·09 | 52546·09 | −26·9 | 0·409 | +0·3 |
| Nov. 7·01 | 585·01 | −27·6 | ·470 | −0·3 |
| 2003 Sept. 18·10 | 52900·10 | −35·4 | 0·961 | +0·2 |
| Oct. 27·00 | 939·00 | −35·2 | 1·022 | −0·2 |
| Nov. 26·95 | 969·95 | −32·7 | ·070 | +0·1 |
| Dec. 17·90 | 990·90 | −31·1 | ·103 | +0·3 |
| 2004 Jan. 24·85 | 53028·85 | −29·7 | 1·162 | −0·3 |
| Feb. 25·81 | 060·81 | −28·7 | ·212 | −0·3 |
| Aug. 20·13 | 237·13 | −27·5 | ·487 | −0·2 |
| Sept. 14·09 | 262·09 | −27·6 | ·526 | −0·1 |
| Oct. 22·07 | 300·07 | −28·0 | ·586 | −0·2 |
| Dec. 16·88 | 355·88 | −28·7 | ·673 | 0·0 |
| 2005 Jan. 8·84 | 53378·84 | −29·3 | 1·709 | −0·2 |
| Feb. 12·81 | 413·81 | −30·2 | ·763 | −0·2 |
| Aug. 13·14 | 595·14 | −34·3 | 2·046 | −0·3 |
| Sept. 28·10 | 641·10 | −30·8 | ·118 | 0·0 |
| Oct. 10·16 | 653·16 | −30·2 | ·137 | −0·1 |
| Nov. 9·96 | 683·96 | −28·9 | ·185 | 0·0 |
| Dec. 16·95 | 720·95 | −27·9 | ·242 | +0·1 |
| 2006 Jan. 4·81 | 53739·81 | −27·9 | 2·272 | −0·2 |
| 28·78 | 763·78 | −27·6 | ·309 | −0·1 |
| Feb. 25·78 | 791·78 | −27·9 | ·353 | −0·6 |
| Aug. 30·15 | 977·15 | −28·3 | ·642 | 0·0 |
| Nov. 1·00 | 54040·00 | −29·4 | ·740 | +0·2 |
| Dec. 8·97 | 077·97 | −30·6 | ·800 | +0·2 |
| 2007 Jan. 1·93 | 54101·93 | −32·1 | 2·837 | −0·3 |
| 20·81 | 120·81 | −33·0 | ·866 | −0·3 |
| Mar. 3·82 | 162·82 | −35·3 | ·932 | −0·4 |
| Oct. 20·00 | 393·00 | −27·3 | 3·291 | +0·3 |
| Nov. 11·95 | 415·95 | −27·5 | ·327 | −0·1 |
| Dec. 12·95 | 446·95 | −27·0 | ·375 | +0·2 |
| 2008 Jan. 16·84 | 54481·84 | −26·7 | 3·430 | +0·5 |
| Sept. 20·09 | 729·09 | −30·9 | ·816 | +0·3 |
| Oct. 2·03 | 741·03 | −31·9 | ·834 | −0·2 |
| 17·05 | 756·05 | −32·2 | ·858 | +0·2 |
| Nov. 7·97 | 777·97 | −33·3 | ·892 | +0·2 |
| 18·98 | 788·98 | −33·9 | ·909 | +0·2 |
| Dec. 2·90 | 802·90 | −34·9 | ·931 | −0·1 |
| 2009 Jan. 6·82 | 54837·82 | −35·4 | 3·985 | +0·4 |
| 20·85 | 851·85 | −35·6 | 4·007 | −0·1 |
| Feb. 7·82 | 869·82 | −34·5 | ·035 | 0·0 |
| 21·81 | 883·81 | −33·2 | ·057 | +0·3 |
| Sept. 4·12 | 55078·12 | −27·1 | ·360 | +0·2 |
| Oct. 9·08 | 113·08 | −27·4 | ·415 | −0·2 |
| Dec. 6·93 | 171·93 | −27·5 | ·507 | −0·1 |

TABLE III (*concluded*)

| *Date (UT)* | *MJD* | *Velocity km s⁻¹* | *Phase* | *(O–C) km s⁻¹* |
|---|---|---|---|---|
| 2010 Feb. 20·80 | 55247·80 | −28·3 | 4·625 | −0·1 |
| Oct. 7·08 | 476·08 | −35·8 | ·981 | 0·0 |
| Nov. 23·89 | 523·89 | −33·7 | 5·056 | −0·2 |
| Dec. 18·95 | 548·95 | −31·5 | ·095 | +0·2 |
| 2011 Oct. 16·07 | 55850·07 | −27·7 | 5·565 | 0·0 |
| 2012 Jan. 3·83 | 55929·83 | −28·7 | 5·690 | +0·2 |
| Sept. 12·13 | 56182·13 | −32·0 | 6·083 | +0·2 |
| Nov. 6·00 | 237·00 | −29·5 | ·169 | −0·2 |
| Dec. 9·96 | 270·96 | −28·2 | ·222 | +0·1 |
| 2013 Feb. 27·80 | 56350·80 | −26·7 | 6·346 | +0·6 |
| Sept. 17·07 | 552·07 | −28·6 | ·661 | −0·1 |
| Nov. 12·96 | 608·96 | −29·5 | ·749 | +0·3 |
| Dec. 4·91 | 630·91 | −30·3 | ·784 | +0·1 |

*Observed with original radial-velocity spectrometer[17]
Not used in orbit solution

HD 10171 was first observed for radial velocity as a Clube Area-11 star in 1971 and 1974; the two measurements differed by 2·0 km s$^{-1}$, not enough to flag the object as a spectroscopic binary. Just as in the case of HD 9592, the star was restored to the observing programme in 2002; the first new observation then was actually made within minutes of the one of HD 9592, and immediately demonstrated a discordance from the 1970s velocities. The number of new observations made with the Cambridge *Coravel* is now 58; they are listed, with the two 1970s ones, in Table III, and readily yield the orbit that is illustrated in Fig. 3. The elements appear in Table VII towards the end of the paper. The second of the early observations, made in 1974, has a very bad residual, of –3·2 km s$^{-1}$ — beyond what is really admissible as 'accidental error' even for the original radial-velocity spectrometer[17]. The relevant 40-year-old record (drawn by a pen on a Brown-Recorder chart) has been re-read and re-reduced in the course of the writing of this paper; it appears to be a 'perfectly good' trace that ought not to give nearly such a bad residual, and there is no evidence of any malfunction or other unusual circumstance on the night concerned. The possibility of misidentification of the star cannot be ruled out, but a random star would not be likely to give a velocity so relatively close as 3 km s$^{-1}$ to the proper value. Thus the origin of the bad residual remains unexplained, but it has been considered inappropriate to choose to accept just the other one — the one that we *like* — of the two early observations, so both have been zero-weighted in the solution of the orbit, although the earlier one has an altogether acceptable residual of –1·0 km s$^{-1}$.

The orbital period of about 641 days is determined to only half a day, even though the two early observations have been omitted from the solution. The eccentricity is moderate, and the mass function is even smaller than that of HD 9592, so it is not surprising that no evidence of the secondary star has been noticed in the radial-velocity traces.

At the distance of 1 kpc that is suggested above as being about as near as is easily compatible with the negative parallax found from *Hipparcos*, the proper motion of about 14 arc-ms per annum (quite well determined by *Tycho 2* in this case) represents a transverse motion of nearly 70 km s$^{-1}$. If we were not keen

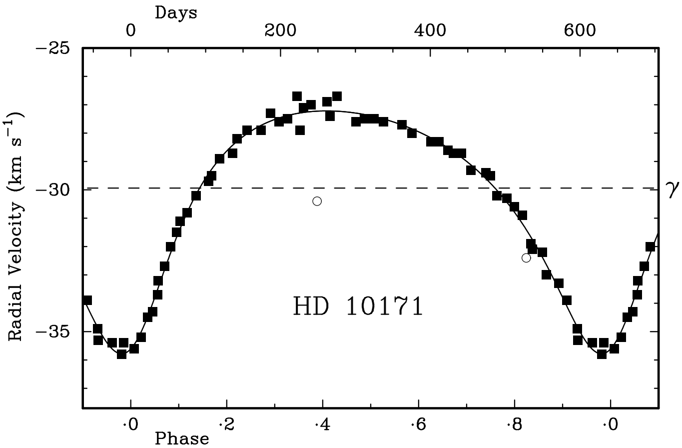


FIG. 3

Just like Fig. 2, but for HD 10171. Here there are 58 *Coravel* velocities; again there are two obtained with the original spectrometer, but because one of them gives such a conspicuously unpleasant residual they have both been zero-weighted in the solution.

to believe such a large value, we could (say) halve it at the cost of implicitly asserting that the true parallax is not 1 arc-ms but 2 — more than 2σ away from the value actually derived from the *Hipparcos* data set. There is no real objection to a 2-σ discrepancy, provided it does not occur too often. In this case, moreover, one might worry — although the author can do so only from a standpoint of ignorance — that the annual parallactic displacement that the satellite would have seen round three times during its operational lifetime may have been fatally compromised by the additional *orbital* displacement of which two cycles would have occurred in that time. At a distance of half a kiloparsec, the semi-amplitude of some 4 km $s^{-1}$ of the radial-velocity changes would, if reproduced across the line of sight, create an apparent oscillation with a semi-amplitude of nearly 2 arc-ms, more than sufficient to falsify angular motion of at most the same order attributable to parallax.

*HD 11738*

HD 11738 is another star that, being shown in the *HD* as being within half a magnitude of $9^m$ and being of type K0, was in principle eligible to be on the 'Clube Selected Areas' programme — but only if its position in the sky were within one of the designated Areas. At the outset of the programme it wasn't; but then, as explained above in the third paragraph of the section on HD 9592, the northern Areas were enlarged in order to increase the number of eligible stars within them, and *that* is how HD 11738 came to be added to the programme (in Area 11, the same as that of HD 9592 and 10171) in 2002, 35 years after its initial inception. The star is in the south-preceding corner of Aries, 4° north-following the $4^m$ star o Psc. Once more we rely on *Tycho* for the photometric data, $V = 8^m{\cdot}67$, $(B - V) = 0^m{\cdot}97$.

There is an *Hipparcos* parallax[19] for HD 11738, this time a positive one by almost 2σ: it is $2{\cdot}44 \pm 1{\cdot}23$ arc-ms. Although it is very uncertain, it is quite

