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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2011 October 14 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

R. L. DAVIES, *President*
in the Chair

The President. It's my sad duty to announce the death of a Fellow, Professor Denis Ian Gough, Professor Emeritus of Physics at the University of Alberta. He was awarded the Chapman Medal in 1988, and he died on the 21st of March of this year. Please will you stand for a moment of reflection to remember Professor Gough. Thank you.

First, some congratulations to our colleagues. On your behalf I want to recognize the recent success of the following Fellows and Medallists: the 2011 Gruber Cosmology Prize was awarded to Marc Davis, George Efstathiou, Carlos Frenk, and Simon White. In a series of pioneering papers in the 1980s that relied on numerical simulations, they provided a powerful new tool for comparing theory and observation on cosmological scales. They then used that tool to validate the cold-dark-matter theory of cosmic growth. Today, virtually every aspect of astronomy relies on numerical simulations and cold dark matter, and cold dark matter is a fundamental component of the standard model of cosmology. The 2011 Grote Reber Gold Medal at the United States National Radio Astronomy Observatory was awarded to Professor Jocelyn Bell Burnell. This was awarded for her lifetime of innovative contributions to radio astronomy. [Applause.]

Moving on to our own prizes, I am very happy to announce that the 2010 Michael Penston Prize has been awarded to Dr. Duncan Forgan of the University of Edinburgh, for a thesis entitled 'Probing self-gravitating discs using smoothed particle hydrodynamics with radiative transfer'. And the runner-up was Dr. Andy Eyre, from the University of Oxford. The parallel prize on the geophysics side is the Keith Runcorn Prize, and that has been awarded to Dr. James Verdon from the University of Bristol, for a thesis entitled 'Microseismic monitoring and geomechanical modelling of CO_2 storage in subsurface reservoirs'. The runner-up was Dr. Richard Morton from the University of Sheffield. We hope that both prize winners will give us talks at the Ordinary Meeting on December 9.

Our programme today is a straightforward one: the first two talks are from our 2011 Winton Capital Prize winners and then we follow them with the George Darwin Lecture. So it's my pleasure to introduce Dr. Sugata Kaviraj from Imperial College London, speaking on 'Early-type galaxies — the last 8 billion years'.

Dr. S. Kaviraj. Massive early-type galaxies (ETGs) dominate the stellar mass density in the local Universe. Hosting over half the stars at the present day, these systems hold a uniquely detailed record of the evolution of the visible Universe over cosmic time. In recent decades, observational astronomy has focussed largely on the optical wavelengths, and our understanding of ETG evolution has naturally been shaped by such studies. The optical properties of ETGs (*e.g.*, red optical colours and high ratios of alpha elements to iron), motivated a long-standing classical model (termed 'monolithic collapse'), which postulated their formation in short, efficient bursts of star formation at high redshift ($z \gg 1$) followed by purely passive evolution thereafter. However, monolithic collapse is difficult to reconcile with the currently accepted hierarchical paradigm of galaxy evolution, in which merger-driven and quiescent star formation is expected to take place in galaxies over the lifetime of the Universe.

Indeed, it can be shown that the *optical* predictions of semi-analytical models based on the standard hierarchical paradigm are virtually indistinguishable from those of monolithic collapse. This is because star formation in ETGs at late epochs ($z < 1$) is too weak to impact significantly the optical spectrum. The optical wavelengths are therefore not a good discriminant between the monolithic and hierarchical models. Accurately quantifying the star-formation history of ETGs at late epochs requires a sensitive indicator of weak star formation, such as the rest-frame ultraviolet wavelength (UV; 1200–3000 Å), which is more than an order of magnitude more sensitive to star formation than the optical wavelengths.

In a series of papers since 2007, Kaviraj *et al.* have exploited rest-frame UV photometry of ETGs, across the redshift range $0 < z < 1$, to measure accurately the stellar mass growth in these galaxies over the last 8 billion years. Efforts using NASA's *GALEX* UV space telescope, combined with optical data from the Sloan Digital Sky Survey (SDSS), showed that, while the *optical* colours of local ($0 < z < 0{\cdot}1$) ETGs are indeed red, they exhibit almost 5 magnitudes of spread in their rest-frame UV colours. The UV luminosities in the bluest 30% of ETGs are larger than the maximum UV flux that can be expected from old (extreme horizontal-branch) stars, suggesting that *at least* 30% of local ETGs contain unambiguous signatures of recent star formation. This result was subsequently consolidated by studying ETGs at intermediate redshift ($0{\cdot}5 < z < 1$), when the Universe was too young for the horizontal branch to be in place, making the UV a rather 'clean' indicator of recent star formation. Combining data from three intermediate-redshift surveys (MUSYC, COMBO-17, and GEMS) Kaviraj *et al.* demonstrated that the UV properties of ETGs remained unchanged across the entire redshift interval $0 < z < 1$. Together with the previous work using *GALEX*, these studies concluded that ETGs of all luminosities form stars over the last 8 billion years, with massive (more luminous than $L_\star$) ETGs forming $\sim 20\%$ of their stellar mass after $z \sim 1$.

While these studies established the presence of star formation in ETGs, ruling out the classical monolithic-collapse model, they offered little insight into the sources of gas that drive this star formation. There are several potential sources of gas in ETGs, such as internal stellar mass loss, accretion from hot gas or ambient H I reservoirs, and mergers. Stellar mass loss does not provide enough gas at the present day, ruling it out as the principal driver of star formation in local ETGs. Indeed, the literature indicates that the interstellar medium of local ETGs may be external in origin. For example, results from the recent SAURON survey, which has performed integral-field spectroscopy of local ETGs, indicate that the gas is often kinematically-decoupled from the stars. Measurements of dust masses in ETGs typically yield values that are in excess of the maximum value expected from stellar mass loss. Furthermore, more than 70% of ETGs appear morphologically disturbed in deep optical imaging.

To establish the rôle of mergers in driving the star formation in ETGs, Kaviraj *et al.* studied whether a correlation exists between the presence of morphological disturbances and blue UV colours. This is a difficult exercise to perform at low redshift, where imaging from surveys such as the SDSS lack the resolution and depth to reveal faint morphological disturbances from, *e.g.*, minor mergers. However, this is possible using *Hubble Space Telescope* (*HST*) imaging at intermediate redshift, using surveys such as COSMOS. Kaviraj *et al.* found that ETGs that had blue UV colours were indeed highly likely to exhibit morphological disturbances. However, the major merger rate at late epochs is several factors too low to satisfy the number of disturbed ETGs, indicating that minor mergers (with mass ratios between 1:4 and 1:10) have driven the star formation in ETGs over the last 8 billion years. It is worth noting that the strong correlation between disturbed morphology and star formation also indicates that processes such as accretion from hot gas and ambient H I reservoirs are not responsible for triggering the star formation in those galaxies.

Although significant progress has been made over the past five years in deciphering the evolution of ETGs, only the broad outline of their star-formation histories has been firmly established. While ~ 80% of the stars in these galaxies are old, the remaining minority formed over the last 8 billion years *via* minor mergers between ETGs and small, gas-rich companions. However, several outstanding questions remain. What are the detailed properties (mass ratios, satellite gas fractions, *etc.*) of the minor mergers that drive star formation in ETGs at late epochs? At what redshifts and through what processes (*e.g.*, major mergers, cold streams) did the old, dominant stellar populations in today's ETGs form? The former can be answered by detailed spatially-resolved UV–optical analyses of local ETGs with new instruments such as *HST*'s *Wide Field Camera 3* (*WFC3*), while the latter can be explored by studying newborn ETGs at the epoch of peak cosmic star formation, using new surveys of the high-redshift Universe that leverage the *WFC3*'s near-infrared capabilities (*e.g.*, CANDELS). The next five years offer us the tantalizing possibility of accurately tracing the formation history of ETGs over 90% of the lifetime of the Universe and revolutionizing our understanding of this important class of galaxy.

The President. Thank you, Sugata; any questions?

Mr. M. F. Osmaston. You mentioned the ram pressure. Personally, I'm a little sceptical for various reasons; I would like to know your view.

Dr. Kaviraj. Ram pressure — in what context, in the simulations?

Mr. Osmaston. In mergers.

Dr. Kaviraj. Well, most of the early-type galaxies that we're studying are in the field. I think ram-pressure stripping will operate primarily in clusters.

Professor C. Tadhunter. Your estimates of age and metallicity for the young stellar population — are they based purely on the colours? And if so, how do you resolve the degeneracy issues?

Dr. Kaviraj. Yes, that is a good question. The degeneracies are much lower if you have access to the UV, essentially. You are right, if I had optical colours, the optical age/metallicity degeneracy will stop me from getting anything even close to this kind of accuracy. So, let me show an analysis of some M 31 globular clusters: these globular clusters have been fitted using photometry alone. The error bars, which are 68-percentile errors, incorporate all the errors you have in the analysis — so that's model errors, observational uncertainties, and degeneracy between parameters. If I had only optical colours, these error bars would span the parameter space. But if you have access to the UV wavelengths then you can pin the age down with high precision. In fact, the age estimates for globular clusters, for example, are comparable to what you would get from spectroscopic-line indices.

The President. Any more questions?

Professor R. C. Kennicutt. Yes: 30% of the early-type galaxies you see have formed stars in the last half-billion years, and mergers are driving this. Is the implication that essentially all galaxies, including all the early types, do have on-going star formation or is that an over-simplification?

Dr. Kaviraj. Yes, I agree with that.

Professor Kennicutt. So there are no truly red and dead galaxies?

Dr. Kaviraj. In my opinion all early-type galaxies form stars and there are no really passive galaxies in the Universe.

Rev. G. Barber. Is it possible to observe, and if so, do we observe, these minor mergers taking place in sufficient numbers?

Dr. Kaviraj. Yes, we do. The minor-merger frequency is much higher than the major-merger frequency. If you consider minor mergers with mass ratios between, say, 1:4 and 1:10, which are the ones which do the most damage, both in terms of star formation and kinematics, they are a factor of 3 or 4 more frequent than major mergers, and you only need half of them to carry in enough gas to give you what you see, in terms of the spread in the UV colours of early-type galaxies.

The President. Thank you very much, Sugata. [Applause.]

Before I introduce the second Winton Prize winner, I should acknowledge that there are two people in the audience from Winton Capital, and it is a good opportunity to thank them for sponsoring these prizes for early-career researchers. They make a huge difference to careers of these people: already one of the previous winners is a lecturer at the University of Warwick, so their careers are certainly given a considerable momentum by the award of this prize. So thank you very much and we hope to see you again soon. The second recipient of the Winton Capital Prize is Dr. Leigh Fletcher from the University of Oxford, and he is going to tell us about 'Exploring Saturn's giant storms and seasonal variability from the *Cassini* spacecraft'.

Dr. L. Fletcher. On a cold Saturnian spring day in 2010 December, something was stirring deep beneath the veil of the gas giant's yellow-ochre clouds. A plume of fresh white material erupted through the planet's usually-serene cloud decks, transporting clouds and gases high into the planet's upper troposphere and stratosphere to generate a roiling, turbulent cloud layer that could be easily seen by observers on Earth. Over the next ten months, this storm evolved into a planetary-scale disturbance, enveloping the entire northern springtime hemisphere, with never-before-seen effects on the planet's thermal structure and chemistry. Our studies of this spectacular phenomenon used infrared imaging and spectroscopy from both the *Cassini* spacecraft (in orbit around the ringed world since 2004 July) and giant ground-based observatories to peer into the heart of the storm system.

One might wonder at our motivations for studying storm systems on far-away planets, but such research has the potential for improving our understanding of the basic physics and chemistry at work in atmospheres throughout our Galaxy. Indeed, with no solid surfaces to interrupt the atmospheric flows, the giant planets are in many ways simpler than terrestrial worlds, serving as natural planetary-scale laboratories for studying planetary meteorology. Furthermore, our own collection of giant planets now serves as the perfect template for our first interpretations of planets being discovered around other stars, so there has never been a better time to address some of our old questions about the deep, churning atmospheres of the outer planets. However, remote sensing can rarely penetrate down through the thick veil of clouds that shroud the giant-planet interiors from view. When we observe dynamic phenomena on these planets, we are restricted to studying only their manifestations in the uppermost ammonia-ice clouds. Peering beneath those cloud decks is a key challenge for planetary science in the coming decades (*e.g.*, *Juno* will use microwave observations to study Jupiter's deep atmosphere in 2016), but for now, we must use the long-term variability of the atmosphere, coupled with numerical models, to probe the inner workings.

Cassini's observations since 2004 (notably from a Fourier-transform spectrometer known as *CIRS*, some elements of which were designed in Oxford) have revealed the slow seasonal evolution of the gas giant. Atmospheric temperatures are largely predictable, provided you know which species absorb sunlight (usually methane), and which species emit infrared radiation back into space (a soup of photochemically-produced hydrocarbons in the planet's stratosphere). One year on Saturn lasts 29·5 Earth-years, so *Cassini* has so far tracked Saturn's slow evolution from southern summer (2002) to northern spring (today). Small dynamical phenomena are sometimes seen, such as dark vortices, storms, or wave chains, but nothing prepared us for the onslaught of the 2010 storm.

The first detection came on 2010 December 5 from *Cassini*'s radio-wave instrument, which picked up the emissions from powerful lightning strikes deep beneath the cloud decks, many times more powerful than previously detected. At around the same time, amateur observers began to track the evolution of an expanding white spot. This spot (fresh ices of ammonia and other constituents dredged from the deeper atmosphere) expanded in size, and was whipped east and west around Saturn's northern hemisphere by the prevailing zonal winds. By early 2011, the storm clouds were visible at all longitudes. Infrared observations showed huge changes to the temperature fields, with cold regions of strong convective upwelling, warm regions of subsidence, and meandering jet streams forming closed loops and new oval-shaped vortices within the storm. All this was happening in the cloud decks of Saturn's troposphere, but the biggest surprise came when we observed Saturn in filters sensitive only to the stratosphere, 200–300 km higher than the roiling clouds.

Normally the stratosphere is very stable, but the violence of the storm sent waves radiating upwards, depositing their energy in two locations either side of the storm centre, but at very high altitudes. Somehow, these warm patches of air (which we started to call beacons) came to intensify, and were blown westwards. One of the beacons moved much faster than the other, and in 2011 April it caught up with the first, interacted, and eventually merged to form one gigantic, circulating hot air-mass. The temperatures observed in the centre of this new feature were larger than ever previously detected in a giant-planet stratosphere, some 60 degrees warmer than the surroundings. Emission from this huge beacon completely drowned out emission from the rest of the planet. And yet despite those incredibly high temperatures, we can see no evidence for this stratospheric beacon in the deeper atmosphere. It is only visible, like a giant 'eye' of Saturn, at infrared wavelengths. We have now tracked this beacon over several months to understand its evolution, and although there are some signs of cooling (and possibly sinking into the lower stratosphere), it still rages on, even though the deeper storm now appears to have calmed.

The emergence of this planetary-scale storm in Saturn's northern spring came as a surprise. Storms of this magnitude have occurred before (approximately once every 30 years, normally in summertime conditions in the northern hemisphere), but never this early in Saturn's seasonal cycle. We must now work to understand why the storm erupted when it did. Why now, and why at this particular northern latitude? One theory suggests that this particular latitude is always moderately unstable, and that seasonal conditions were just right for an instability to grow and penetrate into the upper troposphere where we could observe it. The transport of energy from the storm clouds into the stable stratosphere must also be understood, as the implications for stratospheric dynamics and energy balance on all the giant planets are rather profound. We shall continue to monitor Saturn's atmosphere from the ground and from *Cassini* (up to the end of the mission in 2017, northern summer solstice), to identify the long-term atmospheric effects of this springtime storm. Characterization of these storms, and their implications for large, localized hot regions of stratospheric emission, is vital if we want to interpret correctly the mean state of these atmospheres. Furthermore, if we can identify the underlying causes of these spectacular eruptions, then we might come one step closer to a truly predictive model of giant-planet atmospheric meteorology. One thing's certain — the unexplored depths of the giants contain answers to a number of unresolved mysteries about our Solar System, and we await the observations of NASA's *Juno* mission with baited breath.

The President. Questions for Leigh?

Professor D. Lynden-Bell. Is there a sign of Taylor columns going down from the storms on top?

Dr. Fletcher. With the observations in the infrared, we're unable to probe deep enough into the planet to distinguish between competing hypotheses concerning the depths of these features. The are several models out there — some deal with shallow-water theory, where we assume that the zonal jets and the observable meteorology are restricted to a small, shallow layer of the atmosphere; and others suggest that the belts and zones are manifestations of Taylor columns, extending down through the planet itself to some ill-defined surface down in the depths. *Galileo* measured Jupiter's zonal winds and found that they didn't die away when they reached depths of 20 bar, so the zonal organization must persist to that depth. *Juno* might be able to probe down to the 100-bar level, and it will be able to see contrasts in different gases and abundances down at those depths. So it will help to determine how deep these zonal flows penetrate into the great depths of the planet.

Mr. Osmaston. Are there any means of determining the polarity of the sky when lightning strikes, because 99% of those on Earth have negative charge to ground?

Dr. Fletcher. Not as such with the observations that we have. Most of the observations taken by *Cassini* are taken on the night-side of the planet. That is the only way you get rid of the ring-shine that dominates the flux that the cameras actually receive. With a range of discrete filters in the visible we might be able to measure spectral-energy distributions, but there's no direct measurement of the polarity. But if it's conventional water clouds and charge separation, then maybe the polarity is the same. There is an idea for flying something called an 'Optical Lightning Detector' on one of the future missions to Jupiter, for example, which might be able to do that sort of study. But not yet, sadly.

The President. Thank you again. [Applause.] Ten months to eight billion years, that's a pretty big range — the Royal Astronomical Society tries to give you the complete view, but I'm afraid that's dwarfed by the title of the Darwin Lecture that we are about to hear from our next speaker, Professor Michael Turner from the University of Chicago, which is 'From quarks to the cosmos'.

Professor M. Turner. [It is expected that a summary of this talk will appear in *Astronomy & Geophysics*.]

The President. Well, after such a wide-ranging lecture, I think you can ask questions on absolutely anything! [Laughter.]

Professor Lynden-Bell. Inflation was during a period long ago, but there is another period of inflation right now, is there not?

Professor Turner. Correct.

Professor Lynden-Bell. The inflation long ago ended in a bust-up in which we created all the entropy and all the particles and all the rest of it. When is the bust-up going to occur with this lot, and will it create lots of particles?

Professor Turner. I don't know. But I have some slides that show you what happened. This is the slide that you learned on your mother's knee. That once you measure the shape of the Universe you know your destiny. And of course your mother, while you were falling asleep, said that's not true, there is dark energy. And until we understand the dark energy we don't know whether it will end as you say the way inflation ended, which is that the field rolls to the bottom of the hill and you generate some heat. Now there won't be very much heat this time, because the hill is quite low.

Professor Lynden-Bell. That depends on how long it goes for, doesn't it?

Professor Turner. No, you can never get more out than the hill we're on. And the hill we're on is not very high. But it could be that we continue to accelerate and the sky will go dark in about 100 billion years This is an argument that we use in the US with Congress, because, unlike the 'Brits', we do long-range planning [laughter]. Now is the time to do astronomy, because the sky is going to go dark in 100 billion years. You ask a very important question. In the early days of inflation, we didn't even want to talk about calling it accelerated expansion. Now it is accelerated expansion, we have two periods — are they related? And the answer is, the scales are so different: the first one was very, very rapid, but this one is milder. No one has a good idea how they might be related; and how do you know if it was just two? Maybe it was more.

Professor I. Roxburgh. I want to push you on the matter and antimatter. Isn't the realistic position to take that we just don't know? You are suggesting you put it in as an initial condition, but that's contrary to the whole spirit of the rest of your talk, and really, we should just say we don't yet know!

Professor Turner. I apologise, I was racing there. What we do know is that we find no evidence for antimatter. So if there is both matter and antimatter they must be segregated on enormous scales.

Professor Roxburgh. The question is why?

Professor Turner. What we do know is that, if you combine baryon-number violation and CP violations that have actually been observed in Nature, and the expansion of the Universe, you can take a symmetric Universe and generate an excess of matter over antimatter. And so we could start with a Universe that's just pure radiation, and the laws of physics would allow it to evolve a slight asymmetry between matter and antimatter. We would not have to pose it as an initial condition. And if I didn't make that clear I apologise. One of the things that has happened in cosmology is what I like to call the "self-booting universe" where you don't need initial conditions. If you take inflation, if you take Big Bang nucleo-synthesis, if you take this theory called baryogenesis, you get the Universe that we see, automatically. You don't have to appeal to initial conditions.

Mr. M. Hepburn. Just a criticism of the *WMAP* slide: all the biggest blue and red temperature variations are behind the Galaxy, and therefore they have been invented and are not part of the real observations.

Professor Turner. It is indeed true that the map I showed you is a synthetic map, but *WMAP* had five bands, and so they were able to subtract out the Galaxy, and in their best band the Galaxy is quite thin. So I could have shown you their best band, I believe it is called *W*-band, and you would have seen the Galaxy but it wouldn't have been much of the map. I mean it would have been at the equator of the map. And so I think I agree with you that it's a synthetic map, but I do not agree with your statement that most of the sky is polluted by the Galaxy.

Mr. Hepburn. No, I am saying that all the big red and blue areas are on the Galactic equator, and therefore the synthesis has led to something rather nasty.

Professor Turner. You can see some bad subtractions here. But if I showed you a version where the foreground hadn't been subtracted, I think above about 10 degrees, and below about 10 degrees, it's pretty good.

Mr. Hepburn. Oh yes, I agree with that!

Rev. Barber. We haven't started with a Universe that's decelerating, then inflation kicks in and accelerates so it decelerates again ...

Professor Turner. We don't know that it decelerates.

Rev. Barber. It goes through the Big Bang nucleo-synthesis ...

Professor Turner. Yes, it's definitely decelerating there.

Rev. Barber. And then it accelerates again, from $z = 1$.

Professor Turner. Correct.

Rev. Barber. The result of sort of sticking your foot on the accelerator and the brake, going through history, results in an age of the Universe that's exactly the Hubble time. Isn't that a bit of a coincidence?

Professor Turner. It's close.

Rev. Barber. It's within 0.6 %. If you take those values you put up, and invert the Hubble constant, and get the Hubble time, you find that it's within 0.6% of the age of the Universe!

Professor Turner. One over the Hubble constant is quite close to the age of the Universe.

Rev. Barber. Isn't it a coincidence?

Professor Turner. I think within the error bars of 0·1% it is not *equal* to the age of the Universe.

Rev. Barber. It gets coincidentally close in a sense that the closeness is closer than the size of the error bar! Bearing in mind the acceleration and deceleration, it could be actually anything; if you kick in an arbitrary Λ dark energy you could make the age of the Universe infinite, and get a steady-state expansion. Now what I am saying is that the age of the Universe could be derived from any multiple of the Hubble constant from ⅔ onwards.

Professor Turner. It's quite close to one over the Hubble constant.

Rev. Barber. Isn't it a coincidence that it's actually similar?

Professor Turner. Well, the trouble with coincidences is that sometimes they tell you something and sometimes they don't [laughter]. Fred Hoyle pointed out a remarkable coincidence, which is that if you had stars make all the helium that we see today, then the energy released would be about that of the microwave background. And actually what is remarkable with time, this coincidence became better, which is bad, because that would mean that you don't need the redshifting effect to get the energy density right, and if the stars made the microwave background by making helium, the stars would have to had done it at a redshift of about 0·2, and then there is no material in between the thermalizer. That is a remarkable coincidence, the MOND coincidence. As long as we are mentioning coincidences that I'll accept, the need for dark matter in a galaxy doesn't happen at a length scale, it happens at an acceleration which is c times the Hubble constant. How do we explain that? Is that a tip that MOND is right? I don't think so. Or is that a coincidence that we have to explain? Coincidences can sometimes be clues, and sometimes they are just coincidences.