TABLE IV

*Radial-velocity observations of HD 11738*

*All the observations were made with the Cambridge Coravel*

| *Date (UT)* | *MJD* | *Velocity* *km s*$^{-1}$ | *Phase* | *(O – C)* *km s*$^{-1}$ |
|---|---|---|---|---|
| 2002 Sept. 29·11 | 52546·11 | −11·5 | 0·350 | −0·3 |
| 2005 Jan. 13·81 | 53383·81 | −10·1 | 1·099 | −0·2 |
| 2006 Oct. 3·09 | 54011·09 | −19·0 | 1·660 | +0·1 |
| Dec. 3·96 | 072·96 | −21·0 | ·715 | +0·1 |
| 2007 Jan. 11·78 | 54111·78 | −22·1 | 1·750 | +0·4 |
| Feb. 14·79 | 145·79 | −24·1 | ·780 | −0·2 |
| Mar. 3·78 | 162·78 | −24·9 | ·796 | −0·3 |
| Aug. 7·12 | 319·12 | −32·9 | ·935 | +0·8 |
| 30·12 | 342·12 | −34·5 | ·956 | −0·4 |
| Sept. 16·10 | 359·10 | −32·7 | ·971 | +0·7 |
| 26·12 | 369·12 | −32·3 | ·980 | +0·1 |
| Oct. 14·04 | 387·04 | −29·3 | ·996 | −0·1 |
| 20·01 | 393·01 | −28·0 | 2·001 | −0·2 |
| 31·98 | 404·98 | −25·1 | ·012 | −0·4 |
| Nov. 9·00 | 413·00 | −22·4 | ·019 | +0·2 |
| 14·94 | 418·94 | −21·1 | ·025 | 0·0 |
| 24·00 | 428·00 | −18·4 | ·033 | +0·5 |
| Dec. 5·92 | 439·92 | −16·3 | ·043 | +0·2 |
| 10·93 | 444·93 | −15·6 | ·048 | 0·0 |
| 2008 Jan. 5·90 | 54470·90 | −12·1 | 2·071 | 0·0 |
| 16·85 | 481·85 | −11·3 | ·081 | −0·2 |
| Feb. 26·80 | 522·80 | −8·9 | ·118 | +0·3 |
| Aug. 15·16 | 693·16 | −9·7 | ·270 | 0·0 |
| Sept. 20·10 | 729·10 | −10·1 | ·302 | +0·2 |
| Oct. 19·05 | 758·05 | −10·9 | ·328 | −0·1 |
| 2009 Jan. 2·84 | 54833·84 | −12·3 | 2·396 | −0·1 |
| Aug. 28·14 | 55071·14 | −17·2 | ·608 | +0·2 |
| Nov. 23·93 | 158·93 | −19·5 | ·686 | +0·5 |
| 2010 Aug. 6·14 | 55414·14 | −32·9 | 2·914 | −0·5 |
| Sept. 1·17 | 440·17 | −34·0 | ·938 | −0·2 |
| Oct. 7·08 | 476·08 | −33·5 | ·970 | 0·0 |
| 28·03 | 497·03 | −31·1 | ·989 | −0·2 |
| Nov. 14·94 | 514·94 | −26·8 | 3·005 | +0·1 |
| 26·98 | 526·98 | −23·9 | ·015 | −0·1 |
| 2011 Jan. 9·86 | 55570·86 | −14·5 | 3·055 | −0·1 |
| 18·81 | 579·81 | −13·2 | ·063 | 0·0 |
| 2012 Jan. 3·83 | 55929·83 | −11·5 | 3·375 | +0·3 |
| Mar. 1·79 | 987·79 | −13·3 | ·427 | −0·4 |
| Aug. 9·15 | 56148·15 | −16·5 | ·571 | −0·1 |
| Nov. 3·08 | 234·08 | −18·9 | ·647 | −0·2 |
| 2013 Sept. 3·15 | 56538·15 | −32·8 | 3·919 | −0·1 |
| 2014 Aug. 29·15 | 56898·15 | −9·2 | 4·241 | +0·1 |

compatible with HD 11738's being a normal giant, whose type would be about G8 III to correspond with the colour index and whose absolute magnitude would be near zero. We do not learn much more of interest regarding HD 11738 from the literature. The deadpan computer mentioned[22] in the section above, while finding the distance positive this time, still manages to refine its inversion of a parallax with a 1-σ uncertainty of over 50% to a distance that it thinks is worth giving to six digits, "409·840 pc". And there is a paper[21] that informs us that, in order for perspective acceleration not to spoil the precision of the proper motion soon to be determined by *Gaia*, it will be necessary to determine the radial velocity of HD 11738 to no worse than 9999·99 km $s^{-1}$. We do that below. But would it not be better to reduce the length of the table announced in Ref. 21 (117955 lines) by a factor of 100 (if not 1000) by omitting all stars whose radial velocities are already known to adequate accuracy for the purpose envisaged, or could, even without any measurements being made, be *guessed* as zero to sufficient accuracy, as that of HD 11738 and the vast majority of all other stars certainly could?

The radial velocity of HD 11738 was first observed on 2002 September 29, the selfsame night as that upon which the last two stars treated above were first re-observed after a gap of 28 years. The newly enlarged programme took — is still

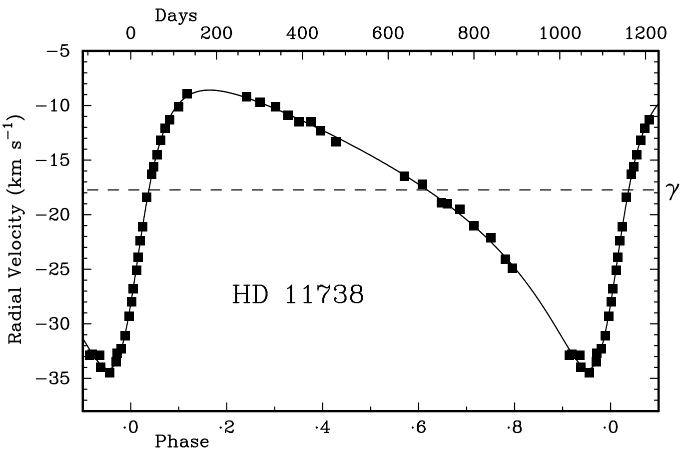


FIG. 4

Just like Fig. 1, but for HD 11738. The observations in this case began only in 2002, and all 42 of them have been made at Cambridge with the *Coravel*. The three annoying gaps in phase coverage arise from the fact that the orbital period differs by only 22 days from the exact value of three years (see text). Whereas the observer is at quite a high northern latitude, the star is south of the ecliptic, and the effective observing season is little more than six months. Thus on the first observed circuit of the orbit there were unavoidably three phase gaps of about six months each, and subsequently they are each reduced by about 22 days per three-year revolution, so it would take about eight circuits (24 years) to close the gaps completely. Only a third of that time has elapsed since the star was discovered to be a spectroscopic binary. Years ago the writer would have thought nothing of retaining the star on the observing programme for another 16 years until the orbit would be nicely covered, but he regrets that that no longer appears a sensible option. BD +59°224 (Fig. 1) is rather analogous in having a period close to an integral number of years, but because the integer is larger (five) the gaps are smaller in terms of phase and appear less vexing.

taking — time to execute, and it was not until 2006 that the third measurement of HD 11738 revealed its binary nature. There are now 42 velocities, set out in Table IV, available for the solution of the orbit, which is shown in Fig. 4. That figure shows in a more extreme fashion than Fig. 1 the unevenness in phase coverage of an orbit whose period is close to a small integral number of years. Although cosmetically disturbing, the unevenness scarcely detracts from the precision and reliability of the orbit. The orbital elements are included in Table VII, where the period is seen to be 1118·5 days (about 3·06 years), determined to better than a day, and the eccentricity is a little over 0·5. The mass function in this case is quite significant, about a seventh of a solar mass. If we were to assign (admittedly rather *ex cathedra*) a mass of 2 $M_\odot$ to the primary star, the secondary would need to have a mass of at least 1·1 $M_\odot$ and therefore to be no later than about G0 if it were a single main-sequence star; it could be up to 4 magnitudes or so fainter than the primary. No sign of its presence has been seen in the radial-velocity traces, and none is apparent as inflexions in the velocity curve of Fig. 4 in the vicinity of the $\gamma$-velocity. The rotational velocity of HD 11738 is very small; too many of the individually determined values are zero, at which the distribution is truncated since negative values are of course not sensible or permitted, for the mean value to be reliable.

*ν Ceti (HR 754, HD 16161)*

Nu Ceti, a little brighter than the fifth magnitude, is the faintest of the six stars that form the quasi-circular asterism that is usually considered to represent the 'head' of Cetus*, although Bayer[23] placed it in the neck. Several sets of *UBV* photometry are available; we refrain from citing all the references, but note that an observer who has proved very reliable is Cousins[25], who found[26] $V = 4^{m}{\cdot}86$, $(B-V) = 0^{m}{\cdot}88$, $(U-B) = 0^{m}{\cdot}52$. As recounted in the last paper[27] in this series, about fifty years ago the 'assistant observer' Noel Argue was deputed by the then Cambridge Director, Redman, to obtain, as a guest investigator at Kitt Peak, photometry of stars on the Cambridge narrow-band programmes; he[28] obtained $V$ and $(B-V)$ identical with Cousins' values, and $(U-B) = 0^{m}{\cdot}54$. The only serious discrepancy among all the authors who undertook normal photoelectric photometry is that of the $V$ magnitude of $4^{m}{\cdot}94$ given by Miczaika[29]. Somewhat more discrepant still is the $4^{m}{\cdot}97$ of the Lutzes[30], but they were concerned to measure separately the $9^{m}$ visual companion 8″ away, and therefore would have been using a diaphragm smaller than would be usual to define the measured area of sky around the star image. Of course they discussed that problem in their paper, reporting the results of observing standard stars through diaphragms of different sizes, but they seem to suggest that in the end their results are reasonably reliable. They give the *UBV* data for the two stars separately and then combined. What is not made clear in the text of their paper is that the combined magnitude does not arise from a mathematical summation

*Though its name is Latin for 'whale', Cetus has usually been represented in star atlases, at least from the time of Bayer[23] more than 400 years ago, as a wholly imaginary curious-looking creature with the fierce head and mouth of a dinosaur, front paws rather like a dog's, and a coiled tail. For example, Ridpath[24] illustrates it, and comments, "Cetus was visualized by the Greeks as a hybrid creature, with enormous gaping jaws and the forefeet of a land animal, attached to a scaly body with huge coils like a sea[-]serpent. Hence Cetus is drawn on star maps as a most unlikely[-]looking creature, more comical than frightening, nothing like a whale although it is sometimes identified as one." Some other 'animal' constellations fare hardly better — for example Capricorn usually appears as a half-goat, half-fish representation of the Sumerian god Enki, and Serpens has a large section missing between its head and its tail.

of the individual brightnesses of the components — it must have been from a separate observation with a diaphragm large enough to include them both. The discrepancy between the two schemes for summing the brightnesses is illustrated in Table V here. It shows the magnitudes that the Lutzes gave for the components separately and then together, and also the magnitudes obtained by the summation (by me) of those of the individual components. The evident shortfall in the total brightness in the Lutzes' summation seems to indicate that the use of a small diaphragm, possibly with the star of interest off-centre in an effort to reduce contamination by the other one, involved the loss of a good deal more of the total flux of the observed stars (more than $0^{m}\cdot1$) than those authors' experiments with standard stars suggested.

TABLE V

*Magnitudes of the components of ν Ceti, separately and together*

| | | $V$ | $(B-V)$ | $(U-B)$ |
|---|---|---|---|---|
| Lutz[30] | Primary | 4·97 | 0·87 | 0·56 |
| | Secondary | 9·08 | 0·56 | 0·19 |
| | Both | 4·83 | 0·88 | 0·54 |
| *My* summation | | 4·95 | 0·86 | 0·54 |

Apart from the Lutzes, all the photometrists who have measured ν Ceti photoelectrically must have used diaphragms — as would be usual — large enough to include most of the light of the visual companion as well as that of the principal star; a slight loss of the companion's light would not be too serious, since the whole of it adds only a few hundredths of a magnitude to the total brightness of the system. Miczaika[29] *may* have been an exception, excusing partially his discordant value of $V$; he has a note against his photometry of ν Ceti, saying that there is a $9^{m}$ companion. On the other hand, there are comparably serious discrepancies between Miczaika's magnitudes and those that he quoted from other authors for the stars that he used as standards. It is perhaps of interest to note that the visual magnitude (literally estimated visually) reported in the *HD*[31], which would have been that of the primary alone, is $5^{m}\cdot02$.

The spectral type, G5 in the *HD*, has been given on the MK system[32] as G8 III (with the rider 'strong-line') by Miss Roman[33], plain G8 III by Stephenson & Sanwal[34], as G5 III by Miczaika[29], as G7 IIIa by Levato & Abt[35], but subsequently as G3 III by Abt[36] alone. Yoss[37] deduced an 'mk' type of G4 II–III from *DDO*-type photometry (no spectroscopy involved), and $M_V = -0^{m}\cdot2$. There have been several assessments[38–42] of the metallicity of ν Ceti; they are in unusually good mutual accord, all indicating a modest metal deficiency, around [Fe/H] ~ –0·3.

The (revised)[19] *Hipparcos* parallax of ν Ceti, at 9·59 ± 0·23 arc-milliseconds, has an unusually small uncertainty; it translates to a distance modulus of $5^{m}\cdot09 \pm 0^{m}\cdot05$ and thus to an $M_V$ very close to $-0^{m}\cdot2$. That is mentioned here, out of chronological order, so that other assessments may be more easily appreciated. The absolute magnitude has a bearing upon ν Ceti's membership in the 'Ursa Major Group', or 'Ursa Major Stream' as it has sometimes been called. Before she undertook her spectral classifications[33] that were published in 1952, Miss Roman wrote a paper[43] (1949) about that group of stars. The paper has an excellent historical introduction, starting with Proctor[44] in 1870*

* Miss Roman actually says 1869. The annual volumes are out of phase with the calendar year and start in June; Vol. 18 *starts* in 1869 June but Proctor's paper was not published until 1870.

and has tables, first, of all the stars to which different authors had at one time or another attributed membership of the Stream, with indications of which ones — one of them was ν Ceti — she considered to be members. Quantities that she gave for that star were a mean radial velocity, $\rho$, of $+5{\cdot}0 \pm 0{\cdot}6$ km s$^{-1}$, having a discrepancy, $\Delta\rho$, of $+6{\cdot}1$ km s$^{-1}$ from the expected value (none too reassuring!), a $\pi_{trig}$ of $0''{\cdot}004 \pm 0''{\cdot}013$ (to be compared with an expected $\pi_{cluster}$ of $0''{\cdot}010$; satisfactory, but the observed quantity was not of adequate precision), and an $(M_V)_{spec}$ (derived from the type of G5) of $+0^{m}{\cdot}3$, to be compared with $M_V = 0^{m}{\cdot}0$ expected from the 'cluster parallax'.