Professor Lynden-Bell. Are you worried about the size of the Sun and the Moon? [Laughter.]

The President. Last question.

A Fellow. You said at the end that you thought we had all the pieces but just hadn't put them together in the right way. Can you put your hand on your heart and say that thirteen years ago, before acceleration, you thought there was a huge piece missing, and we can't do anything until we have this new big piece? So, are you absolutely sure that there are no big pieces off the table?

Professor Turner. You have two questions there. The first one: yes, I can put my hand over my heart, because in 1995 I wrote a paper saying we are missing a piece, and there should be dark energy out there. But the second one, you know, I'm a theorist so I choose my hands, and I'll put my left hand near my heart [laughter]. I think you make a very good point, which is, when you look how complicated it is, you have to be a fool to say that there's not another component out there. How significant is it? One thing is that we know the other component out there isn't bigger than a few per cent, because we can measure the matter separately, we can measure the dark energy separately, and we can add them up and they come close to 100%. They come, say, within a few per cent. So we know what's left is only a few per cent, but you are probably right, that there is another piece.

The President. This has been a tremendous discussion, and an absolutely wonderful lecture; let's finish by thanking Mike again! [Applause.] Continuing the theme of small components of things, you are invited to the reception at the RAS Library which follows this, and we will meet again on Friday, November 11th.

AN ACCURATE LOCAL-SIDEREAL-TIME CLOCK

By R. V. Willstrop
Institute of Astronomy, Cambridge

Knowledge of the local sidereal time (LST) is required when setting an equatorial telescope on any object too faint to be seen in a finder; the time of any observation is usually reported in Universal Time (UT1; formerly GMT). In the 19th and most of the 20th Centuries those times would be provided by two pendulum clocks; the Institute of Astronomy holds an identical pair of clocks (strictly, timepieces as they have no chiming mechanism) made by Dent for the Solar Physics Observatory in about 1886, serial numbers 42459 and 42460.

UT1 can now be obtained to high precision from a variety of sources: radio signals, global positioning satellites, World-wide-web, *etc*. It is not possible to obtain LST directly from any of those sources, because LST necessarily depends on the observer's longitude. Programs are available, and can be run on a laptop computer, to obtain LST from UT1 in real-time, but it is sometimes inconvenient to have to keep (securely) a dedicated laptop in a dome, or to have to transfer it from office to dome whenever one is observing.

Analogue-display clocks controlled by quartz crystals are now available very cheaply, and it is possible to modify them to change the rate of oscillation of the crystal to display sidereal time. But a pair of clocks of this type adjusted to show mean solar time and local sidereal time would be independent of each other, just as pendulum clocks were 100 years or more ago.

This note describes three possible arrangements of digital counters which can generate both mean solar time and local sidereal time from one crystal oscillator. One arrangement uses decimal scalers and a small number of dividers by 2, 3, and 5 (Fig. 1); the other two arrangements, shown in Figs. 2 and 3, use binary counters exclusively. In all three schemes two cascades of counters are needed, one to generate a 1-Hz signal at mean solar rate, and a second cascade to generate '1 Hz' at sidereal rate. It is necessary to be able to advance the hours and minutes, and to reset the seconds display to zero on both displays, not only for initial setting-up but also after any interruption to the electrical power. It is probably not necessary to set the sidereal time more accurately than to the nearest second, but if this were required it could be accomplished by a brief interruption of the input to the sidereal-time divider chain. Corrections must be applied to the rate of the crystal oscillator to allow for the tolerance and any secular drift. It is assumed that the mean-solar-time display will be compared at appropriate intervals with a radio-controlled digital clock, and that the time shown will be corrected by adjusting the frequency of the pulses entering both divider chains, and not by resetting the minutes or seconds of the mean-time display.

In all that follows, nutation is ignored and it is assumed that the duration of a sidereal day is the average interval between successive transits of the first point of Aries across the observer's meridian. This amounts to $23^h\ 56^m\ 4^s{\cdot}090524$ (86164·090524 s) in mean solar time; because of precession it is a little over 8 ms shorter than the true period of rotation of the Earth (86164·098904 s)[1].

The arrangement in Fig. 1 shows a crystal oscillator running at a nominal rate of 10 MHz. After it has passed through the 'mixer box' the signal is divided in seven decimal scalers, and is used to drive a mean-solar-time display. Typical tolerances of inexpensive crystal oscillators are quoted as 50 parts per million (ppm). If uncorrected, they would result in an error of up to 4 or 5 seconds per

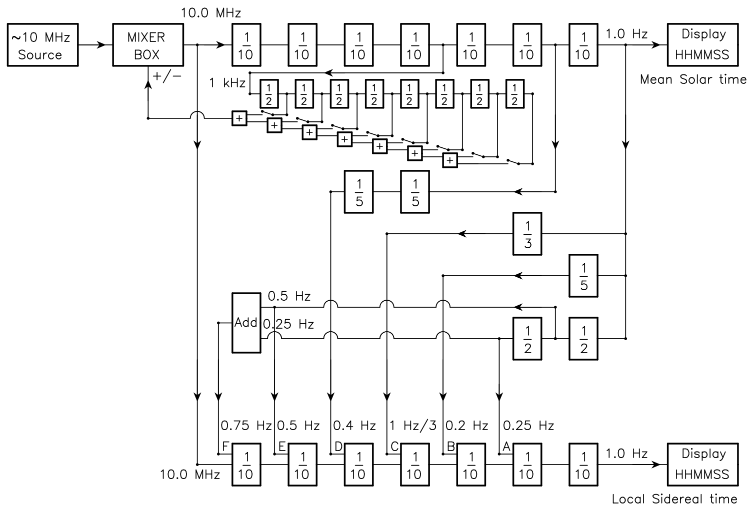

FIG. 1

Mean-solar-time and local-sidereal-time displays generated from one nominal 10-MHz crystal oscillator, using decimal, binary (and four other) scalers.

TABLE I

Sidereal clock pulses per second (decimal scalers)

Crystal source, 10·0 MHz divided by 10^7:			1·00000000000000
A	Add	1/400	0·0025
B	Add	1/5000	0·0002
C	Add	1/30000	0·00003333333333
D	Add	10/2500000	0·000004
E	Add	1/2000000	0·0000005
F	Add	1/20000000	0·00000005
and	Add	1/40000000	0·000000025
		Total	1·00273790833333
		Ideal	1·00273790943031
		Difference:	– 0·00000000109698

day, which would be obvious within six or eight hours if the mean solar time displayed is compared with a radio-controlled digital clock. A cascade of binary scalers, driven at 1 kHz, could provide signals at 500 Hz, 250 Hz, *etc.*, down to 3·9 Hz (approx), a selection of which could be added together and added to (or subtracted from) the nominal 10-MHz signals in the mixer box. If the crystal drifts away from its original rate it will be necessary to adjust the feedback, just as it may be necessary to make small corrections to a pendulum clock. If the mean-solar-time display is kept nearly in synchronism with the radio-

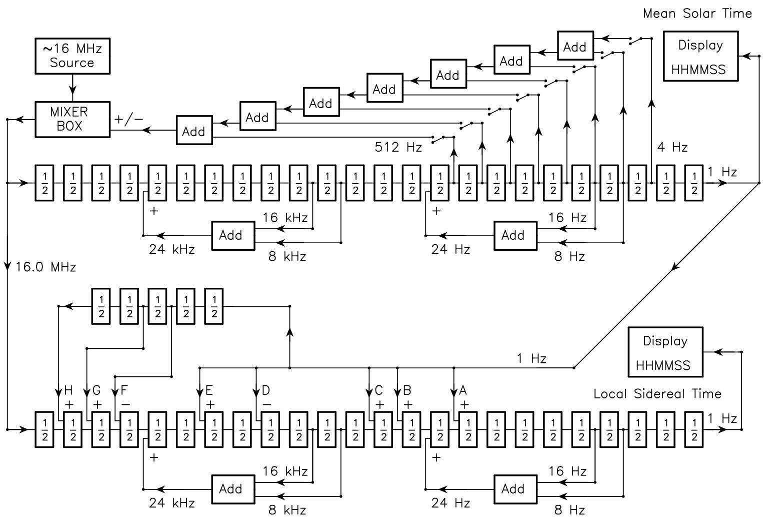

FIG. 2

Mean-solar-time and local-sidereal-time displays generated from one nominal 16-MHz crystal oscillator, using binary scalers. Oscillators running at 8 MHz (or 32 MHz) could also be used if one binary scaler were to be omitted from (or added to) the high-frequency end of each cascade.

TABLE II

Sidereal clock pulses per second (binary scalers)

Crystal source:			1·00000000000000	
A	Add	2/1000	+ 0·002	
B	Add	1/2000	+ 0·0005	
C	Add	1/4000	+ 0·00025	
D	Subtract	$16/10^6$		− 0·000016
E	Add	$4/10^6$	+ 0·000004	
F	Subtract	$1/8 \times 10^6$		− 0·000000125
G	Add	$1/32 \times 10^6$	+ 0·00000003125	
H	Add	$1/256 \times 10^6$	+ 0·00000000390625	
			+ 1·00275403515625	− 0·000016125
			− 0·000016125	
		Total	1·00273791015625	
		Ideal	1·00273790943031	
		Difference	+ 0·00000000072594	

controlled clock without resetting the display, then the long-term average rate of the crystal, after correction in the mixer box, will be very close to the ideal 10·0 MHz.

Because both sets of counters are driven from the same source, in each second of mean solar time 10^7 pulses are input at each of them. Additional pulses must be fed into the counters which are to generate sidereal time. The number of additional pulses can be calculated from the ratio:

$$86400 / 86164{\cdot}090524 = 1{\cdot}00273790943031$$

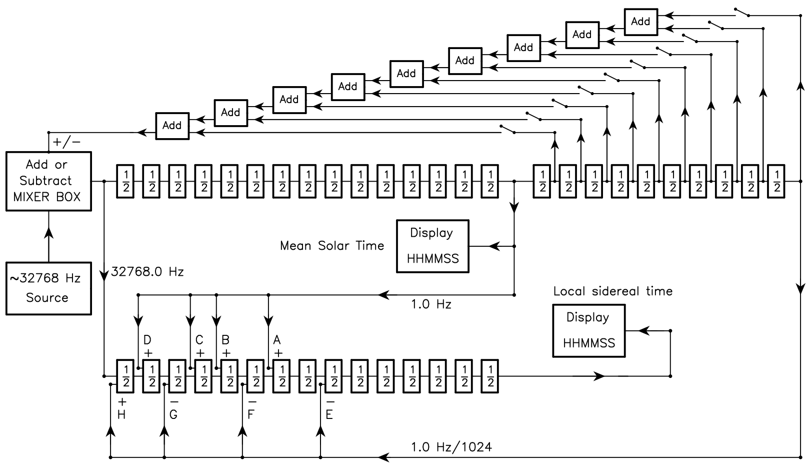

FIG. 3

Mean-solar-time and local-sidereal-time displays generated from one nominal 32768-Hz crystal oscillator, using binary scalers.

TABLE III

Sidereal clock pulses when using a 32768-Hz crystal

Crystal source:			1·00000000000000	
A	Add	1/ (2^9)	+ 0·001953125	
B	Add	1/(2^{11})	+ 0·00048828125	
C	Add	1/(2^{12})	+ 0·000244140625	
D	Add	1/(2^{14})	+ 0·00006103515625	
E	Subtract	1/(2^{17})		– 0·00000762939453
F	Subtract	1/(2^{20})		– 0·00000095367432
G	Subtract	1/(2^{23})		– 0·00000011920929
H	Add	1/(2^{25})	+ 0·00000002980232	
			+ 1·00274661183357	– 0·00000870227814
			– 0·00000870227814	
		Total	1·00273790955543	
		Ideal	1·00273790943031	
		Difference	+ 0·00000000012512	

During each second of mean solar time the sidereal-time display will receive exactly one pulse originating from the 10-MHz crystal. The additional contributions are listed in Table I. All of the corrections required to generate sidereal time are additive, and with one exception only one stream of correcting pulses is applied to each decade counter. The cumulative error amounts to a loss of 1 second in 28 years, provided that the electrical supply can be maintained for that period.