Miczaika[29], too, considered that the cluster parallax for ν Ceti should be $0''{\cdot}010$, corresponding to an $M_V$ of $-0^{m}{\cdot}06$, and that the $(M_V)_{spec}$ was $+0^{m}{\cdot}3$. Johnson & Knuckles[45] agreed that the star was a member of the UMa stream. Eggen[46] included it as a member of his 'Sirius Group', which seems to be the same entity under a different name. In another paper[47] he promised that the three G-type giant stars in his list, one of which was ν Ceti, "will be discussed elsewhere", but that 'where' has not proved identifiable by the present writer — at least not, as the assertion implies, in a paper that was then in the future. Eggen had, in fact, already included ν Ceti in his Table XVIII, "Young-disk-population giants" in an *earlier* paper[48] entitled "Luminosity and velocity distribution of high-luminosity red stars. IV. The G-type giants", so perhaps *that* was really his "elsewhere". That table does not indicate that he thought that ν Ceti belonged to any particular group of stars; it lists for it a distance modulus of $4^{m}{\cdot}4$.

Wilson's usually reliable *K*-line method[49] of determining $M_V$ yielded[50] a value of $+1^{m}{\cdot}0$, which would correspond to a parallax of about $0''{\cdot}016$, rather discordant with the cluster parallax. An earlier discussion by Yoss & Lutz[51] (in part depending on the 'CN anomalies' derived for many stars by Griffin & Redman[52]), of possible effects of chemical abundance differences, led to a somewhat less discordant $\pi_{spec}$ of $0''{\cdot}013$ for ν Ceti. Levato & Abt's spectral classification[35], already mentioned above, was made in connection with a specific investigation of the types of UMa Stream stars, so ν Ceti evidently enjoyed their *imprimatur* as a member of that stream.

### *Radial velocities and orbit of ν Ceti*

By virtue of its brightness, ν Ceti featured in the great Lick survey[53], conducted in the first quarter of the 20th Century, of practically all stars brighter than $5^{m}{\cdot}5$. Five radial-velocity measurements were made, four at Lick Observatory itself and one at the Lick out-station in Chile. They are listed at the head of Table VI here, and are seen to have a range of $4{\cdot}2$ km s$^{-1}$, which in the Lick work would be unusually large for a star whose velocity was actually constant, but half the range is attributable to one observation that is noted as being half-weight, and no suggestion was made in the publication that real variation was suspected. The r.m.s. residual of the five observations from the orbit determined below is only $0{\cdot}7$ km s$^{-1}$, so the Lick authors might be seen as a bit conservative in not trusting that their velocities indicated actual variability. Matters rested then for about 60 years, before Beavers & Eitter[54] offered two velocities (not in very good accord with the Lick ones) from their spectrometer at the 24-inch reflector of the Iowa State University at Ames, Iowa, and then de Medeiros & Mayor[55] gave two from the Haute-Provence *Coravel*. Those last two were sufficiently discordant to flag the star as a spectroscopic binary: from the fact that the r.m.s. residual from the mean was given as $4{\cdot}76$ km s$^{-1}$, one could deduce that the two observations differed by just twice that amount.

TABLE VI

*Radial-velocity observations of ν Ceti*

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

| *Date (UT)* | *MJD* | *Velocity* *km s⁻¹* | *Phase* | *(O – C)* *km s⁻¹* |
|---|---|---|---|---|
| 1918 Jan. 28·13★ | 21621·13 | +8·4 | $\overline{43}$·571 | +0·7 |
| Oct. 21·41★ | 887·41 | +4·2 | ·943 | −0·5 |
| 1919 Nov. 10·43★ | 22272·43 | +6·2 | $\overline{42}$·482 | −0·1 |
| 1921 Nov. 4·24★ | 22997·24 | +6·0 | $\overline{41}$·497 | −0·6 |
| 1923 Oct. 19·42★ | 23711·42 | +5·4 | $\overline{40}$·496 | −1·2 |
| 1977 Jan. 2·10† | 43145·10 | +9·6 | $\overline{13}$·696 | +0·6 |
| 1978 Oct. 28·32† | 43809·32 | +8·2 | $\overline{12}$·626 | −0·2 |
| 1986 Nov. 18·89‡ | 46752·89 | +9·2 | $\overline{8}$·746 | 0·0 |
| 1987 Sept. 17·11‡ | 47055·11 | −0·3 | $\overline{7}$·169 | −0·1 |
| 2002 Sept. 2·14 | 52519·14 | +8·9 | 0·816 | 0·0 |
| Oct. 28·09 | 575·09 | +6·8 | ·895 | −0·2 |
| 2003 Jan. 7·89 | 52646·89 | +2·0 | 0·995 | +0·1 |
| Feb. 14·82 | 684·82 | −0·3 | 1·048 | 0·0 |
| Aug. 30·12 | 881·12 | +3·1 | ·323 | −0·1 |
| Sept. 24·13 | 906·13 | +3·8 | ·358 | −0·2 |
| Oct. 17·04 | 929·04 | +4·7 | ·390 | +0·1 |
| Nov. 13·03 | 956·03 | +5·3 | ·428 | −0·1 |
| Dec. 15·90 | 988·90 | +6·2 | ·474 | 0·0 |
| 2004 Jan. 24·86 | 53028·86 | +7·2 | 1·530 | +0·1 |
| Feb. 25·80 | 060·80 | +7·8 | ·574 | 0·0 |
| Aug. 20·15 | 237·15 | +8·9 | ·821 | +0·1 |
| Sept. 1·15 | 249·15 | +8·5 | ·838 | 0·0 |
| 15·13 | 263·13 | +8·1 | ·857 | 0·0 |
| 26·15 | 274·15 | +7·7 | ·873 | 0·0 |
| Oct. 19·04 | 297·04 | +6·5 | ·905 | 0·0 |
| Nov. 5·04 | 314·04 | +5·5 | ·929 | 0·0 |
| 14·03 | 323·03 | +4·9 | ·941 | +0·1 |
| 20·06 | 329·06 | +4·2 | ·950 | −0·2 |
| Dec. 26·87 | 365·87 | +1·7 | 2·001 | +0·2 |
| 2005 Jan. 4·92 | 53374·92 | +0·9 | 2·014 | 0·0 |
| 12·88 | 382·88 | +0·3 | ·025 | −0·2 |
| Feb. 12·80 | 413·80 | −0·5 | ·068 | +0·2 |
| Aug. 13·15 | 595·15 | +3·3 | ·322 | +0·1 |
| Sept. 17·14 | 630·14 | +4·1 | ·371 | −0·1 |
| Nov. 7·05 | 681·05 | +5·7 | ·442 | +0·1 |
| Dec. 16·96 | 720·96 | +6·5 | ·498 | −0·1 |
| 2006 Jan. 28·83 | 53763·83 | +7·6 | 2·558 | +0·1 |
| Feb. 25·79 | 791·79 | +7·8 | ·597 | −0·3 |
| Mar. 3·78 | 797·78 | +7·9 | ·606 | −0·3 |
| Aug. 30·17 | 977·17 | +8·3 | ·857 | +0·2 |
| Sept. 20·12 | 998·12 | +7·3 | ·886 | 0·0 |
| Nov. 17·06 | 54056·06 | +3·3 | ·967 | −0·1 |
| 24·05 | 063·05 | +2·7 | ·977 | −0·1 |

TABLE VI (*concluded*)

| Date (UT) | MJD | Velocity km s⁻¹ | Phase | (O–C) km s⁻¹ |
|---|---|---|---|---|
| 2007 Feb. 14·82 | 54145·82 | −1·0 | 3·093 | 0·0 |
| Aug. 10·14 | 322·14 | +3·8 | ·340 | +0·2 |
| 2008 Jan. 7·89 | 54472·89 | +7·6 | 3·551 | +0·2 |
| Sept. 28·08 | 737·08 | +5·9 | ·920 | 0·0 |
| 2009 Feb. 21·81 | 54883·81 | −0·7 | 4·126 | +0·1 |
| Sept. 10·18 | 55084·18 | +5·0 | ·406 | +0·1 |
| Nov. 25·94 | 160·94 | +6·7 | ·514 | −0·2 |
| 2010 Feb. 17·82 | 55244·82 | +8·4 | 4·631 | −0·1 |
| Mar. 1·76 | 256·76 | +8·7 | ·648 | +0·1 |
| 2011 Sept. 28·11 | 55832·11 | +6·0 | 5·453 | +0·2 |
| 2012 Mar. 7·78 | 55993·78 | +8·8 | 5·679 | −0·1 |
| 2013 Jan. 9·87 | 56301·87 | −0·9 | 6·111 | 0·0 |
| Feb. 2·80 | 325·80 | −0·8 | ·144 | −0·2 |
| Mar. 2·76 | 353·76 | −0·1 | ·183 | −0·2 |
| Sept. 15·11 | 550·11 | +6·1 | ·458 | +0·2 |
| 2014 Sept. 8·20 | 56908·20 | +3·9 | 6·959 | +0·1 |

*Lick photographic observation[53]; weight 1/30
†Ames spectrometer observation[54]; weight 1/10
‡Haute-Provence *Coravel* observation[55]; weight 1

Exactly the same information as was given by de Medeiros & Mayor, apart from the strange omission of the actual radial velocity, was repeated in a different journal by de Medeiros, da Silva & Maia[56].

Three years after de Medeiros & Mayor published, at about the time that their *Coravel* spectrometer was de-commissioned, their catalogue[55] of mean velocities, they made available on the Web a great list of the individual radial velocities that underlay those mean values. In almost all cases the mean of the velocities from the Web disagrees with the previously published mean, but we have to suppose that the individual values are the ones to trust. The present writer, having eagerly scanned that list, adopted about sixty promising objects onto his programme of spectroscopic binaries needing orbit determinations. One of them was $\nu$ Ceti, observations of which were promptly begun in 2002 and have been continued to date. There are 50 of them, shown in Table VI after the Lick, Ames, and Haute-Provence velocities. They readily yield the orbit which is plotted in Fig. 5 and whose elements are included in Table VII. In the solution of the orbit, in an effort to put all the observations on the Cambridge zero-point[57] the others were all increased by 0·8 km s$^{-1}$, and to put the Cambridge ones themselves onto it, 0·5 km s$^{-1}$ was subtracted from their 'as reduced' values, to make the total offset between the Haute-Provence and Cambridge *Coravel*s about what is to be expected from Fig. 1 in ref. 58. Only the Cambridge and Haute-Provence velocities have been given full weight in the solution; the Ames ones have been weighted 1/10 and Lick ones 1/30, to bring their variances into approximate accord with those from the *Coravel*s.