The second arrangement, using binary counters, is shown in Fig. 2. A crystal running at 8, 16, or 32 MHz is used here. After division by 3, 4, or 5 binary scalers, the rate is reduced to 1 MHz. Exact division by a further factor of 10^6 can be achieved with binary counters by making use of the near equality of 2^{10} (1024) and 10^3 (1000). Pulses at a frequency of 16 kHz and 8 kHz can be taken from the divider cascade, added together to produce 24 kHz, and fed back into the chain with the 1-MHz (1000-kHz) pulses to give 1024 kHz. After the next 10 binary scalers this is reduced to 1 kHz. Then pulses at frequencies of 16 Hz and 8 Hz can be taken from the divider chain, added to produce 24 Hz, and reintroduced with the 1-kHz pulses, creating 1024 Hz, which is reduced to 1 Hz exactly at the input to the mean-solar-time display. As in the arrangement using decimal scalers, the rate of the crystal oscillator will almost certainly need to be trimmed to bring it to exactly 8, 16, or 32 MHz; any correction in the range ± 1020 Hz, in steps of 4 Hz, can be obtained by selecting a suitable combination of the switches in the feedback circuits, and either adding or subtracting the sum of them in the mixer box.

The correction from mean solar time to sidereal time can be made by adding or subtracting 1-Hz pulses, obtained from the input to the mean-solar-time display, at five points (A – E) along the sidereal divider chain, and less-frequent pulses at three more positions (F – H). The effects of these extra pulses are listed in Table II. To minimize the number of places on the divider chain at which some correction must be applied, two of the corrections are negative. This sidereal-time display will run fast by 1 second in 43 years.

A number of manufacturers produce crystal oscillators which run at 32768 Hz, with stability claimed to be better than 5 ppm, or in some cases 3 ppm, and tolerance 20 ppm[2]. The block diagram for an oscillator running at this frequency is shown in Fig. 3. Division by 2^{15} produces a frequency of 1 Hz to drive the mean-solar-time display. This is not slow enough to allow fine adjustment of the rate of the crystal, so the sequence of binary scalers is continued to produce one pulse in 1024 seconds at the lowest frequency. The ten feedback routes shown allow corrections of ± 0·5, 0·25, *etc.*, down to (1/1024) Hz. The largest two of these together would be more than sufficient to correct an error in the crystal rate at the limit of the tolerance, 20 ppm, and the smallest is probably finer than is necessary to correct any irregular drift in the rate of the crystal. A cascade of only 15 scalers is sufficient for the sidereal-time display. The calculation of the sidereal rate is shown in Table III.

Here the residual difference between the sum of the pulses per second and the ideal is, quite by chance, less than one two-hundredth of the smallest of the items (H) in the summation. The sidereal-time display will gain less than one second in 250 years, provided that the mean-time display is kept in synchronism with a radio-controlled digital clock and the electrical power is not interrupted.

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THE HORNED MOON, WITH ONE BRIGHT STAR: TRANSIENT LUNAR PHENOMENA

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Brief appearances of star-like lights on or in front of the Moon have been of continuing scientific interest and controversy. An explanation of the phenomenon is advanced, based on recently proposed high-altitude dust clouds above the shadowed lunar surface produced in the wake of the solar wind. Rayleigh-scattering particles at the outer extremity of the dust veil act as a screen on which light from a celestial object, passing close to the dark limb of the Moon, is projected. When this veil lies between the Moon and Earth, the celestial object will appear, from Earth, to be in front of the Moon.

Introduction

In his poem, *The Rime of the Ancient Mariner*, Samuel Taylor Coleridge[1] describes "The horned moon, with one bright star / Within the nether tip", a puzzling image that moved Stratton, in this periodical[2], to call for a physical explanation of the lines. Coleridge composed them after reading[3] *The Botanic Garden*, a poem by the polymath Erasmus Darwin, in which he imagines the Moon developing an atmosphere in the future, and alludes to "Mr. Herschell [*sic*] having discovered a volcanic crater three miles broad burning on her [the Moon's] disk."[4].

More than four centuries of observations of points of light seen for short periods of time, apparently on the lunar surface, have been published[5–7]. These 'transient lunar phenomena', TLP, are of various types, and have been explained in terms of a number of mechanisms. For example, some TLP on the sunlit lunar surface with durations of minutes have been suggested to be caused by sunlight reflected from, or luminescence emitted by, material disturbed by outgassing matter from the interior of the Moon[8–13]. Flashes of light with durations of fractions of a second have been attributed to incandescent vapour plumes generated by meteoriod impacts[14–16].

Here, in the same publication and 60 years after Stratton sought a physical basis for Coleridge's description, "The horned moon, with one bright star", we suggest another model to explain the transient points of light appearing on the shadowed surface of the Moon.

18th-Century TLP

A number of reports of TLP appeared in the latter half of the 17th Century and throughout much of the 18th Century. In his *The History and Present State of Discoveries Relating to Vision, Light and Colours*, Joseph Priestley[17] alludes to Jurin's essay on distinct and indistinct vision in 1738 published as an appendix to Smith's *Opticks*. Priestley quotes Jurin's suggestion that, to individuals with "indistinct vision", when "a star approaching very near to the edge of a planet, may appear within its limb, as if the planet was transparent, and the other was seen through it; which accounts for some observations of astronomers to that purpose, and also for Mars or Venus, &c. appearing within the limb of the moon."[17] In his analysis of *The Rime of the Ancient Mariner*, Lowes[18] presents several pieces of evidence from Coleridge's notebooks[3] from which he concludes that Coleridge had read Priestley's book. Further, Priestley's book appears in the 1790 catalogue of the Bristol Lending Library[19] of which Coleridge was a member and to which therefore he would have had access when he wrote *Ancient Mariner*. One example of the type of phenomenon Jurin described was that where a number of inhabitants of the Boston area on a morning in 1668 November saw "a star appear'd below the body of the moon within the horns of it" when Venus was close to the Moon[20]. It is unlikely that all the observers of this event were afflicted with 'indistinct vision' and even less likely was William Herschel mistaken by an optical illusion when he reported a star-like light in front of the dark surface of the Moon on 1783 May 4[21], the first of a cluster of similar observations reported towards the end of the 18th Century. It occurred when "there was about to be an occultation of a star at the Moon's dark limb"[22]. Herschel[21] reported two more similar sightings on 1787 April 19 and 20 which, "seen in the telescope resembled a star of the fourth magnitude as it appears to the natural eye". He explicitly and categorically dismisses the proposition that the spots he observed were associated with any known topographical features on the lunar surface illuminated by 'earthshine'. "The spots are plainly distinguished from the rest of the marks on the moon; for the reflection of the sun's rays from the earth is, in its present situation, sufficiently bright, with a ten-foot reflector, to show the moon's spots, even in the darkest of them: nor did I perceive any similar phenomena last lunation, though I viewed the same places with the same instrument."[21] Nevil Maskelyne[23], the Astronomer Royal, communicated two independent reports of a similar event on 1794 March 7, the same evening as there was an occultation of a star at the northern limb of the Moon. When Herschel attributed his sightings to volcanic eruptions on the Moon[21], the proposal, not surprisingly, attracted much attention and it has been of interest and controversy ever since[4,5,11,12,14].

At the time of Herschel's and Maskelyne's sightings[21,23], as well as several bright celestial objects close to the Moon, solar magnetic storms were occurring, as evidenced by auroral activity on Earth[24]. The conjunction of these two astrophysical conditions suggests a new explanation for the star-like apparitions of 1787 and 1794 located inside the Moon's northern dark limb[21,23]. Inspection of nautical almanacs[25] reveal, of the bright celestial objects that were close to the Moon on these occasions, only one, Capella, was suitably positioned to the north of the Moon at the times of the sightings. Specifically, on 1787 April 19 at 10:36 sidereal time[21], on 1787 April 20 at 10:02 sidereal time[21], and on 1794 March 7 at about 20:00 GMT[23] the angular distances of Capella were respectively 29–30°, 22°, and 30° from the northern dark limb of the moon. Although Herschel gives the times of his observations in 'sidereal' time, which Haas[24] has suggested to be local 'civil' time, a difference between this time and GMT of 2 hours results in a less-than-1° change in the lunar angular distance of Capella. With regard to a possible link between TLP and solar magnetic storms, it is significant, as noted by Middlehurst & Moore[5], that there were no reports of the phenomenon in the first two decades of the 19th Century during the Dalton minimum, a period of low auroral and solar activity.

Lunar dust clouds

Mathematical models have been constructed recently that predict clouds of lunar dust extending high above the lunar surface to the shadowed side of the lunar terminator[27,28] that are consistent with observations made by the *Apollo 17* astronauts[29]. Electrical potentials at the Moon's surface of ~–40 V develop in the wake of the solar wind that charges the lunar dust and it is proposed that the resultant electrostatic repulsions launch the dust grains to substantial altitudes above the shadowed part of the Moon. Small grains with radii of ~ 0·01 μm ascend to altitudes of ~ 100 km while larger grains are present at lower elevations[27,28]. Near the time of the new moon, as it was on 1787 April 19 and 20, light from distant celestial objects passing close to the dark limb or the lunar poles will enter the dust cloud. Large dust grains with radii > 0·1 μm attenuate light but, according to the Stubbs *et al.* model[27], those grains are confined to a region within 1 km above the lunar surface. Light traversing dust grains with radii between approximately 0·1 μm and 0·02 μm in regions of the cloud at higher altitudes is largely scattered in the forward direction characteristic of particles with those dimensions. However, when light encounters smaller dust grains with diameters less than one tenth of visible wavelengths, *i.e.*, radii < 0·02 μm, that are present towards the outer extremity of the dust veil, it will be scattered in all directions in a pattern characteristic of Rayleigh scattering. The outer sheath of the cloud, therefore, serves as a screen on which light from the celestial object is projected and, if the dust cloud screen lies between the Moon and Earth, then, from Earth, a virtual image of the object will appear on the Moon's shadowed surface as shown in Fig. 1.

During solar magnetic storms, the charging of the lunar surface in the wake of the solar wind is substantially greater than that under quiescent conditions[30,31] with commensurately increased elevations of the dust grains. The solar energetic-particle events experienced on the *Lunar Prospector* spacecraft mission in 1998 produced negative charging of the lunar surface on the dark side of the terminator that frequently reached potentials of –200 V to –400 V[31], an order of magnitude greater than that under quiescent conditions. The same energetic particles in the solar wind generated by magnetic storms on the Sun cause aurorae on Earth, and within a few hours of Herschel's[21] and Maskelyne's[23] observations of star-like lights in front of the Moon, aurorae were reported on Earth[25]. On those occasions, the lunar dust cloud above the shadowed part of the Moon would have extended further from the Moon's surface and towards Earth than usual.

For the sighting Herschel made on 1787 April 19 at 10:36 sidereal time[21], he measured the position of the light that "resembled a star" to be at 3′ 57″ inside the "northern limb of the moon". To illustrate how this could occur by the mechanism proposed here, a two-component lunar exosphere is assumed comprising a sheath of very small Rayleigh-scattering dust grains acting as a light-projection screen at the perimeter of the exosphere and larger, forward-scattering particles at lower altitudes. Analysis of the geometric optics (*i.e.*, without diffraction) of light from the star, Capella, in its location relative to the Moon on 1787 April 19 at 10:36 sidereal time, has its light entering the lunar dust cloud at the northern dark edge of the lunar disc at an angle of 29–30° with respect to the Earth–Moon axis. With this trajectory, a light ray from Capella would form an image of the star on the dust-cloud perimeter in the position observed by Herschel if its effective height were ~ 150–200 km above

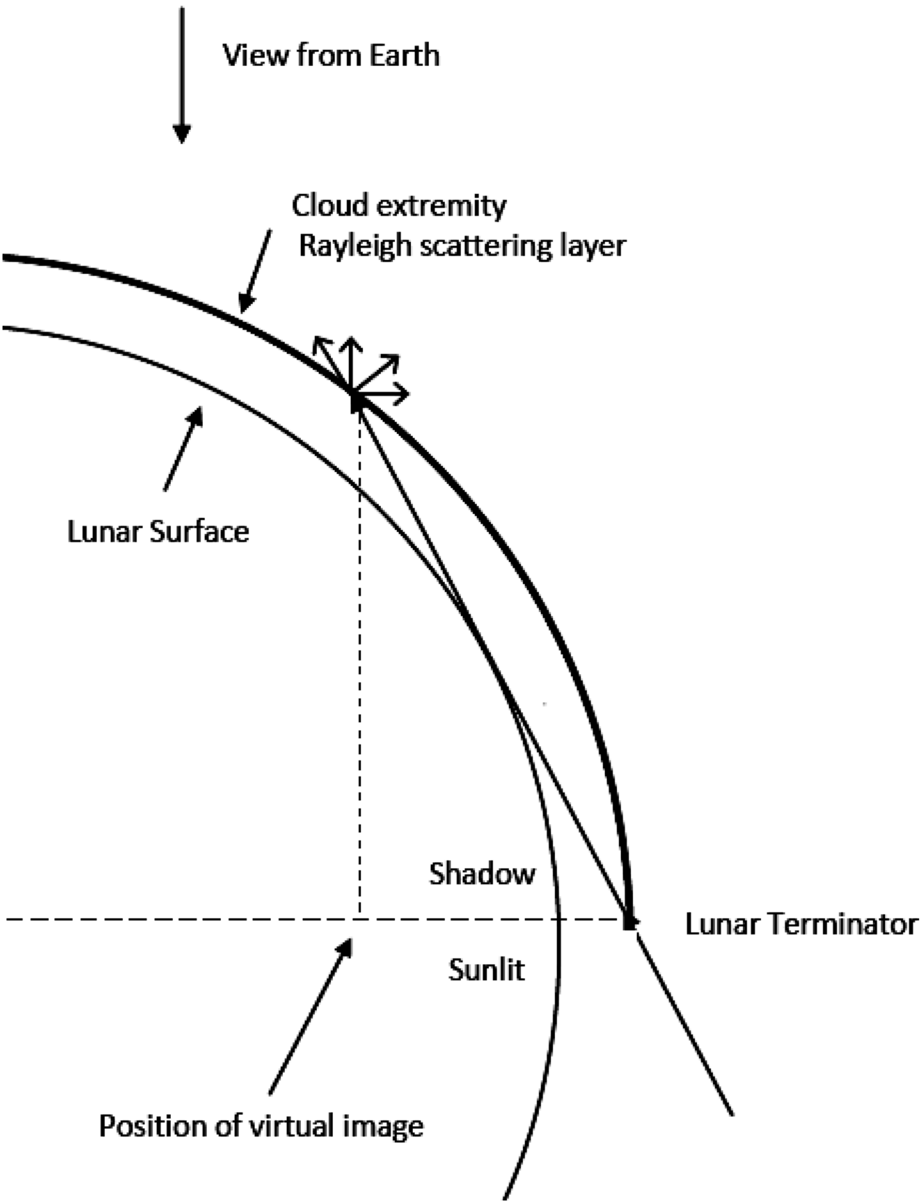

FIG. 1

A ray of light from a bright celestial object with an angular distance of 29–30° from the Moon passing close to the lunar terminator projected on and scattered from a sheath of Rayleigh-scattering lunar dust particles ~ 150 km above the Moon's surface. The position of the virtual image of the object viewed from Earth is shown on the lunar disc.

the shadowed lunar surface as shown in the ray diagram (Fig. 1). Assuming the screen consists of dust grains with radii, r_d, $<0{\cdot}02$ µm, from the relationship describing the maximum elevation of lunar dust grains, Z_{MAX}:

$$Z_{MAX} = 3\varepsilon_0\, \phi^2/\rho g_L\, r_d^2$$

and values for the permittivity, ε_0, the density of the dust, ρ, the acceleration due to lunar gravity, g_L, used by Stubbs *et al.*[27], a surface potential, ϕ, of –200 V would be expected to produce a sheath of dust grains with a 0·02-µm radius at a height of 150 km. This level of surface potential was frequently found during the solar-energetic-particle events encountered during the *Lunar Prospector* mission[31] and therefore the model proposed here predicts a veil of dust at the elevation above the Moon's surface on which to form a virtual image of Capella on the dark lunar disc in the position measured by Herschel[21].

Conclusions

Our model, where the image of a star close to the Moon forms on the outer reaches of the lunar dust cloud between the Moon and Earth, suggests the most probable time for such an apparition is at the new moon, during solar magnetic storms, and when a bright (magnitude 1) celestial object is at angular distances less than ~ 30° from the dark limb of the Moon.

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 223: HR 396, HR 7477, HR 7636, AND 6 ANDROMEDAE

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HR 396 is a G8 subgiant in an 84-day almost-circular orbit. In addition to the orbital motion, its radial velocities since 2002 have shown a slow but steady upward trend of about 0·17 km s^{-1} per thousand days; the trend can be traced back 40 years. The Cambridge work on the star has, however, been largely pre-empted by much more precise radial velocities obtained by a large syndicate that is observationally based at Lick Observatory.

The other three stars have orbital periods of the order of a decade and orbits of moderate eccentricity. HR 7477 is widely supposed to be of type G6 V — hard to believe in the light of $M_V \sim +0^{\rm m}\!\cdot\!7$ and $(B-V) = 1^{\rm m}\!\cdot\!02$. HR 7636 is of type G8 III, while 6 And has been classified F5 IV but has no more than main-sequence luminosity. 6 And has a considerable rotational velocity ($v \sin i \sim 19$ km s^{-1}) and a mass function of 0·2 $M_\odot$ that is probably to be understood in terms of duplicity of the secondary.

HR 396 (*HD 8375*)

HR 396 is a sixth-magnitude star about 3° south-following β Andromedae. It has a conspicuously large proper-motion of 0″·26 annually, which had already been recognized[1] at Cincinnati in the 19th Century. In fact *Simbad* gives the arcane main heading of 'LTT 10503' in its bibliography of HR 396, no matter under what identity one raises it, from its entry in Luyten's *Two-Tenths* [annual proper-motion] catalogue[2]. There is just one set of ground-based *UBV* magnitudes for the star; they were obtained at Kitt Peak on a guest-investigator basis by Argue[3], an observer from the Cambridge Observatories. He was deputed in the early 1960s by the then Director, Redman, to visit KPNO and obtain photometry for stars that lacked it but were on the Cambridge narrow-band-spectrometry programmes, of which the first was an investigation of the violet CN band by Griffin & Redman[4]; in the case of present interest he obtained $V = 6^{\rm m}\!\cdot\!28$, $(B-V) = 0^{\rm m}\!\cdot\!83$, $(U-B) = 0^{\rm m}\!\cdot\!48$. The spectral type of HR 396 was determined as G8 IV by Halliday[5], whose visual classification of David Dunlap Observatory spectrograms (33 Å mm^{-1} at Hγ) was supported by a luminosity classification made by Hossack's 'oscilloscopic microphotometer' method[6,7], which yielded luminosities on a continuous numerical scale rather than discrete steps. That method attributed to HR 396 a luminosity class of 3·7, which according to an absolute-magnitude calibration corresponded to $M_V = +1^{\rm m}\!\cdot\!96$ and thence to $\pi_{spectr} = 0''\!\cdot\!0145$ (the V magnitude being given as $6^{\rm m}\!\cdot\!15$). Eggen[8] rather resourcefully derived $M_V = +2^{\rm m}\!\cdot\!20$ from *DDO* photometric indices that he estimated by transformation from Geneva photometry[9]. The *Hipparcos* parallax[10] is 0″·01765, and leads to

$M_V = +2^{m}\cdot 52 \pm 0^{m}\cdot 05$. The same type of G8 IV that Halliday gave was also found by Harlan[11], and the luminosity class is clearly well supported by the trigonometrical parallax.

The first radial-velocity measurements of HR 396 were made at the David Dunlap Observatory, very possibly from the same 33-Å mm^{-1} plates as were used by Halliday[5] for spectral classification; there were four of them, taken in the 1940s, but their dates and individual results were not published, only a mean velocity[12] of +3·8 km s^{-1} with a 'probable error' of 0·6 km s^{-1}. Beavers & Eitter[13] published two velocities, with dates, obtained with the photoelectric spectrometer[14] at the Fick Observatory of Iowa State University at Ames; the discrepancy (~8 km s^{-1}) between the two values was enough for those authors to identify the object as having a variable velocity. De Medeiros & Mayor[15] gave a mean of four *Coravel* velocities and likewise identified the star as a spectroscopic binary. They subsequently placed the individual data on file at the Centre de Données Stellaires. In 2005 Snowden & Young[16] anachronistically published three velocities from photographic plates taken more than 30 years previously with the Kitt Peak 84-inch telescope or coudé feed. A computer-accessible tabulation referred to by Massarotti *et al.*[17] includes five more velocities, obtained with the Center for Astrophysics digital spectrometers, for HR 396.

Lastly, Bowler *et al.*[18] (an 11-person syndicate that acknowledges support by at least eight named observing assistants) recently published for HR 396 an orbit based on 28 radial velocities obtained with the very precise 'planet-finding' instrument at the coudé focus of the Lick 120-inch reflector. The present author was unaware of their work until he came to write this paper and retrieved the literature on HR 396 from *Simbad*; the star is not mentioned in the abstract of Bowler *et al.*'s paper like the other five stars for which those authors give orbits. There is, perhaps, still some purpose in publishing here a confirmatory result, particularly to demonstrate such information as can be gleaned from the previously published velocities.

The writer's interest in HR 396 began in 2002, when the star was among those selected for observation with the Cambridge *Coravel* from the data file lodged with the Centre de Données Stellaires by de Medeiros & Mayor[15]. The rapidity of the velocity variation was recognized immediately, and the 84-day quasi-circular orbit was well established by 33 measurements in the ensuing two years or so. In accordance with the writer's usual principle of maintaining observations even of well-observed stars, albeit at a relatively low frequency, until their respective orbits are actually published, he continued to observe HR 396 about twice a year. It was a matter of some chagrin that the orbit seemed actually to become *worse* as time went on! — until it was recognized that the residuals began to show a systematic run from negative at the start of the data set to positive at the end. This is the eighth time that a monotonic trend has been noticed in the radial velocities of a star treated in this series of papers; the most recent of the previous ones was HD 152109 in Paper 216[19], where references will be found to the six earlier cases. The orbit of HR 396 has been treated with the modified computer program first described and used in Paper 189[20], which incorporates in the orbital solution a seventh element representing a linear trend.

All the available radial velocities have been listed in chronological order in Table I. The Bowler *et al.*[18] data are not in the public domain, and anyway the intention here is to present an orbit that is entirely independent of them. In an effort to place the different sources represented in Table I on a common zero-point — the one usually adopted in this series, set up[21] in 1969 — all the

TABLE I

Radial-velocity observations of HR 396

Except as indicated, the observations were made with the Cambridge Coravel.
Note: rounding can cause discrepancies of 0·1 km s⁻¹ among computed quantities.