The period of 714·5 days is 16 days short of two years, so, just as in the cases of BD +59° 224 and HD 11738, there are unavoidable gaps in the phase coverage of the orbit, gaps that would take a long time to close. The phasings

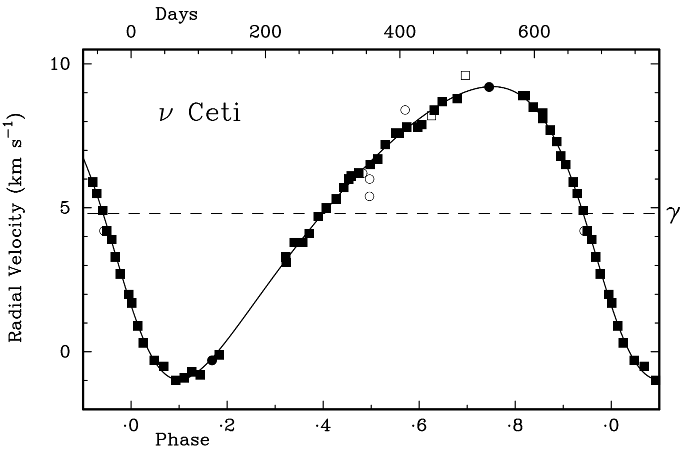


FIG. 5

The observed radial velocities of ν Ceti plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The orbit very largely depends on the author's 50 observations, obtained with the Cambridge *Coravel* and plotted as usual with filled squares. Three other sources are represented in the diagram. There are five measurements made the best part of a century ago in the comprehensive survey[53] made at the Lick Observatory of all the bright stars; they are plotted as open circles and were accorded a weight of 1⁄30 in the solution of the orbit. Then there are two measures made with the Ames spectrometer by Beavers & Eitter[54] (open squares; weight 1⁄10), and two made with the Haute-Provence *Coravel* and quasi-published by de Medeiros & Mayor[55] (filled circles; full weight). This orbit is another that has a period close to a small integral number of years — it is 16 days short of two years, so the phase gaps of about six months in the initial orbit are in principle reduced by 16 days in each succeeding two-year cycle, so it would take about 11 such cycles to close the gaps altogether. The present writer has been observing ν Ceti for only six cycles, and has thereby been able to fill in about half the widths of the two very large initial gaps in phase coverage. One of the Haute-Provence measures, made 14 cycles back, happens to fall right in the middle of one of the remaining gaps (phase ·75), rendering it less conspicuous.

will evidently migrate around the year at a rate of 16 days in every two-year orbital cycle, in an interval of 714/16 years, about 45 years. Suitable diligence at the appropriate ends of the observing seasons should of course enable the phase coverage to be equalized in a shorter time than that. In the case of ν Ceti, which is at only 5° declination and is 10° south of the ecliptic, the effective observing season from Cambridge ($\phi \sim 52°$) is little more than six months, from August to February, so the intervening six-month lacunae could in principle be filled in within about 23 years, half of which time has already elapsed in the course of the observing campaign, so the phase gaps have in fact been halved in comparison with how they would appear from the observations possible in just a single cycle. They do not actually detract significantly from the reliability of the orbit, and the only real benefit that could be achieved by the prolongation of the observing campaign for another decade or so — if the observer were of an age to contemplate that — would be cosmetic. The orbit could actually be viewed with considerable favour as it stands, since the r.m.s. residual of the Cambridge observations, 0·13 km $s^{-1}$, is one of the smallest ever found in this series of papers. It admittedly does not bear comparison with the precisions

TABLE VII

*Orbital elements for HD 9592, HD 10171, HD 11738, and ν Ceti*

| *Element* | *HD 9592* | *HD 10171* | *HD 11738* | *ν Ceti* |
|---|---|---|---|---|
| $P$ (days) | 1002·5 ± 0·9 | 640·8 ± 0·5 | 1118·5 ± 0·8 | 714·48 ± 0·15 |
| $T$ (MJD) | 54493 ± 23 | 54206·4 ± 2·5 | 54391·4 ± 1·1 | 53364·9 ± 1·9 |
| $\gamma$ (km s$^{-1}$) | −2·90 ± 0·03 | −29·94 ± 0·04 | −17·73 ± 0·06 | +4·81 ± 0·02 |
| $K$ (km s$^{-1}$) | 4·51 ± 0·04 | 4·28 ± 0·06 | 12·78 ± 0·07 | 5·09 ± 0·03 |
| $e$ | 0·057 ± 0·009 | 0·380 ± 0·010 | 0·535 ± 0·004 | 0·274 ± 0·005 |
| $\omega$ (degrees) | 160 ± 8 | 196·3 ± 1·8 | 237·0 ± 0·7 | 119·5 ± 1·1 |
| $a_1 \sin i$ (Gm) | 62·1 ± 0·54 | 34·9 ± 0·58 | 166·1 ± 1·1 | 48·1 ± 0·3 |
| $f(m)$ ($M_\odot$) | 0·00953 ± 0·00025 | 0·00414 ± 0·00017 | 0·1462 ± 0·0029 | 0·00871 ± 0·00016 |
| R.m.s. residual (wt. 1) (km s$^{-1}$) | 0·18 | 0·24 | 0·28 | 0·13 |

currently attained by instruments used by observers whose principal concern is to detect reflex motions of stars from the circulation of planets around them, but such observers are not so numerous and keen that they observe all the stars that are on the present writer's programme and whose orbits may not need 'planetary' precision for adequate documentation!

The only comment to be made on the orbital elements of ν Ceti is that the mass function is so small that it is not at all surprising that no evidence has been noticed of the companion star in the radial-velocity traces. Those traces, however, furnish an estimate of the rotational velocity of the star, at 2·6 ± 0·2 km s$^{-1}$, although as usual we caution that such an estimate should not be trusted to better than ±1 km s$^{-1}$; the Haute-Provence figure[55,56] is 2·7 km s$^{-1}$, but as it stems from only two observations and is no more free from potential systematic error than the Cambridge value, it is certainly not to be preferred to the latter.

Hekker & Melendez, in a paper[59] in a series entitled *Precise radial velocities of giant stars*, give a rotational velocity of 4·70 km s$^{-1}$ for ν Ceti. Despite the precision with which it is specified, it does not promise to be particularly reliable. Whereas the *Coravel*s' line profiles are in effect averaged over the ~1500 spectral lines passed by the mask within the instrument, the Hekker & Melendez ones come from measurements of the half-widths of just seven lines. The dispersion of the half-widths is claimed to be the unbelievably small value of 0·025 mÅ, and the mean value is interpreted in terms of a calibration involving measurements made elsewhere. By comparison, the *Coravel* method seems rather straightforward, comparing the widths averaged from a relatively enormous number of lines directly between different stars, among which a sizeable fraction shows a particular minimum value that must represent negligible rotation, and the broadening of others is quantified as rotational velocity through plausible numerical modelling of a rotating, conventionally limb-darkened, stellar disc.

Caution over not stating quantities to unwarranted precisions seems to have declined in recent years. The two most recent papers retrieved by *Simbad* for ν Ceti are examples. The parallax uncertainty of 5% evidently applies also to the distance, while the luminosity must correspondingly be uncertain by 10%; yet we are told[22] that the star's distance is 104·980 pc, and that its luminosity is 116·44 times that of the Sun — numbers given to precisions thousands of times higher than the accuracy of the underlying data. We are also told[21] that, in order to avoid spoiling the precision of the hoped-for *Gaia* parallax, we must determine the radial velocity of ν Ceti to a precision of 167·30 km $s^{-1}$, or, if we were to look at it another way, to 167·51 km $s^{-1}$ — as if someone might meet one criterion and not the other, or indeed make a velocity measurement that was that marginal at all!

*ν Ceti B*

Nu Ceti has a relatively faint but obvious visual companion. The system was first observed by Wilhelm Struve with the then-new 9-inch *Fraunhofer* refractor at Dorpat. He listed it as Σ 281 in his initial *Catalogus Novus*[60] of 1827, where it is shown as being in Category III (separations 4–8 seconds of arc); the magnitudes are given as 5 and 12 and there is a note, "difficilis". Struve was also the first to make micrometer measurements of the pair; he published four of them in his monumental *Mensurae Micrometricae*[61] in 1837, noting, as he typically did, their colours, as yellow and "ash". He found the separation of the components to be 7″·72 and the position angle to be 83°·3; the relative positions have remained, within observational error, the same ever since. Inasmuch as the primary star has an accurately determined proper motion of a little over 3″ per century, which the secondary evidently shares exactly, it is clear (quite apart from the statistical improbability of finding two such stars so close together) that ν Ceti is a physical double star; the separation of the stars, as we see it in projection on the sky, is as much as 800 AU, so it is understandable that orbital motion is very slow. In the ν Ceti system, whose total may must be near 4 $M_\odot$, a circular orbit with a radius equal to the minimum present separation of the stars (800 AU) would have a period of $800^{1\cdot5}/\sqrt{4}$ years — about 11 000 years, so an indicative estimate of the orbital motion might be 3° per century.

The system features in the irrepressible 'Admiral' Smyth's *Bedford Catalogue*[62], which describes objects observed by its author with his 6-inch refractor; it receives the Roman number CII. Smyth comments, "A 4½, pale yellow; B 15, blue. This very delicate object is one of those marked by Σ "difficilis;" and not without reason, for the *comes* can only be seen by glimpses, on ardent gazing; and its details are therefore mere estimations."* One has to wonder how he could have seen that it was blue (which in fact it is probably not) when it could be seen "only by glimpses".

Webb himself[63] (page 83) gave the magnitudes of the ν Ceti pair, very plausibly, as 5 and 9·6 — a difference of $4^{m}\cdot6$; whether they were his own estimates is not clear. Those same magnitudes were listed in Burnham's great catalogue of double stars[65] of 1906, and in Aitken's update[66] of it in 1935. We saw in Table V above that the Lutzes' measurement gave a $\Delta V$ of only $4^{m}\cdot11$ for the system. Stephenson[67] and Stephenson & Sanwal[34] reported the spectral type of the companion as F7V, and gave absolute magnitudes of –0·6 and +4·2

*Magnitude scales for stars below naked-eye visibility had not been formalized at the time that Smyth was writing, and observers seemed to feel free to adopt their own conventions. Smyth considered the faintest star that he could see in good conditions with his 6-inch refractor to be magnitude 16. Webb[63] (page 6) actually gives a table of magnitude equivalences between Smyth, Struve, (Sir J.) Herschel, and Argelander. Struve's magnitudes are the most similar to our present-day ones; by comparison, Smyth's are seen to run away at the faint end, so while Smyth's magnitude 11 is Struve's 10·0, his 12 and 13 are only equivalent to Struve's 10·4 and 10·7, and his 14, 15 and 16 are *all* equivalent to Struve's 10·9! Agreement was not reached until after 1856, when Pogson[64] made the proposal that the brightness ratio between successive magnitudes should be *defined* as 2·512 (the fifth root of 100), thus making five magnitudes a factor of exactly 100, as had long been recognized as the approximate factor between stars of the first and sixth magnitudes. Of course, even when the principle was accepted, it was quite difficult to implement it before the days of photoelectric detectors.

for the two stars — a $\Delta V$ of $4^{m}\cdot 8$. They ascribed that to Wallenqvist[68], who from his own measurements gave $\Delta V = 4^{m}\cdot 80 \pm 0^{m}\cdot 03$; in a much later revision[69] of his catalogue, however, he substituted the magnitudes that were found by the Lutzes[30] and are shown above in Table V, notwithstanding that they make his own result appear to be in error by 23 standard deviations. Ferrer[70], in a paper specifically devoted to magnitude differences of double stars, found a $\Delta V$ of $4^{m}\cdot 28$ with a claimed "mean error" of only $0^{m}\cdot 044$.

As a matter of curiosity, the second time that the writer measured the radial velocity of the principal star of ν Ceti with the *Coravel* instrument, he tried to observe the companion too — and obtained a result. Thereafter he made another 20 measurements, many but not all of them on the same occasions as he measured the primary. The radial velocities are set out in Table VIII below, but before discussing them we might touch upon the photometric aspect of the observations. Of course the *Coravel* is not at all suited to stellar photometry, since it does not reckon to measure the complete star image but on the contrary employs a relatively narrow entrance slit whose actual *purpose* is to *restrict* the light entering the instrument to that part of it that falls within a small rectangle, about 1 × 4 seconds of arc. It might be hoped, however, that similar fractions of the light would be passed by the slit from each of two mutually adjacent stars observed at adjacent times. The counting rates from ν Ceti A and B have been compared for each of the 12 cases where the stars were observed consecutively. A nominal allowance of 20 per second, about 5–10% of the typical counting rate on the faint star, has been made for the dark count of the photomultiplier. None too encouragingly, the apparent brightness ratios range from 44 to 88, but are quite concentrated towards the middle of that range, and have a mean of $65 \pm 4$, corresponding in magnitude terms to $4^{m}\cdot 54 \pm 0^{m}\cdot 08$. The *Coravel* operates in a wavelength range approximating to the photometric *B* band. The $(B - V)$ colour index of the main-sequence companion can be expected — and has been measured[30] — to be about $0^{m}\cdot 3$ bluer than that of the primary, so the $\Delta V$ expected on the basis of the *Coravel* counting rates would be about $4^{m}\cdot 8$. That agrees nicely with Wallenqvist's own measure[68] of $4^{m}\cdot 80 \pm 0^{m}\cdot 03$, but compares poorly with the $\Delta V$ of $4^{m}\cdot 11$ given by the Lutzes and the $4^{m}\cdot 28$ by Ferrer, and the $\Delta B$ of $3^{m}\cdot 80$ found by the former. There is a bad discrepancy, a factor of two in flux, between that $\Delta B$ and our $4^{m}\cdot 54$, but Ferrer's $\Delta V$ (to say nothing of all the visual estimates, which tend to agree rather well with the *Coravel* value) is also larger than the Lutzes' one. The counting-rate ratio itself has been seen to be liable to considerable uncertainty. It should also be remarked that the *Coravel* ratio, although already larger than the 'official' photometric ones, must actually be regarded as *under*-estimated, because (as will be shown immediately below) there is much evidence of contamination of the light of the fainter component with spillage from the brighter one, so the faint one must really be somewhat fainter even than its counting rate suggests. There is, therefore, a degree of conflict that cannot be resolved here, between some of the photometric estimates of the $\Delta m$ and the experience of the writer with the radial-velocity instrument.