Date (UT)	*MJD*	*Observed Velocity km s^{-1}*	*Phase*	*Computed velocity* γ *km s^{-1}*	*Orbital km s^{-1}*	*(O−C) km s^{-1}*
1972 Nov. 21·27★	41642·27	+5·9	$\overline{129}$·261	+5·5	+0·9	−0·5
23·27★	644·27	+6·5	·285	+5·5	+0·1	+0·9
1974 Oct. 14·32★	42334·32	+2·4	$\overline{121}$·506	+5·6	−4·7	+1·5
1976 Dec. 21·07†	43133·07	+11·2	$\overline{111}$·021	+5·7	+5·0	+0·4
1978 Dec. 12·12†	43854·12	+2·9	$\overline{103}$·611	+5·9	−4·5	+1·5
1987 Sept. 7·07‡	47045·07	+2·1	$\overline{65}$·624	+6·4	−4·3	+0·0
1988 Aug. 30·03‡	47403·03	+9·7	$\overline{61}$·888	+6·5	+2·8	+0·5
1992 Jan. 31·77‡	48652·77	+6·4	$\overline{46}$·776	+6·7	−0·7	+0·4
1993 Nov. 16·87‡	49307·87	+2·3	$\overline{38}$·580	+6·8	−4·8	+0·3
2002 Aug. 2·12	52488·12	+3·2	0·465	+7·3	−4·3	+0·2
Sept. 2·11	519·11	+8·5	·835	+7·3	+1·2	0·0
28·06	545·06	+11·5	1·144	+7·3	+4·0	+0·2
Oct. 27·98	574·98	+2·7	·500	+7·3	−4·7	0·0
2003 Jan. 7·91	52646·91	+5·3	2·357	+7·3	−2·0	−0·1
17·87	656·87	+2·9	·476	+7·3	−4·4	0·0
25·80	664·80	+2·4	·570	+7·4	−4·8	−0·1
Feb. 14·81	684·81	+7·8	·809	+7·4	+0·4	+0·1
July 28·12	848·12	+6·1	4·754	+7·4	−1·3	0·0
Aug. 4·14	855·14	+8·8	·838	+7·4	+1·3	+0·1
15·11	866·11	+11·9	·968	+7·4	+4·5	0·0
Sept. 14·09	896·09	+6·4	5·325	+7·4	−1·1	+0·1
20·06	902·06	+4·5	·397	+7·4	−3·0	+0·1
Oct. 12·07	924·07	+3·9	·659	+7·4	−3·7	+0·2
17·03	929·03	+4·9	·718	+7·4	−2·3	−0·1
18·01	930·01	+5·3	·730	+7·4	−2·0	−0·1
Nov. 4·05	947·05	+11·4	·933	+7·4	+3·9	+0·1
12·96	955·96	+12·5	6·039	+7·4	+5·1	0·0
16·93	959·93	+12·1	·086	+7·4	+4·9	−0·2
26·93	969·93	+ 10·1	·205	+7·4	+2·5	+0·2
27·91	970·91	+9·7	·217	+7·4	+2·2	+0·1
Dec. 5·91	978·91	+6·6	·312	+7·4	−0·7	−0·1
7·96	980·96	+6·1	·337	+7·4	−1·4	+0·1
28·90	53001·90	+2·8	·586	+7·4	−4·7	+0·1
30·06§	003·06	+3·1	·600	+7·4	−4·6	+0·3
2004 Jan. 2·85	53006·85	+3·4	6·645	+7·4	−4·0	0·0
24·85	028·85	+10·5	·907	+7·4	+3·3	−0·2
Feb. 25·82	060·82	+7·2	7·288	+7·4	+0·1	−0·3
Sept. 2·07	250·07	+2·5	9·542	+7·4	−4·9	−0·1
11·27§	259·27	+4·7	·652	+7·5	−3·9	+1·1
14·09	262·09	+4·1	·686	+7·5	−3·2	−0·2
21·10	269·10	+6·6	·769	+7·5	−0·9	0·0
Oct. 26·05	304·05	+10·5	10·185	+7·5	+3·1	0·0
Nov. 14·03	323·03	+4·0	·412	+7·5	−3·3	−0·1
14·98	323·98	+4·0	·423	+7·5	−3·6	+0·1

TABLE I (*concluded*)

Date (UT)	*MJD*	*Observed Velocity km s⁻¹*	*Phase*	*Computed velocity γ km s⁻¹*	*Computed velocity Orbital km s⁻¹*	*(O – C) km s⁻¹*
2005 Nov. 29·91	53703·91	+11·6	14·949	+7·5	+4·2	−0·1
Dec. 17·87	721·87	+11·3	15·163	+7·5	+3·6	+0·2
26·92	730·92	+7·8	·271	+7·5	+0·6	−0·3
2006 Nov. 24·03	54063·03	+9·4	19·227	+7·6	+1·9	−0·1
2007 Jan. 7·06§	54107·06	+ 5·6	19·751	+7·6	−1·4	−0·6
29·10§	129·10	+11·9	20·014	+7·6	+5·0	−0·7
Feb. 28·09§	159·09	+5·7	·371	+7·6	−2·4	+0·5
Sept. 26·12	369·12	+10·0	22·873	+7·6	+2·4	0·0
Oct. 5·06	378·06	+12·3	·980	+7·6	+4·7	0·0
2008 Sept. 20·08	54729·08	+11·4	27·161	+7·7	+3·6	+0·1
Oct. 28·01	767·01	+3·2	·613	+7·7	−4·4	−0·1
2009 Oct. 12·01	55116·01	+7·1	31·771	+7·8	−0·8	+0·1
Nov. 20·93	155·93	+9·2	32·246	+7·8	+1·3	+0·1
2010 Feb. 1·79	55228·79	+12·1	33·114	+7·8	+4·5	−0·2
Oct. 7·03	476·03	+12·9	36·060	+7·8	+5·0	0·0
2011 Jan. 14·82	55575·82	+9·3	37·248	+7·8	+1·3	+0·2

* Snowden & Young[16]
† Beavers & Eitter[13]
‡ De Medeiros & Mayor[15]
§ Massarotti *et al.*[17]
} Weight 0

published velocities have been increased by 0·8 km s^{-1} and those obtained with the Cambridge *Coravel* have had 0·4 km s^{-1} subtracted from the 'as reduced' values. The 46 Cambridge observations, only, have been entered into the solution of the orbit; they have the advantage of homogeneity and their r.m.s. residuals are agreeably small at 0·13 km s^{-1}, and in any case the addition of data from different epochs and with possible discrepancies still remaining in zero-points would be likely to vitiate the determination of (particularly) the trend.

Table I sets out the results of the calculation, showing the separate contributions of the trend and the actual orbit to the computed velocity, and the ensuing velocity residuals, as well as the phases in the orbit. The two velocity contributions are illustrated by Figs. 1 and 2, which are of course on very different scales — the 'trend' graph in Fig. 1 shows the variation of the γ-velocity of the orbit, over the whole 8½-year duration of the observations, plotted directly against time, and its velocity scale is exceptionally open owing to the smallness of the change, which obviously is nevertheless very significant. Fig. 2 is a normal plot of the orbit, except that its γ-velocity is shown as zero because that quantity is the variable whose gentle linear rise is plotted in Fig. 1. The velocity curve is very nearly a sine wave, but the orbital eccentricity is significantly non-zero. The orbital elements are set out here in Table II, with those given by Bowler *et al.*[18] for comparison. The two sets of elements are seen to be in very good agreement, though the Bowler *et al.* ones are much more precise than the writer's.

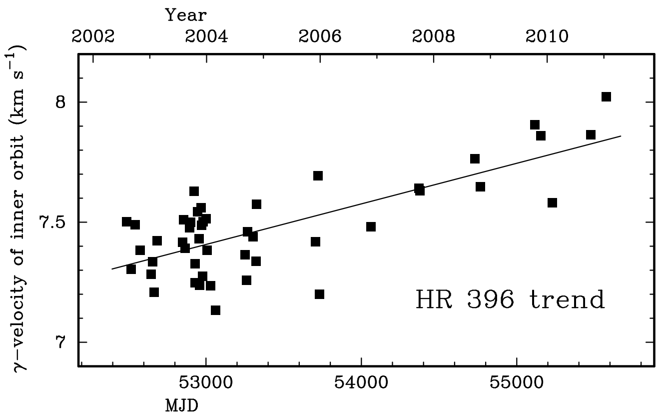

FIG. 1

Variation of the γ-velocity of HR 396 during the time that it has been under observation from Cambridge. The plotted points represent the observed radial velocities *less* the computed orbital velocities, and thereby represent the apparent γ-velocity at each time. The straight line is a computed linear fit to the points and represents the best approximation that can be made from the available observations of the trend of the γ-velocity.

TABLE II

Orbital elements for HR 396

Element		*This paper*	*Bowler et al.*
P	(days)	83·944 ± 0·008	83·9408 ± 0·0016
T	(MJD)	53372·4 ± 3·9	54038·8 ± 0·5
T_0	(MJD)	53376·1 ± 0·2	—
γ	(km s^{-1})	+7·58 ± 0·03*	—
Trend	(km s^{-1})†	+0·169 ± 0·027	+0·193 ± 0·007
K	(km s^{-1})	4·97 ± 0·03	4·9392 ± 0·0026
e		0·021 ± 0·006	0·0179 ± 0·0004
ω	(degrees)	344 ± 17	321·8 ± 1·9
$a_1 \sin i$	(Gm)	5·73 ± 0·04	5·704 ± 0·003
$f(m)$	($M_\odot$)	0·001068 ± 0·000022	0·001050 ± 0·000002
R.m.s. residual (km s^{-1})		0·13	—

*At MJD 54000

†Per thousand days. The γ-velocity rises by 0·169 km s^{-1} per 1000 days, so at (MJD) time t, $\gamma = +7{\cdot}58 + 0{\cdot}169(t - 54000)/1000$ km s^{-1}

In the above table, the uncertainties given by Bowler *et al.* are treated as standard deviations, to which they appear to be intended to be equivalent although they were determined in an unusual manner. Bowler *et al.* did not give any γ-velocity.

In an orbit of low eccentricity, the longitude of periastron inevitably has a large uncertainty, which is not shared by the timing of the velocity variations. In such cases it is useful to give, as well as the epoch T of periastron, the time T_0 of the passage through the ascending node (the time of maximum velocity of recession), which is indeed the timing quantity that alone is available for

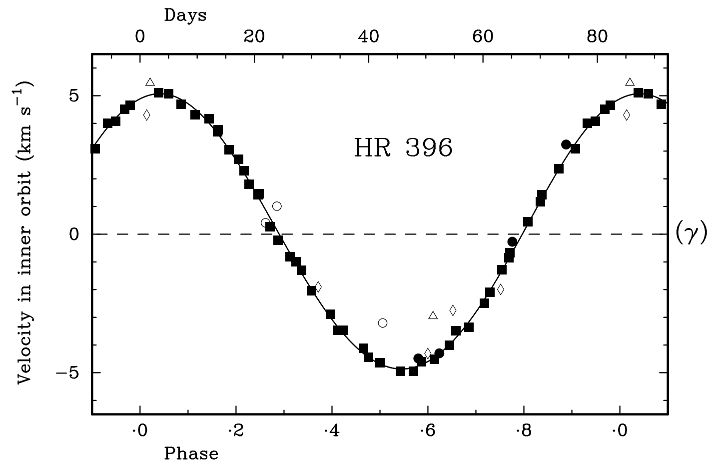

FIG. 2

The observed radial velocities of HR 396 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The orbital velocities are plotted with respect to the γ-velocities at the times of the respective observations, so in this diagram the γ-velocity appears as zero. Only the Cambridge velocities, plotted as filled squares, were used in the calculation of the orbit; the other symbols refer to published radial velocities whose sources are identified in the caption to Fig. 3.

specifying the phasing of an orbit that is truly circular. In the present case, the standard deviation of the eccentricity is 2⁄7 of the eccentricity itself. That is accurately reflected, first, in the uncertainty in the longitude of periastron, which must be 2⁄7 of a radian (16°·4) and then in the uncertainty of *T*, which must be 16·4/360 times the period (3·82 days). The minor discrepancies with the values in Table II doubtless arise merely from rounding errors largely stemming from the limited precision of the standard error of the eccentricity, which at 0·006 can be accurate only to one part in 12. Of course there are other contributors to the uncertainties of ω and *T*, but they are small in comparison with the contribution from *e*. The same relationship holds, more or less, between the uncertainties of the three elements in the solution by Bowler *et al.*

It is naturally of interest to look for further information about the long-term variation in the radial velocity of HR 396, of which we have documented only a linear approximation to what is evidently but a small fraction of the whole period. All that we can do to that end is to look at the earlier published velocities, which are plotted directly against time in Fig. 3, after the major variations represented by the orbital elements above have been subtracted. The 'trend' is drawn exactly as in Fig. 1 but extrapolated back into the past. The other measurements obviously tend to be less reliable than the Cambridge ones, and there may be uncorrected zero-point discrepancies between the various sources. The general impression given by Fig. 3, however, is that the rise in the γ-velocity of HR 396, that is so certain in the past decade, has probably been taking place for at least the past 40 years, but has speeded up a bit in recent years. There is certainly no sign that the orbital period could be less than 40 years, and the indications are that it is very much longer. Clearly it will be desirable to monitor the radial velocity of HR 396 for a very long time into the future.