The 21 radial-velocity measurements of ν Ceti B listed in Table VIII (they have been adjusted by an offset of $-1\cdot 0$ km s$^{-1}$ as suggested by the diagram in ref. 58, noted above, for particularly blue objects) show a total range of nearly 5 km s$^{-1}$. That is plenty large enough, in the normal way, to warrant the conclusion that the star is a spectroscopic binary. Unfortunately, in this case it appears that much, if not all, of the spread beyond that which could ordinarily be attributed just to observational uncertainty must be due to contamination of the light

TABLE VIII

*Radial-velocity observations of ν Ceti B*

*The observations were made with the Cambridge Coravel*

| *Date (UT)* | *MJD* | *Velocity* *km s*$^{-1}$ | *Primary star* *Phase* | *km s*$^{-1}$ |
|---|---|---|---|---|
| 2002 Oct. 28·09 | 52575·09 | +7·2 | 0·895 | +7·0 |
| 2003 Jan. 7·89 | 52646·89 | 4·8 | 0·995 | +1·9 |
| Feb. 14·82 | 684·82 | 3·7 | 1·048 | −0·3 |
| Oct. 17·04 | 929·04 | 4·3 | ·390 | +4·6 |
| Nov. 13·03 | 956·03 | 6·4 | ·428 | +5·4 |
| Dec. 15·90 | 988·90 | 5·1 | ·474 | +6·2 |
| 2004 Jan. 24·86 | 53028·86 | 6·5 | 1·530 | +7·1 |
| Feb. 25·80 | 060·80 | 5·7 | ·574 | +7·8 |
| Aug. 20·15 | 237·15 | 6·4 | ·821 | +8·8 |
| 2006 Sept. 11·13 | 53989·13 | 7·3 | 2·874 | +7·7 |
| Nov. 25·91 | 54064·91 | 4·5 | ·980 | +2·7 |
| 2007 Jan. 23·76 | 54123·76 | 4·4 | 3·062 | −0·6 |
| Feb. 1·79 | 132·79 | 2·4 | ·075 | −0·8 |
| 3·76 | 134·76 | 2·6 | ·078 | −0·9 |
| Oct. 10·02 | 383·02 | 6·2 | ·425 | +5·3 |
| 2008 Feb. 12·77 | 54508·77 | 5·9 | 3·601 | +8·1 |
| 2009 Jan. 6·80 | 54837·80 | 4·8 | 4·061 | −0·6 |
| Nov. 25·95 | 55160·95 | 6·2 | ·514 | +6·9 |
| 2011 Sept. 28·10 | 55832·10 | 4·6 | 5·453 | +5·8 |
| 2013 Jan. 9·86 | 56301·86 | 4·7 | 6·111 | −0·9 |
| Feb. 2·81 | 325·81 | +2·0 | ·144 | −0·6 |

of the faint star with that of the brighter one which, as we have seen, is fifty (arguably more!) times brighter and only eight seconds of arc away. The angular separation and $\Delta m$ are extraordinarily similar to those of $\phi$ Psc[14,71], in whose case the faint star made such an interesting subject for Paper 100 of this series. In that case, because both stars were binaries, the residuals from the orbit of the faint component could be plotted against the velocity difference between the components to demonstrate and evaluate the contamination; the large velocity amplitudes, however, sometimes made the contamination almost irrelevant. Moreover the observational situation was greatly ameliorated by the availability of the 200-inch telescope, on which a rather small amount of observing time commandeered from the official programme delivered the *coup de grâce* to what had seemed to be an intractable problem[71]. The demonstrated falsification of the velocities of $\phi$ Psc B was sometimes as large as 5 km s$^{-1}$ and in one case 10. Here, the effect is less drastic, but that may well be only because a limit is set by the maximum difference of only about 6 km s$^{-1}$ that can ever occur between the velocities of the two stars. It is best visualized by superimposing the velocities of the faint star, B, upon the orbital velocity curve (copied directly from Fig. 5) of the bright one, A, and that is done in Fig. 6. It seems evident that the velocities measured for B are systematically 'dragged' towards those of A by amounts that, after allowance for ordinary observational error which could be expected to be

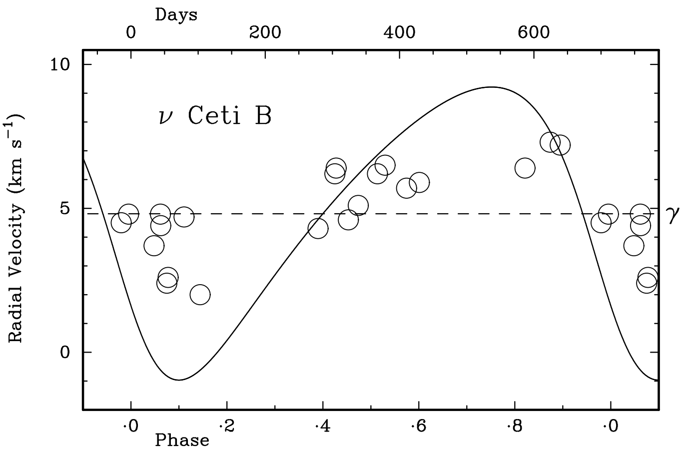


FIG. 6

Radial velocities of $\nu$ Ceti B plotted against the phase of the primary star. Although it is component B whose velocities are plotted here, by the open circles, the full line shows the *primary*'s (A's) orbital velocity, while the dotted horizontal line shows its $\gamma$-velocity. B gives radial-velocity traces showing a weak and broad 'dip', whereas A, which is fifty or more times brighter and only 8″ away, gives a deep and narrow one. This figure is offered as evidence for the author's conclusion that the spread in the apparent radial velocities of the B component is related to the velocity of A at the relevant times. It appears that the velocity measured for B is 'dragged' towards that of A, no doubt by slight spillage of the light of A into the entrance slit of the spectrometer when B was centred in it. The amount of spillage would vary according to the seeing, and it would pull the measured velocity towards its own (A's) velocity by much more than the relative amount of the spilled light entering the slit owing to A's intrinsically much stronger dip. It is suggested that *all* of the apparent variation of velocity can be attributed to the effects of inadvertent blending of the light of B with small and variable amounts of that of A, plus ordinary accidental error of the order of 1 km $s^{-1}$, without any need to suppose that B itself actually varies in radial velocity at all.

of the order of 1 km $s^{-1}$, range up to about half the difference of velocities if the real velocity of B is considered to be constant.

It does not by any means follow that, if the velocity of B is sometimes dragged as much as half-way to that of A by the unfortunate admixture of some light from A with that of B, then half the light in the mixture must be from A. The forms of the radial-velocity 'dips' have to be considered too. Whereas A gives a nice sharp dip whose depth is about 30% of the 'continuum' upon which it is imposed, B gives a shallow dip that is also quite wide (no doubt as a result of rotational broadening) and thus still more liable to be shifted by adulteration with a small proportion of the A dip. The 'equivalent width' (defined exactly as in spectroscopy) of B's dip is only just over half that of A's; the mean value found for the projected rotational velocity of B is $12{\cdot}8 \pm 0{\cdot}5$ km $s^{-1}$. (The usual *caveat* applies, to the effect that a $v \sin i$ estimated purely from the dip width found with the radial-velocity spectrometer ought not to be trusted to better than 1 km $s^{-1}$.)

The formal mean of the radial velocities found for B in Table VIII is $+5{\cdot}0 \pm 1{\cdot}0$ km $s^{-1}$. That is almost identical with the $\gamma$-velocity of A ($+4{\cdot}81 \pm 0{\cdot}02$ km $s^{-1}$), but the quantitative similarity cannot honestly be taken at face value. The velocities measured for B have been shown not to be independent of those of

A, so the exact mean velocity found for B is at the mercy of the distribution of the timings of the observations in relation to the phasing of A, and therefore is *very* non-uniform owing to the unhelpful approximation of A's period to two years, as discussed above. The mean velocities of both A and B are also critically dependent upon the empirical corrections that have been applied globally to their velocities on account of their respective colours. Those disclaimers, however, are not intended to be an oblique admission that really there is *no* useful information in the observations reported here for ν Ceti B! The deductions that the writer believes can genuinely be made from the observations and this discussion of the radial velocity of B are that (*a*) it is so close to that of A that it certainly confirms the pair as being a genuine physical binary system, and (*b*) there is no evidence of real radial-velocity variability that would lead us to imagine that B is anything other than a single star.

## *References*

(1) J. C. Kapteyn, *Plan of Selected Areas* (Hoitsema, Groningen), 1906, p. 59.
(2) R. F. Griffin, *MNRAS*, **219**, 95, 1986.
(3) A. Schwassmann & P. J. van Rhijn, *Bergedorfer Spektral-Durchmusterung* (Hamburger Sternwarte, Bergedorf), **1**, 79, 1935.
(4) R. O. Gray & B. A. Skiff, *PASP*, **116**, 1123, 2004.
(5) O. J. Lee, T. J. Gore & D. W. Bartlett, *Ann. Dearborn Obs.*, **5**, 1C, 1947.
(6) E. S. Brodskaya, *Izv. Krim. Astrof. Obs.*, **24**, 160, 1960.
(7) U. Sjogren, *Ark. Astr.*, **3**, 339, 1964.
(8) P. C. Keenan & R. C. McNeil, *ApJS*, **71**, 245, 1989.
(9) A. C. Maury, *HA*, **28**, part I, pp. 93, 99, & 110, 1897.
(10) R. F. Griffin, *The Observatory*, **125**, 1, 2005 (Paper 180).
(11) R. F. Griffin, *MNRAS*, **219**, 95, 1986 (*M.N.* Paper XIII).
(12) W. L. Gorza & J. F. Heard, *PDDO*, **3**, 97, 1971.
(13) R. F. Griffin, *The Observatory*, **104**, 148, 1984 (Paper 56).
(14) R. F. Griffin & G. H. Herbig, *The Observatory*, **111**, 155, 1991 (Paper 99).
(15) R. F. Griffin, *The Observatory*, **111**, 201, 1991 (Paper 100).
(16) C. Soubiran *et al.*, *A&A*, **515A**, 111, 2010.
(17) R. F. Griffin, *ApJ*, **148**, 465, 1967.
(18) R. F. Griffin & A. P. Cornell, *MNRAS*, **371**, 1140, 2006 (*M.N.* Paper XVI).
(19) F. van Leeuwen, *Hipparcos, the new reduction of the raw data* (Springer, Dordrecht), 2007.
(20) (Announced by) G. A. Gontcharov, *Astr. Lett.*, **32**, 759, 2006.
(21) (Announced by) J. H. J. de Bruijne & A.-C. Eilers, *A&A*, **546A**, 61, 2012.
(22) (Announced by) I. McDonald, A. A. Zijlstra & M. I. Boyer, *MNRAS*, **427**, 343, 2012.
(23) J. Bayer, *Uranometria* (Mang, Augsburg), 1603.
(24) http://www.ianridpath.com/startales/cetus.htm
(25) D. Kilkenny, in C. Sterken & D. W. Kurtz (eds.), *ASP Conf. Ser.*, **96**, 1, 2002.
(26) A. W. J. Cousins, *MNASSA*, **22**, 12, 1963.
(27) R. F. Griffin, *The Observatory*, **134**, 316, 2014.
(28) A. N. Argue, *MNRAS*, **133**, 475, 1966.
(29) G. R. Miczaika, *AJ*, **59**, 233, 1954.
(30) T. E. & J. H. Lutz, *AJ*, **82**, 431, 1977.
(31) A. J. Cannon & E. C. Pickering, *HA*, **91**, 177, 1918.
(32) W. W. Morgan, P. C. Keenan & E. Kellman, *An Atlas of Stellar Spectra with an Outline of Spectral Classification* (Univ. of Chicago), 1943.
(33) N. G. Roman, *ApJ*, **116**, 122, 1952.
(34) C. B. Stephenson & N. B. Sanwal, *AJ*, **74**, 689, 1969.
(35) H. Levato & H. A. Abt, *PASP*, **90**, 429, 1978.
(36) H. A. Abt, *ApJS*, **59**, 95, 1985.
(37) K. M. Yoss, *AJ*, **104**, 327, 1992.
(38) A. McWilliam, *ApJS*, **74**, 1075, 1990.
(39) B. J. Taylor, *ApJS*, **76**, 715, 1991.
(40) D. F. Gray & K. Brown, *PASP*, **113**, 723, 2001.
(41) D. F. Gray, H. R. Scott & J. E. Postma, *PASP*, **114**, 536, 2002.
(42) S. Hekker & J. Melendez, *A&A*, **475**, 1003, 2007.
(43) N. G. Roman, *ApJ*, **110**, 205, 1949.

(44) R. A. Proctor, *Proc. R. Soc.*, **18**, 169, 1870.
(45) H. L. Johnson & C. F. Knuckels, *ApJ*, **126**, 113, 1957.
(46) O. J. Eggen, *MNRAS*, **118**, 65, 1958.
(47) O. J. Eggen, *AJ*, **89**, 1350, 1984.
(48) O. J. Eggen, *PASP*, **86**, 129, 1974.
(49) O. C. Wilson & M. K. V. Bappu, *ApJ*, **125**, 661, 1957.
(50) O. C. Wilson, *ApJ*, **205**, 823, 1976.
(51) K. M. Yoss & T. E. Lutz, *PASP*, **80**, 717, 1968.
(52) R. F. Griffin & R. O. Redman, *MNRAS*, **120**, 287, 1960.
(53) W. W. Campbell & J. H. Moore, *Publ. Lick Obs.*, **16**, 31, 1928.
(54) W. I. Beavers & J. J. Eitter, *ApJS*, **62**, 147, 1986.
(55) [Announced by] J. R. de Medeiros & M. Mayor, *A&AS*, **139**, 433, 1999.
(56) J. R. de Medeiros, J. R. P. da Silva & M. R. G. Maia, *ApJ*, **578**, 943, 2002.
(57) R. F. Griffin, *MNRAS*, **145**, 163, 1969.
(58) R. F. Griffin & A. Stroe, *JA&A*, **33**, 245, 2012.
(59) (Announced by) S. Hekker & J. Melendez, *A&A*, **475**, 1003, 2007.
(60) F. G. W. Struve, *Catalogus Novus Stellarum Duplicium et Multiplicium* (Typographia Academia, Dorpat), 1827, p. 8*.
(61) F. G. W. Struve, *Stellarum Duplicium et Multiplicium Mensurae Micrometricae per Magnum Fraunhoferi Tubum Annis a 1824 ad 1837 in Specula Dorpatensis* (Typographia Academia, Petropolis), 1837, p. 106.
(62) W. H. Smyth, *A Cycle of Celestial Objects* (Parker, London), 1844, vol. **2**, p. 64.
(63) T. W. Webb, *Celestial Objects for Common Telescopes* (fifth edn.) (Longmans, Green, London), 1894, pp. 6, 83.
(64) N. R. Pogson, *MNRAS*, **17**, 12, 1856.
(65) S. W. Burnham, *General Catalogue of Double Stars Within 121° of the North Pole* (Carnegie Institution of Washington, Washington, D.C.), 1906, Part I, p. 26.
(66) R. G. Aitken, *New General Catalogue of Double Stars Within 120° of the North Pole* (Carnegie Institution of Washington, Washington, D.C.), 1932, **1**, 172.
(67) C. B. Stephenson, *AJ*, **65**, 60, 1960.
(68) A. Wallenqvist, *Uppsala Astr. Obs. Ann.*, **4**, no. 2, 1954.
(69) A. Wallenqvist, *ibid.*, no. 22, 1981.
(70) O. E. Ferrer, *A&A*, **84**, 108, 1980.
(71) R. F. Griffin, *The Observatory*, **111**, 201, 1991 (Paper 100).

*On that page the column headings for RA and Dec are inadvertently reversed.

## REVIEWS

**Nearest Star: The Surprising Science of Our Sun, Second Edition**, by L. Golub & J. M. Pasachoff (Cambridge University Press), 2014. Pp. 297, 23 × 15·5 cm. Price £50/$80 (hardbound; ISBN 978 1 107 05265 9), £17·99/$24·99 (paperback; ISBN 978 1 107 67264 2).

This is a carefully composed, very readable account of the physics of the Sun, written with the non-specialist in mind. There are essentially no equations — instead the relationships between relevant phenomena are explained but without any loss of rigour. The explanations are easy to follow but do not talk down to the readership and do not resort to the dreadful analogies that so bedevil many 'popular science' books. So, that being said, I would not describe it as popular science but solar science for the logical and maybe rational non-specialist.

For me, writing as a specialist of sorts, with 30 or so years' experience at the instrumentation end of space science, even I learned a new word — syzygy — the alignment of three celestial objects, which if nothing else has to be worth about a million points in Scrabble.

One could make niggly uncharitable remarks about the US-centric text — for example, the *SOHO* spacecraft gets quite a lot of coverage and yet ESA, NASA's partner in the production of this most successful scientific spacecraft, doesn't even merit an acknowledgement; which is unusual as the authors have been quite thorough in acknowledging the main intellectual source of particular ideas or discoverers of phenomena. I imagine that NASA was paying some of the bills, but that is a minor quibble about an otherwise thoroughly readable and enjoyable account.

The clarity of writing is apparent in so many examples; from the description of the linking of light and colour to form spectra — "But we do not see colour flashing past us in the air …" — to the physical properties then derived. Other phenomena such as limb darkening, solar neutrinos, the formation of the elements are all excellent stuff; and if you want more, each chapter ends with suggested further reading

Another minor quibble comes from the chapter dealing with descriptions of space missions. For a few pages in Chapter 6, in which various space missions are described, the previously clear human voice degenerates into corporate-management speak. The Japanese spacecraft *Hinode* is described as "an excellent opportunity for highly leveraged US participation in a major mission that is greatly advancing our understanding of the crucial first link in the Sun Earth connection". Most of those words are padding and "highly leveraged" presumably means the US worked a scam that got it some great science at little cost to itself. I suspect that the interaction was much more nuanced than the naked opportunism implied by those words, and that some mutual scientific benefit might also have been a result worth mentioning, if only to illustrate the international cooperative nature of solar science (a point the authors actually make themselves in one of the readable chapters).

One final example: we learn that the *Helioseismic and Magnetic Imager* on the *Solar Dynamics Observatory* enables "line of sight magnetograms with an optical channel for full Stokes polarisation measurements and hence [yes, hence] vector magnetogram determinations". Stokes polarization measurements had not been discussed and certainly not explained at that point — or indeed anywhere else in the book — even the handy four-page glossary fails. It is as if a different author had been brought in to write that stuff — somebody who had not been briefed on the 'science for the non-specialist' target readership. It is a great pity as this chapter diminishes the opinion built up in the previous chapters of the authors as fine educators.

Fortunately Golub and Pasachoff return to their previous excellent form with Chapter 7, which is a very considered discussion on the Sun's influence on climate, which they then use as an example of the way science works in general. Incidentally, this is one of the clearest expositions that I have read on climate change and the difficulties in assigning causes and predicting likely outcomes.

The overwhelming impression from reading this book is of clarity and economy; clarity of explanation and expression and also economy of description; nothing is said that is not needed, and no image is superfluous, each one used to illustrate a particular feature being described. So apart from the few aberrant pages in Chapter 6, I would recommend this book to specialist and non-specialist alike as a fine, 'non-preachy', and concise account of the current state of knowledge of the workings of our local star, the Sun, and also of the instruments by which that information has been obtained. Unusually for such non-specialist books it maintains a running theme of highlighting the intellectual processes being followed to obtain this knowledge, and as such is a valuable addition to books on the more general topic of 'doing science'. — BARRY KENT.

**Catchers of the Light: The Forgotten Lives of the Men and Women who First Photographed the Heavens**, by Stefan Hughes (ArtdeCiel Publishing, Paphos, Cyprus) 2013. Volume 1, pp. 735; Volume 2, pp. 877, 30·5 × 21·5 cm. Price $199 (about £123) (hardbound; ISBN 978 1 4675 7992 6).

There are only four major milestones in the development of astronomy. The first, the introduction of the telescope in 1609, saw astronomers race past the limitations of the naked human eye. Suddenly we could see fainter, and more-distant objects, and also much more detail. But if we wanted to record what was seen we had to get out pen and paper and start drawing. That was rather unsatisfactory because subjective differences were introduced and it was extremely difficult to ascertain whether astronomical objects, like nebulae, were changing with time. The second milestone was the introduction of photography in around 1840. Fortunately the sensitivity of the photographic process increased gradually by a factor of about a million over the next century and a half. Photography removed subjectivity and also meant that much less time had to be spent with one's eye metaphorically glued to the telescope eye-piece. It also produced a permanent record of the positions and brightnesses of stars, nebulae, planetary features, and spectral lines. The other two milestones came together around the 1960s. One was the introduction of the computer and this enabled astronomers to tackle a completely new range of problems that previously they merely dreamt about. Finally there was the escape from the Earth's blanketing atmosphere. That not only opened up a much expanded range of wavelengths to astronomical investigation, but also, for the planetary astronomer, took us to the near vicinity of asteroids and comets and into the atmospheres and onto the surfaces of our planetary and satellite neighbours.

*Catchers of the Light* covers the second astronomical milestone mentioned above. It is a thorough and insightful history of both the aims, technicalities, and results of astronomical photography and the lives of the pioneers of this vital part of our subject. This huge two-volume book benefits greatly from the fact that Stefan Hughes (unfortunately no relation to the reviewer!) was a professional astronomer at the universities of Leicester and London (Queen Mary College) who then morphed into a highly skilled astro-photographer, genealogist, and historian.

This book divides into nine sections. We start with an historical review of the first faltering footsteps of photography and its capturing of celestial images. We read about the daguerreotype and the calotype and the first imperfect images of the Moon and the Sun. Then in 1851 came the major breakthrough of the wet collodion process. This produced a sensitivity increase by a hundredfold and a concomitant decrease in the exposure time. Another leap forward occurred in 1871 with the introduction of the gelatino-bromide dry plate. Messy chemicals near the camera were eliminated and plates could be easily carried around and developed at leisure. By the early 1880s sensitivity had increased sufficiently to enable the Orion Nebula to be imaged, and also stars were being recorded that were invisible to the eye. This speedily led to photography being used for both celestial mapping and accurate photometry using large glass plates that did not warp or shrink when being handled and developed. Over the next hundred years or so the subject underwent a steady improvement until there was a revolutionary breakthrough in the early 1980s with the introduction of the charged-coupled device and its associated computer software.

Section two covers the Moon, a field that ended with the production of a series of major lunar atlases and the USA's *Orbiter* spacecraft using 70-mm Todd-AO photographic film to record lunar features from low lunar orbit. Section three considers the Sun and solar-eclipse photography and investigates the pioneering images of sunspots, granulation, prominences, and the solar corona. In section four we move to comets and planets and investigate the way in which astrophotography took over the task of discovering faint asteroids. Much is made of the use of primitive cinematographical techniques when it came to following Venus as it transits the Sun. Astro-photographers then turned their attention to deep space, and we read of the early images of clusters such as Praesepe and the Pleiades. By 1880 Henry Draper recorded the first image of M 42, the Orion nebula. Soon followed the imaging of Milky Way star fields and external galaxies.