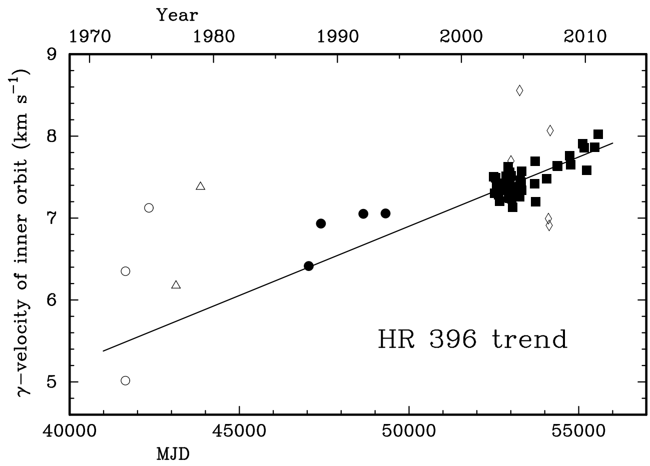

FIG. 3

The same as Fig. 1, except that the computed fit to the Cambridge velocities (represented as in Fig. 1 by the filled squares) has been extrapolated back to 1970 and all other available radial velocities have been plotted after the respective velocity contributions from the adopted orbit have been subtracted. The open circles and open triangles in the 1970s-epoch plot Kitt Peak photographic observations[16] and Ames photoelectric measurements[13], respectively. The four filled circles near 1990 are OHP *Coravel* velocities listed in a table referred to by de Medeiros & Mayor[15], while the five open diamonds plot CfA measurements, contemporaneous with the Cambridge ones, referred to by Massarotti *et al.*[17]. A tentative conclusion is that the rising trend of the γ-velocity has probably existed throughout the 40-year interval that is plotted but has probably accelerated in recent years.

HR 7477 (*HD 185657*)

Nicely placed for observation from Cambridge, HR 7477 is about 1° south of, and slightly following, θ Cygni; it is particularly easy to identify in *Tirion*[22], without even opening the atlas, since it appears in the map excerpted on the dust jacket, both on the front and back of the book. Photometry has been given by Eggen[23] and Oja[24], with results near $V = 6^{m}\cdot46$, $(B-V) = 1^{m}\cdot01$, $(U-B) = 0^{m}\cdot75$ (the colour indices given by the two authors do not agree very well).

It was discovered in the 1930s that HR 7477 has a high radial velocity. Adams & Joy[25], writing from Mount Wilson in 1938, included the star in a paper which was entitled "A list of stars with unpublished radial velocities greater than 75 Km/Sec" but is otherwise remarkable for its terseness. Occupying but a single page of the *PASP*, it has five lines of text and then a tabulation with 25 lines, each of which identifies a star and gives a mean velocity — in the case of HR 7477 it is –82 km s^{-1}. Much later, Abt[26] listed the individual details of the two observations that must have underlain that mean velocity, as well as a third measurement made later.

In a paper published in 1964, in the heyday of differential curve-of-growth studies of stellar elemental abundances, Pagel[27] included HR 7477 as one of five stars so studied. He concluded that it has an absolute magnitude of $+1^{m}\cdot6 \pm 1^{m}\cdot5$, and that it is "a subgiant or giant lying not far from the M67 sequence in the HR diagram", with most elements deficient by about 0·5 dex with respect to solar abundances. In particular he found [Fe/H] = –0·51, but a glaring exception to the general trend was sodium, with [Na/H] = +0·23:. The Cayrels[28] considered the spectral type of HR 7477 to be G6 V, a type that has been widely quoted since; the luminosity class is clearly in error (the parallax[10] yields $M_V \sim +0{\cdot}72 \pm 0{\cdot}10$), and that was recognized quite soon by Cayrel herself *et al.*[29], who then classed the star as G6 III. Adding further to the confusion over its luminosity class, however, Pritchet & van den Bergh[30] gave its type as G6 VI; it is not a misprint, because the same type appears both in their Table 1 and their Fig. 5. It is unfortunate — and symptomatic of the way that mistakes become entrenched in the literature — that the Cayrels' original misclassification of HR 7477 as G6 V was adopted in the *Bright Star Catalogue* and is still being quoted even by *Simbad* and by all the recent syndicates[31–33] who claim to determine the real properties of HR 7477 (and many other stars) from 'spectral libraries' to be found on the Web.

Several authors have tried to classify HR 7477 on the basis of photometric indices of one sort or another. Christensen[34] tabled HR 7477, with three other stars, as a subgiant, but noted, "Any of the four stars classified as subgiants could conceivably be reclassified as a giant, especially HD 185657 [*i.e.*, HR 7477]. Distinguishing between luminosity classes on the basis of indices becomes especially difficult when a wide range of metallicity is possible." He goes on to say that if HD 185657 is a giant, then the indicated value of [Fe/H] is –0·28. Saio & Yoshii[35] included the star in a table of 'low-velocity dwarfs'. Hartkopf & Yoss[36], despite tabulating its $(B-V)$ as 0·00, found a type of G6 III and an absolute magnitude of +1·6 from *DDO* indices. Vilnius photometry led Bartkevičius & Sperauskas[37] to a type of G9 III, an [Fe/H] of 0·0, and an M_V of +0·6. Komarov, Mishenina & Motrich[38], in a paper largely devoted to abundances of sodium, found that "the star HD 185657 has the 'solar' ratio of Na to Fe content, since [Na/Fe] = –0·16, in disagreement with [Pagel[27]]. At the same time, the deficit in the Fe and Na content relative to their content in the solar atmosphere is pronounced for this star, and it can be considered as a peculiar star in its content of chemical elements in the same measure as Arcturus." In a second paper, with particular reference to non-LTE effects, Korotin & Komarov[39] again referred to HD 185657 as a "chemically peculiar star", and slightly revised the [Na/Fe] relative abundance to –0·07. A further effort[40] at classification by Vilnius photometry produced a type of "MD?–G9III" (where 'MD' stands for 'metal-deficient'), [Fe/H] = –0·18, and $M_V = +0{\cdot}85$. Still another[41] by the same method yielded corresponding results of K0 III–IV, –0·11, and +0·95.

The discovery of the high (negative) radial velocity of HR 7477 by Adams & Joy[25] has already been mentioned above. The literature also includes three papers, published from the Royal Greenwich Observatory in the 1960s, carrying radial velocities measured from spectrograms taken at Mount Wilson Observatory on a guest-investigator basis by the then Astronomer Royal, Sir Richard Woolley. First Woolley, Jones & Mather[42] reported on two plates obtained at 10 Å mm^{-1} at the coudé focus of the 100-inch telescope. Next, Jones & Woolley[43] referred to two exposures at the 60-inch Cassegrain, but as the dates were not divulged and the velocities were given only as a mean the result is not of utility here. Then Woolley & Harding[44] provided two more velocities from the 100-inch coudé. The last publication of radial velocities for HR 7477 appears to be that of Beavers & Eitter[13], who gave 18 measures from the Ames photoelectric spectrometer[14] in the years 1976–78. The velocity was not considered variable; in retrospect the Ames data can be seen to be confined to a small range of phase (about a fifth of the period) that is fortuitously centred on

TABLE III

Radial-velocity observations of HR 7477

Except as noted, the sources of the observations are as follows:
1976–1978 — Ames[13] *(weight 0); 1997–2011 — Cambridge Coravel (weight 1)*

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O–C) km s^{-1}
1935 July 11·35*	27994·35	−85·3	$\bar{4}$·254	+0·8
1938 May 10·50*	29028·50	−79·5	$\bar{4}$·505	+4·7
1942 Aug. 1·36*	30572·36	−90·3	$\bar{4}$·881	−1·9
1959 Oct. 10·18†	36851·18	−85·8	$\bar{2}$·409	−1·3
11·22†	852·22	−88·4	·409	−3·9
1961 Oct. 6·21‡	37578·21	−84·7	$\bar{2}$·586	−0·5
31·15‡	603·15	−82·5	·592	+1·7
1976 July 2·29	42961·29	−85·1	$\bar{1}$·896	+3·8
Aug. 31·13	43021·13	−90·7	·910	−1·1
1977 July 1·25	43325·25	−91·1	$\bar{1}$·984	+1·6
5·33	329·33	−93·1	·985	−0·3
31·25	355·25	−93·5	·992	−0·6
Aug. 29·12	384·12	−91·1	·999	+1·9
Sept. 6·13	392·13	−89·2	0·001	+3·8
Oct. 10·10	426·10	−89·4	·009	+3·6
1978 July 3·26	43692·26	−91·9	0·074	−0·6
24·25	713·25	−93·0	·079	−1·9
28·25	717·25	−90·1	·080	+0·9
Aug. 4·23	724·23	−93·5	·081	−2·5
6·19	726·19	−88·7	·082	+2·3
29·18	749·18	−91·5	·088	−0·8
Oct. 17·06	798·06	−93·2	·099	−3·0
19·06	800·06	−93·3	·100	−3·1
21·04	802·04	−93·2	·100	−3·0
24·05	805·05	−93·1	·101	−2·9
1986 Aug. 28·94§	46670·94	−86·3	0·799	−0·2
1992 Aug. 17·05§	48851·05	−85·3	1·329	−0·2
1993 Feb. 15·23§	49033·23	−84·9	1·373	−0·1
1994 Aug. 5·00§	49569·00	−84·1	1·504	+0·1
1996 Dec. 25·72§	50442·72	−85·1	1·716	−0·2
1997 May 13·13	50581·13	−85·1	1·750	+0·2
1998 July 11·03§	51005·03	−86·9	1·853	+0·5
2000 Aug. 11·98	51767·98	−92·6	2·039	0·0
Sept. 16·92	803·92	−92·2	·048	+0·1
Oct. 13·83	830·83	−92·1	·054	0·0
Nov. 13·77	861·77	−91·8	·062	0·0
Dec. 9·70	887·70	−91·2	·068	+0·3
2001 Jan. 7·72	51916·72	−91·3	2·075	−0·1
May 12·14	52041·14	−89·9	·105	+0·1
July 5·02	095·02	−89·4	·118	+0·1
Sept. 22·87	174·87	−88·9	·138	−0·1
Nov. 1·78	214·78	−88·4	·148	+0·1