Section six turns to one of the most important uses of photography in astronomy, which was the recording of spectra. Here we have a topic that led to the measurement of the chemical composition of the stars, their surface temperatures, and their radial velocities. It also led to the realization that some of the nebulae were gaseous and non-stellar. Harvard University Observatory then introduced the objective prism which meant that over 200 spectra could be recorded on a single photographic plate. This opened the floodgates to spectral classification, the Hertzprung–Russell diagram, and the details of stellar evolution with its main-sequence, giant, and supergiant stars. The combination of photography, spectroscopy, Doppler shifts, and large telescopes also enabled us to measure the size of the Universe and opened the way to modern cosmology.

Section seven reviews one of the great 'dead ends' of astronomical photography, the *Carte du Ciel* project. The idea sprang from the successful *Cape Photographic Durchmusterung* in which David Gill imaged the southern skies down to a magnitude of 10·2. But the *Carte du Ciel* decided to 'up the stakes' and the plan was to photograph, catalogue, and map the whole sky down to $14^{m}$ — a huge leap. An 1887 congress was held in Paris to parcel out different celestial areas to the world's observatories. Unfortunately the project was hugely over ambitious and it ended up as a complete and utter shambles. It was eventually overtaken by the technological breakthroughs of dedicated astrographic telescopes such as the 48-inch Schmidt telescope at the Palomar Observatory which took only ten years to polish off the National Geographic Society Palomar Observatory Sky Survey.

Section eight deals with the telescopes that were specially designed with astronomical photography in view. Here we see a great advance in the reflectors, their lack of chromatic aberration being a significant bonus. Lick Observatory's use of the 36-inch *Crossley* reflector showed the world what was possible. A string of great imaging instruments followed, the most memorable being the 100-inch *Hooker*, the 200-inch *Hale*, and finally the *Hubble Space Telescope*.

The last section deals with the role of the amateur astrophotographer, and also the usefulness of the 'pretty picture' in the advancement of astronomy. Many professional astronomers will happily spend all their academic life without including a 'photograph' in their publications. But the influence of seeing, for example, the first coloured picture of the solar green flash, the wispy nebulosity around the Pleiades, the dark foreboding of the Horsehead nebula, the majesty of the *Hubble* image of the 'Pillars of Creation' in the Eagle nebula, and the haunting fragility of the blue planet Earth rising over the barren lunar surface, an image taken by *Apollo 8* astronaut William Anders, is immense. The fact that astronomy is beautiful and image-rich has opened the doors of many funding sources. And we must be extremely grateful that the advances of modern small-telescope design coupled with readily available CCD cameras and laptop image-processing has meant that many dedicated amateur astronomers can now produce absolutely amazing celestial images.

What I loved about *Catchers of the Light* was its skilful combination of astronomical understanding, technical knowhow, and a realization of the historical and scientific importance of specific advances, all coupled with a deep interest in the biographical and genealogical details of the personnel involved. I learnt a huge amount. Let me give you one typical genealogical example. Take our great astronomical hero Edwin Powell Hubble. Before reading Stefan Hughes' book I had absolutely no idea that the 'Hubble' family, when leaving Ribblesford, Worcestershire, in the 1630s and emigrating to Connecticut, USA, was originally called Hubball. This eventually was changed to Hubbell, and finally Hubble. I also did not know that Edwin tried never to use his middle name because his maternal granddad, Major General Joseph Powell, was dismissed from the military for indiscipline and law breaking.

I was greatly impressed by the tables, a few examples being the key stages in the chronology of photographic processing, important lunar photographs and Moon atlases, major steps in solar photography, highlights of astronomical spectroscopy, key images of Solar System objects, spacecraft images of planets, significant historic images of the Horsehead nebula, the world's major astrographs, a time-line of deep-sky-object imaging, and the 109 most important astronomical photographs.

This book is truly a *magnum opus*, a labour of love, and a great work of scholarship. It is authoritative, detailed, thorough, superbly illustrated, well referenced, and all-encompassing. There is no nook or cranny of the history of astronomical photography or its proponents that has not been investigated, noted, and embellished with a relevant image. It is worth every single cent of its price. It is an essential addition to every astronomy library. Anyone with even a vague interest in the development of astrophysics will need to have this book to hand; it is a vital and reliable starting place for any historical research into the last two centuries of astronomical endeavour. — DAVID W. HUGHES.

**A Tale of Seven Elements**, by Eric Scerri (Oxford University Press), 2013. Pp. 270, 21 × 13·5 cm. Price £12·99 (hardbound; ISBN 978 0 19 539131 2).

Having looked at all of *The Periodic Table* in 2007 (see **130**, 175), Maltese-born author Eric Scerri has now turned his attention to the last seven elements (with atomic number less than $Z = 92$) to be discovered. These are, in order of discovery, Protoactinium (1917), Hafnium, Rhenium, Technetium, Francium, Astatine, and Promethium (1945). All were difficult, two because they are rare earths (Hf, Re), and the others because they are radioactive, with only very sparse natural presence on Earth, either as decay products of U, Th, Rn, and Ra or as made by the natural uranium reactor at Oklo, Gabon. Several had to be synthesized in terrestrial reactors and bombs, though recognized naturally thereafter. At least three were discovered or co-discovered by women (Lise Meitner, Ida Tacke Noddack, and Marguerite Perey, with C. S. Woo, Bertha Swirles Jeffreys, Maria Goeppert Meyer, and Charlotte Moore Sitterly involved in various ways).

All seven are fascinating stories, full of priority disputes, nationalistic squabbles, firm announcements of non-existent elements, and flashes of comedy and tragedy. Among my favourites of the false alarms are Jargonium (named, we suppose, for the language in which the paper was written) and Virginium (misnamed for the state, not your reviewer). No astronomer who has followed the tales of Coronium and Nebulium can afford to sneer at those coinages (of which Scerri mentions more than two dozen). But our primary interest is, of course, in Tc, recognized by Paul W. Merrill in 1952 on the basis of four (laboratory-calibrated) absorption lines in the spectra of 13 S-type giants. The plates were of the highest resolution then available, coming from the coudé focus of the brand-new 200-inch telescope at Palomar Mountain and exposed by Ira S. Bowen as part of the test process before he let the telescope loose into astronomical hands. Tc has been found in other stars since. Many are long-period Mira and SR variables.

Type-S spectra show excesses of barium and other elements made by the slow capture of neutrons on iron and mixed to the surface during the asymptotic-giant-branch (double-shell-burning) phase of evolution. The ones with Tc clearly represent stars with s-process nucleosynthesis occurring 'now' (in the last $10^6$ years or less). Those without are probably/perhaps stars polluted by mass transfer from more evolved companions now sunk into old age as white dwarfs. The book makes clear that Tc in evolved low-mass stars is evidence for synthesis there of elements of intermediate mass. But the author seems to think that its absence from the solar spectrum has "had a significant role in confirming the view that the Sun is a relatively young star". We are, of course, grateful that the Sun is not on the AGB (or we would all have fried) and would hardly have time to finish reading the book before our star shed a planetary nebula and became a white dwarf), but you don't have to look for Technetium to learn those things.

I had hoped that the author might have delved deeply enough into the astronomical literature to find the 2005 paper by William P. (Billy) Bidelman in which he reported the possible presence, among 13 000 lines in the spectrum of HD 101065 = V816 Cen = Przybylski's star, of a few, agreeing in wavelength to within 0·07Å with laboratory features of Promethium, Polonium, Actinium, and Protoactinium (another of Scerri's seven), as well as trans-Uranics from Neptunium to Einsteinium. Because the star is of spectral type Ap (p for peculiar) it cannot have had reaction products mixed to its surface yet, and Bidelman supposed the reactions had been triggered by very-high-energy particles from flares.

Perhaps someday there might be a second edition (my copy is already from the second printing) in which Billy could make a cameo appearance and "Mosley" on the fly-leaf could have his second "e" back, "Birtha" (Swirles) Jeffreys in the notes could come back as Bertha, Walter "Noddacks" in the index could have his singularity restored, and Marguerite could settle down between "Peyer" in the introduction and "Perey" in the text. Meanwhile, please be grateful that the 4–5-billion-year future life expectancy of the Sun will give you time to read this edition. — VIRGINIA TRIMBLE.

**The Edge of the Sky**, by Roberto Trotta (Basic Books, New York), 2014. Pp. 85, 17 × 14·5 cm. Price £10/$19·99 (hardback, ISBN 978 0 4650 4471 9).

The idea of this book is to write about the 'All-There-Is' using just the 1000 words everyone speaks all the time. In this review you now read, I manage with the same number of words. The first story is about a woman using a Big-Seer to find dark matter. The second story tells of the Crazy Stars named after old gods that race round the Sun. From the Big Flash to dark matter, the Dark Push and the Early Push, all the serious facts about the 'All-There-Is' are made clear for simple minds. Even the weird question "Is the All-There-Is All There Is in space?" is explained without a worry in story nine — it is a 'wow' answer. We're told about an important problem sorted out by Mr. Einstein and given the 'yes' by Mr. Hubble. Also we meet the good Doctor Higgs, who lives in a land where a strong brown drink helps humans to giggle. He imagined that a different drop of matter explained the 'All-There-Is'. Student-people in jeans, working in a land with lots of safe places to keep money, found this Higgs Drop in a large ring under the ground. Mr. Higgs was very happy and was invited to a party in a different cold land. *Edge of the Sky* will make the people who sell books very happy. They will have a lot of money when all the mums, dads, and uncles rush to buy for kids this cute Number-One-Book that explains the sky, the Sun and its night sister, and stars in the White Road and Star-Crowds far away. A fun book for kids, very different, like a word game, must be read. Do not be afraid! Buy! Enjoy! — SIMON MITTON.

**The Stars of Galileo Galilei and the Universal Knowledge of Athanasius Kircher**, by Roberto Buonanno (Springer, Heidelberg), 2014. Pp. 178, 24 × 16 cm. Price £90/$129 (hardbound; ISBN 978 3 319 00299 6).

The 17th Century was a crossroads in astronomical investigation invigorated by the introduction of the new-fangled telescope and its revelations. Astronomers fell into two camps and their respective dilemmas are investigated in detail in this most readable, erudite, superbly referenced, and insightful book written by Professor Roberto Buonanno, an astrophysicist at the University of Rome, Tor Vergata.

As examples he takes two gentlemen living in Italy at the time, men who had very little in common and who hardly ever met. On the one hand we have the German priest Athanasius Kircher S. J. (1601–1680) who became the Professor of Mathematics at the Jesuit Collegio Romano in 1633, around the time of Galileo's trial for heresy. Kircher was clever, inventive, open-minded, cheerful, and allegedly the last man to know nearly everything. He lived way before the days of specialization and enjoyed greatly dabbling his feet in every intellectual pond available. He was a great disseminator of knowledge, wrote about 44 books, collected a museum's worth of natural-history objects, and lived most of his adult life in Rome. In trying to understand the natural world, the baroque Kircher leant heavily on the authority of the scriptures and the messages passed down by God in both the *Bible* and in Egyptian hieroglyphic texts. Much time was, for example, expended on such pressing topics as working out which animals were taken into Noah's ark and how they were accommodated.

On the other hand we have Galileo Galilei (1564–1642) the pioneer experimentalist, the 'new man', someone who would not be out of place in modern academia. Galileo wrote "I think that in disputes about natural problems, we should not start from the authority of passages from *The Holy Writ*, but rather from the experience of the senses and from necessary demonstrations." Galileo was a genius who was also technically adept, extremely hard working, and organized. Galileo had great self-belief, and was unimpressed by people who did not immediately grasp the huge significance of his discoveries. To say that Galileo was anti-establishment is an understatement. Galileo and Kircher are chalk and cheese. Galileo seemed to revel in being 'modern' and thus putting other people's backs up and making waves; whereas Kircher went with the flow of the orthodoxy of ancient times and inoffensively blended in with the society of the day.

This book is a fascinating exploration of a key stage in the history of astronomy. I recommend it unreservedly. — DAVID W. HUGHES.

**Accretion Processes in Astrophysics**, edited by I. G. Martínez-País, T. Shahbaz & J. C. Velázquez (Cambridge University Press), 2014. Pp. 294, 26 × 18 cm. Price £75/$120 (hardbound; ISBN 978 1 107 03019 0).

The two-week 21st Canary Islands Winter School of Astrophysics attracted 37 participants, at least 23 of whom (along with six of the eight lecturers) came from places likely to be chillier than Tenerife in November. A winter school is different from a conference in many ways: fewer people, eight coherent chapters in the volume instead of 80 miscellaneous items, and more women (at least 13 of the 37 students and two of the eight lecturers). This one also took from 2009 November to spring 2014 to be published. The preface tells us that the lecturers are "actively working on a variety of leading research projects and have played key roles in the advances made in the field in recent years". Evidence for this is that each of them cites six to 16 papers of which he/she is the first author. The stated goal of the volume as well as the school is to "offer young researchers key analytical tools for supporting and carrying out the next generation of front-line research". That the references do not extend later than 2010 may be an impediment to that goal.

Most of the chapters focus on accretion in binary star systems, though active galactic nuclei make an appearance with accretion discs, black holes, and numerical methods.

Both the preface and the back cover begin by saying that it has been more than 50 years since the first significant paper on accretion. I took this as a challenge, the more so because it isn't clear whether they meant 50 years before 2009 or before 2014. In either case, the classic 'disc' papers of Lynden-Bell, Prendergast and Burbidge, Pringle and Rees, and Shakura and Sunyaev come too late. Kuiper's 1941 exposition (still a very impressive one) of how the physics of Roche-lobe overflow might account for observations of Beta Lyrae is probably too early. Perhaps we are meant to think of Hermann Bondi and Fred Hoyle (1944) 'On the mechanism of accretion by stars' (cited by Brian Warner) and/or Bondi (1952) 'On spherically symmetrical accretion' (cited by Henk Spruit), since Hoyle was nearly always serious and Bondi frequently so, at least about astrophysics.

But there is a lovely bon-bon at the end (in lieu, sadly, of an index). Tenerife was the site of the very first, temporary, mountain-top observatory, established on Guajara and later Alta Vista in 1856 by Charles Piazzi Smyth. Edward S. Holden, the first director of Lick, was aware of Piazzi Smyth's work and knew that "mountain stations possess striking advantages" (as Newton had suspected in 1704). This fascinating appendix comes from Brian Warner, who has spent much of his career in South Africa, where Smyth worked from 1835 to 1845. His 1842(!) photograph of the Cape observatory is a good deal more informative than the much-reproduced one by John Herschel of one of his father's large telescopes. Smyth's photo was a calotype, and I guessed "processing by heat", assuming the word derived from *calor* (Latin for heat). I was wrong. — VIRGINIA TRIMBLE.

**Dynamics of Magnetically Trapped Particles, 2nd Edition**, by J. G. Roederer & H. Zhang (Springer, Heidelberg), 2014. Pp. 192, 24 × 16 cm. Price £90/$129 (hardbound; ISBN 978 3 642 41529 6).

The theory of collision-free plasmas can be approached from two 'opposite' directions, understanding both of which is desirable for a reasonably sound level of knowledge. The first concerns the motion of individual charged particles in an electromagnetic field, possibly subject to additional forces such as gravity. The second concerns the behaviour of such particles in bulk and their mutual interactions with the field, described in terms of fluid and field parameters derived from the Vlasov–Maxwell equation set. The majority of Roederer & Zhang's book is concerned with the first of those approaches, as principally applied in practice to energetic radiation-belt particles in planetary magnetospheres, where the spatially and temporally varying fields can be regarded as wholly generated by external agency (*e.g.*, the planetary dynamo and the impinging solar wind), and not by mutual interaction with the particles under consideration themselves. Thus the topics are those of gyration, bounce, and drift motion of charged particles in specified fields governed by adiabatic invariants that are preserved when the fields at the particle vary sufficiently slowly. Those brought up in these topics using Northrop's modest monograph published 50 years ago, tight in mathematical exposition and spare of explanation and discussion, will find the present volume an altogether opposite experience, with many helpful hints on the trickier points, signalled by exclamation marks, together with lots of 'kindergarten' examples! These chapters also contain useful in-principle discussions on drift effects associated specifically with the fields in the Earth's magnetosphere, now once more brought to the research fore with the launch in 2012 of the NASA *Van Allen Probes*, no doubt one of the reasons that excited the up-dating and revision of Roederer's original volume in this second edition of the same title. Of course, the single-particle description of plasma systems must morph into the fluid description, at some order of approximation, when summed over the particles. That topic is approached in two final chapters (out of five) of the book through a discussion of distribution functions and bulk parameters, together with the conservation equations that they, coupled with Maxwell's equations, must obey. Overall, this book provides a substantial discussion of the above fundamental topics in space-plasma physics, and will undoubtedly form a useful future resource for students (of all ages) when delving into those subjects. — STAN COWLEY.

**6th Conference on Hot Subdwarf Stars and Related Objects** (ASP Conference Series, Vol. 481), edited by V. Van Grootel, E. M. Green, G. Fontaine & S. Charpinet (Astronomical Society of the Pacific, San Francisco), 2014. Pp. 315, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 846 6).

This volume represents the proceedings of a conference held at Steward Observatory, University of Arizona in 2013, comprising 37 participants from 24 institutions. The papers summarize the 42 presentations which fall into the major themes of planets around hot subwarfs, astroseismology, atmospheric studies, evolutionary aspects, and subdwarfs in binaries.

These proceedings are comprehensive, and a considerable number of the papers are well-written and properly illustrated. A few of the papers would benefit from colour as graphics, such as 3D and contour maps, become very difficult to read in black and white.

This thoughtfully edited text would be a useful resource for researchers new to the subject and at $77 it is a reasonable price and a worthwhile purchase. — PAMELA MARTIN.

**The Falling Sky**, by Pippa Goldschmidt (Freight Books, Glasgow), 2013. Pp. 256, 20 × 13 cm. Price £8·99 (paperback; ISBN 978 1 908754 14 1).

"What else is there? Sex and physics." No, this is not my summary of Pippa Goldschmidt's debut novel *The Falling Sky* (not to be confused with a book of the same name by a Yanomami shaman[1]), but rather Dennis Overbye's description[2] of his biography of the young-adult Einstein, *Einstein in Love*[3]. However, it does capture two of the three main themes, the third being the dysfunctional family of the protagonist. There was a time when science fiction was rather deficient in sexual details; I seem to remember a multi-generational spaceship with an all-male crew (and, no, there was no mention of homosexuality either). (To be fair, though, this was often not the fault of the author, but rather of the publisher and/or society at the time. Partly for that reason, Isaac Asimov delayed writing the third volume[4] of his series of robot novels for several decades.) This is of course no longer the case, allowing Goldschmidt to paint a three-dimensional portrait of her main character. Although perhaps not science fiction in the strict sense (it takes place in the present and no non-existing technology is assumed), it is a novel in which the main character and several other characters are scientists and the plot revolves around science, in particular astronomy and cosmology.

As might be expected of a writer who used to be a professional astronomer, most of the details of the science discussed are correct. There are, however, a few minor goofs, which I'll leave to the reader to spot. (I didn't notice any goofs in the descriptions of female sexuality.) More importantly, the atmosphere of scientific research is captured quite well and it is obvious that the author is writing from experience (though, of course, "All the characters in this book are fictitious and any resemblance to actual persons, living or dead, is purely coincidental"). Having worked for two years in cosmology in the UK, albeit in England, I feel like I actually know some of characters and even some locations which I haven't actually visited. The descriptions of various types of scientists, institutes, observatories, *etc.*, are spot on. Some reviewers have described the book as satire, but to me it is much closer to realism.

Of course, reviewing a novel shouldn't give away anything which would take away from the pleasure of discovering it for the first time in context while reading, so I won't give a summary *per se*. The story, told in the third person from the protagonist's point of view, consists of two timelines, 'then' and 'now', exploring the three themes mentioned above. The various locations correspond to the locations of real astronomical institutes, though apart from ESA the corresponding names are not mentioned (the only occurrence of "eso" is as part of "threesome"). Most of the book is in the 'now' timeline and takes place mainly in Edinburgh. It manages to be a page-turner without relying on cliff-hangers.

The ending was a surprise, but not in any way unfair to the reader. In retrospect, it is actually quite logical and expresses one of the themes Goldschmidt wishes to convey. I enjoyed the book and recommend it. — PHILLIP HELBIG.

*References*

(1) D. Kopenawa & B. Albert, *The Falling Sky: Words of a Yanomami Shaman* (Belknap Press, Cambridge, MA, USA), 2013.
(2) http://edge.org/conversation/sex-and-physics
(3) D. Overbye, *Einstein in Love* (Penguin Books, London), 2001.
(4) I. Asimov, *The Robots of Dawn* (Doubleday, New York), 1983.

## Paperback Release

**A Photographic Atlas of Selected Regions of the Milky Way**, by E. E. Barnard; foreword by G. E. Dobek (Cambridge University Press), 2014. Pp. 358, 27 × 27 cm. Price £45/$80 (ISBN 978 1 107 44287 0). Reviewed in **131**, 320, 2011.

## THESIS ABSTRACT

### X-Ray Observations of the Outskirts of Galaxy Clusters

*By Stephen Alexander Walker*

My doctoral thesis has centred on pioneering observations using the *Suzaku* observatory of the X-ray emission from the outskirts of galaxy clusters. The low X-ray surface-brightness emission from the low-density gas in cluster outskirts is challenging to observe with *Chandra* and *XMM–Newton* because their large elliptical orbits give them a high and variable particle background. *Suzaku*'s low Earth orbit gives it the low and stable particle background required to allow robust measurements of the intracluster-medium (ICM) thermodynamic properties out to the virial radius $r_{200}$, providing exciting and unique observations of those previously unexplored regions. First, I present the first-ever X-ray analysis using *Suzaku* data of the outskirts of the galaxy cluster Abell 2029. I find significant anisotropies in the temperature and entropy profiles, with a region of lower temperature and entropy occurring to the south-east, possibly the result of accretion activity in that direction. Away from that cold feature, the thermodynamic properties are consistent with an entropy profile which rises, but less steeply than the predictions of purely gravitational hierarchical structure formation.

Second, I use new *Suzaku* observations of PKS 0745–191 (which was the first cluster to be explored in the outskirts with *Suzaku*) to measure the thermodynamic properties of its ICM out to and beyond $r_{200}$ (reaching 1·25 $r_{200}$) with better accuracy than previously achieved, owing to a more accurate and better understood background model. I investigate and resolve the tensions between the previous *Suzaku* and *ROSAT* results for PKS 0745–191.

Third, I fit a functional form for a universal ICM entropy profile to the scaled entropy profiles of a catalogue of X-ray galaxy-cluster-outskirts results, which are all relaxed cool-core clusters at redshifts below 0·25. Fourth, I present *Suzaku* observations of the Centaurus cluster out to 0·95 $r_{200}$, taken along a strip to the north-west. I have also used congruent *Chandra* observations of the outskirts to resolve point sources down to a threshold flux around seven times lower than that achievable just with *Suzaku* data, considerably reducing the systematic uncertainties in the cosmic X-ray background emission in the outskirts. The entropy profile demonstrates a central excess (within 0·5 $r_{200}$) over the baseline entropy profile predicted by simulations of purely gravitational hierarchical structure formation. I further the analysis of Chapter 4 which studies the shapes of the entropy profiles of the clusters so far explored in the outskirts with *Suzaku*. When scaled by the self-similar entropy, the *Suzaku* entropy profiles demonstrate a central excess over the baseline entropy profile, and are consistent with it at around $r_{500}$. However, outside $r_{500}$ the entropy profiles tend to lie below the baseline entropy profile.

Finally, I present the results of *XMM–Newton* observations of the regions around the core of the Centaurus cluster where evidence for merging activity between the subgroup Cen 45 and the main Centaurus cluster has previously been observed by using *ASCA* and *ROSAT*. I confirm the *ASCA* findings of a temperature excess surrounding Cen 45. I find that this temperature excess can be explained using simple shock heating given the large line-of-sight velocity difference between Cen 45 and the surrounding main Centaurus cluster. — *University of Cambridge; accepted 2014 February*.

A full copy of this thesis can be requested from swalker@ast.cam.ac.uk

## *Here and There*

STARS IN EVERY SENSE

… a camera sensitive enough to record stars down to 10th magnitude at TV fame rates … — *The Astronomer*, **51**, no. 602, 2014 June, p. 35.

DOLCE & GABBANA PERHAPS?

Image of impact flash taken by a Swish-Italian observing group — *The Astronomer*, **51**, no. 602, 2014 June, p. 35.

THE ONLY ONE OF HIS KIND

— has the unique ability to make science entertaining and informative. — *JRASC*, **108**, 111, 2014.