TABLE III (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
2002 Jan. 31·28	52305·28	−88·2	2·170	−0·4
Mar. 27·15	360·15	−87·8	·183	−0·3
May 17·12	411·12	−87·3	·195	−0·1
July 20·02	475·02	−86·7	·211	+0·2
Sept. 1·95	518·95	−86·6	·222	0·0
Nov. 4·85	582·85	−86·4	·237	−0·1
2003 Feb. 21·25	52691·25	−86·0	2·263	−0·1
Apr. 8·16	737·16	−85·6	·275	+0·2
June 19·09	809·09	−85·4	·292	+0·1
Aug. 9·00	860·00	−85·4	·305	0·0
Oct. 18·90	930·90	−85·3	·322	−0·1
Dec. 15·77	988·77	−85·2	·336	−0·1
2004 Apr. 22·16	53117·16	−84·7	2·367	+0·1
June 19·10	175·10	−84·6	·381	+0·1
Aug. 12·99	229·99	−84·3	·395	+0·3
Oct. 18·91	296·91	−84·6	·411	−0·1
Dec. 6·84	345·84	−84·7	·423	−0·2
2005 Apr. 19·15	53479·15	−84·3	2·455	0·0
June 11·10	532·10	−84·2	·468	+0·1
July 20·01	571·01	−84·1	·478	+0·2
Sept. 12·97	625·97	−84·2	·491	0·0
Nov. 9·83	683·83	−84·0	·505	+0·2
2006 Apr. 5·17	53830·17	−84·4	2·541	−0·2
June 22·08	908·08	−84·1	·560	+0·1
Aug. 10·04	957·04	−84·1	·572	+0·1
Oct. 24·89	54032·89	−84·1	·590	+0·1
Dec. 16·76	085·76	−83·9	·603	+0·4
2007 Apr. 4·19	54194·19	−84·6	2·629	−0·3
June 1·11	252·11	−84·7	·643	−0·3
Aug. 1·03	313·03	−84·5	·658	0·0
Oct. 4·92	377·92	−84·9	·674	−0·3
2008 Feb. 16·26	54512·26	−85·1	2·707	−0·3
Apr. 24·17	580·17	−85·1	·723	−0·1
July 22·01	669·01	−85·0	·745	+0·2
Sept. 13·93	722·93	−85·5	·758	−0·1
Dec. 2·82	802·82	−85·8	·777	−0·1
2009 Jan. 20·75	54851·75	−85·5	2·789	+0·4
May 24·11	975·11	−86·6	·819	−0·1
July 24·07	55036·07	−87·0	·834	−0·1
Sept. 25·91	099·91	−87·2	·850	+0·1
Dec. 17·78	182·78	−87·9	·870	0·0
2010 May 24·12	55340·12	−89·5	2·908	0·0
July 18·04	395·04	−90·2	·921	−0·1
Sept. 15·94	454·94	−90·7	·936	+0·1
2011 Jan. 14·71	55575·71	−92·0	2·965	+0·1
May 15·13	696·13	−93·1	·995	−0·2
Aug. 10·01	783·01	−93·0	3·016	0·0
Sept. 12·91	816·91	−93·0	·024	−0·1

* Mount Wilson photographic observation[25,26] (wt.0).
† Mount Wilson photographic observation[42] (wt.0).
‡ Mount Wilson photographic observation[44] (wt.0).
§ Observed with Haute-Provence *Coravel* (weight 1).

the minimum of velocity. The discrepancy of the mean from that of the Mount Wilson plates might well, however, have been seen as significant.

The star's velocity was measured by the writer six times with the OHP *Coravel*, starting in 1986. Again, there were discordances whose significance was not regarded at the time as conclusive but only as warranting occasional further monitoring. It was when the Cambridge *Coravel* came into routine operation in 2000 that a really substantial discordance immediately arose, and the star has since been kept under reasonably systematic observation; 59 measurements, which just cover one 11-year orbital cycle systematically, have accumulated. They are set out in Table III, together with the earlier OHP data, which go back more than another cycle, and the velocities from the literature. The adjustment of +0·8 km s^{-1} that, in papers in this series, is usually made to published velocities has been applied to the Greenwich measurements but has been withheld from the earlier Mount Wilson ones and the Ames velocities, where it would only worsen their agreement with the more recent data. It is not an issue of any real significance anyway, because the relative raggedness of the published velocities, which would warrant weightings only of the order of 0·01, exacerbated by their very restricted coverage of phase, argues against incorporating them in the solution of the orbit, which is accordingly based on the writer's observations alone. The OHP measures are listed in Table III with the usual offset of +0·8 km s^{-1}, and the Cambridge ones have been placed in systematic agreement with them by an empirical adjustment of –0·2 km s^{-1}, which is in line with what has been found appropriate in other comparisons for stars with colour indices similar to that of HR 7477. The OHP velocities have needed to be given half weight to bring their weighted variance nearly into accord with that of the Cambridge ones. The resulting orbit is illustrated in Fig. 4 and has the following elements:

P	=	4109 ± 16 days	$(T)_6$	=	MJD 51608 ± 14
γ	=	–86·88 ± 0·03 km s^{-1}	$a_1 \sin i$	=	229·6 ± 2·7 Gm
K	=	4·42 ± 0·05 km s^{-1}	$f(m)$	=	0·0286 ± 0·0009 $M_{\odot}$
e	=	0·395 ± 0·008			
ω	=	172·6 ± 1·1 degrees	R.m.s. residual (wt. 1)	=	0·17 km s^{-1}

The most interesting and significant feature of the elements is obviously the high γ-velocity, which is not a new discovery. The mass function requires the companion star to have a mass not much less than 0·6 $M_{\odot}$ (corresponding to that of a main-sequence star near type K7) if the mass of the primary is arbitrarily taken as 2 $M_{\odot}$.

Although it is not in the densest part of the Milky Way (its Galactic latitude is about 13°), HR 7477 is in a field rich with telescopic stars. The relative positions of three of them were measured by Burnham and were given in his great *Catalogue of Double Stars*. Two of them, identified as BDS 9506 B and C, have been observed for radial velocity at Cambridge, and so have two others, more distant in angular terms from the bright star. The most distant (more than 3′ away) was observed because the writer was impressed by the extraordinary redness of its appearance in the thumbnail field-picture that accompanies the *Simbad* bibliography. Table IV has entries identifying the four stars and giving their angular distances and position angles (roughly measured on an *Aladin* picture brought up on *Vizier*) with respect to HR 7477 itself, and giving the approximate magnitudes where they are available from *Tycho*, and the measured radial velocities.

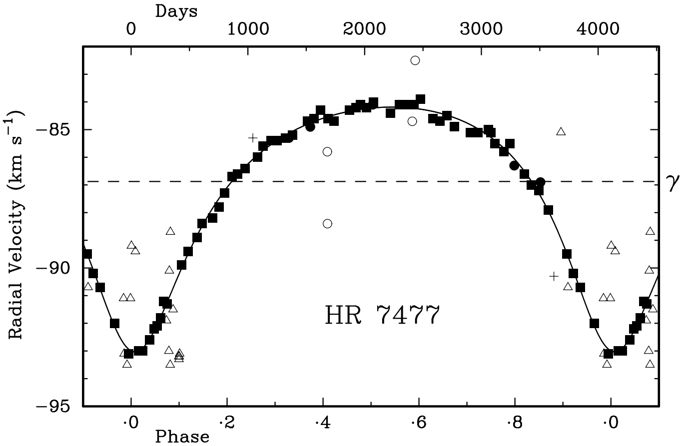

FIG. 4

The observed radial velocities of HR 7477 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The Cambridge observations (filled squares) and the OHP ones (also obtained by the writer; half-weight; filled circles) are the only ones utilized in the calculation of the orbit, but previously published measurements are plotted — three early Mount Wilson ones[25] as plusses (one is missing, off the top of the diagram), 1960s measures[42,44] from the Mount Wilson 100-inch coudé as open circles, and Ames photoelectric observations[13] as open triangles.

TABLE IV

Radial velocities for visual companions of HR 7477

Star	*Tycho*	*From HR 7477* *arcsec*	*P.A. (deg.)*	*V* *m*	*(B – V)* *m*	*Radial velocities* *UT Date*	*Vel. (km s^{-1})*
BDS 2599 B	—	31	236	—	—	2011 Sept. 8·97	−4·3
BDS 2599 C	3564–3098–1	62	248	10·83	1·06	1998 July 11·03	−5·0
						2002 Sept. 1·95	−5·1
						2002 Nov. 4·85	−5·5
						2003 Oct. 18·90	−5·1
						2011 Sept. 8·97	−4·7
"D"	3564–3103–1	64	52	10·78	0·54	1998 July 11·03	−38·5
						2002 Sept. 1·95	−38·6
						2002 Nov. 4·85	−37·0
						2011 Sept. 8·97	−37·2
"E"	3564–2499–1	195	328	9·40	1·61	2002 Nov. 4·85	−40·6
						2011 Sept. 8·97	−39·9

HR 7636 (*HD 189322*)

HR 7636 is to be found close to the celestial equator, in Aquila. It is nearly 2° following the Cepheid variable η Aql, for which it has repeatedly been adopted[45–47] as a comparison star, with a *V* magnitude and (*B* – *V*) colour index of $6^{m}\cdot17$ and $1^{m}\cdot13$; similar values, plus a (*U* – *B*) colour near to $0^{m}\cdot91$, have also been given by Argue[3], Cousins[48], and Johnson *et al.*[49]. The (*B* – *V*) index, particularly, is unusually red for the spectral type of G8 III that has been attributed to the star by Harlan[11]. The star's parallax[10] shows its distance modulus to be $6^{m}\cdot86$, with an uncertainty of about $0^{m}\cdot4$, so the absolute magnitude is about $-0^{m}\cdot7 \pm 0^{m}\cdot4$.

The radial velocity of HR 7636, like that of HR 396, was first measured at the David Dunlap Observatory, whence a mean value of +7·0 km s^{-1} from four plates was published by Heard[12]. The 'probable error' was given as 1·1 km s^{-1}, and there is a flag to indicate that "the velocity is more uncertain than for the general run of stars", and "we judge that in these cases the variation [between the velocities from the individual plates] is somewhat greater than would be expected from the character of the lines." Thus Heard may be considered to have suspected real variability in the radial velocity. Unfortunately the individual plate velocities are not available, but the paper gives their range as 10 km s^{-1}. There the matter of the radial velocity of HR 7636 rested until de Medeiros & Mayor[15] published a mean of two *Coravel* velocities, +3·79 ± 2·34 km s^{-1}, which expression ought therefore also to give the two velocities themselves. The dates remained unknown, however, until those authors deposited their results with the Centre de Données Stellaires in 2002; the velocities then were not exactly what the paper[15] itself had led readers to expect. Much the same information as was in the de Medeiros & Mayor paper was subsequently repeated by de Medeiros, da Silva & Maia[50], but with the strange omission of the actual velocity of the star.

It was the discordance between the two velocities that were in the list that became available at the Centre de Données Stellaires that led to the placing of HR 7636 on the Cambridge observing programme as a binary system awaiting orbit determination. The two listed observations are recorded at the head of Table V, which also sets out the 55 measurements subsequently obtained with the Cambridge *Coravel*. They cover about 1¼ cycles of the 7-year variation. All the measurements were given equal weight in the solution of the orbit, which is plotted in Fig. 5 and has the following elements:

P	= 2621 ± 5 days	$(T)_1$	= MJD 53404 ± 39
γ	= +7·00 ± 0·04 km s^{-1}	T_0	= MJD 53881 ± 3
K	= 7·44 ± 0·06 km s^{-1}	$a_1 \sin i$	= 267·3 ± 2·2 Gm
e	= 0·080 ± 0·007	$f(m)$	= 0·1111 ± 0·0026 $M_{\odot}$
ω	= 295 ± 5 degrees	R.m.s. residual (wt. 1)	= 0·28 km s^{-1}

Although Fig. 5 looks at first sight very much like a sine wave, a more careful look convinces one that the maximum of the velocity curve looks considerably more 'pointed' than the minimum; the eccentricity of the orbit is actually ten times its own standard deviation and so is very certainly non-zero. Another significant quantity is the mass function which, if the mass of the observed star is supposed to be 2 $M_{\odot}$, requires the companion object to have a mass of no less than 1 $M_{\odot}$. That object (unless double itself) could well be a main-sequence star of solar type or above, but it could still be as much as five magnitudes fainter than the primary. If it is single, the orbital inclination must be quite high, otherwise the mass function, which includes the factor $\sin^3 i$, would demand for it an unacceptably large mass. We could therefore suppose that the major axis of the orbit, whose projected value ($a_1 \sin i$) is given as 267 Gm in the little table above, is no more than about 2 AU, and with a mass ratio of about two between the components the actual distance between the components will not be more than about 6 AU, which at the distance of HR 7636 (about 240 pc) could at favourable times yield an angular separation of about 0″·025. It is not surprising, therefore, that McAlister *et al.*[51] did not resolve the system with the 3·6-m *CFHT*.

TABLE V

Radial-velocity observations of HR 7636

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

Date (UT)	*MJD*	*Velocity* km s^{-1}	*Phase*	*(O–C)* km s^{-1}
1986 Aug. 6·01*	46648·01	+7·3	$\bar{2}$·422	+0·1
1987 June 14·10*	46960·10	+2·6	$\bar{2}$·542	−0·1
2002 June 1·11	52426·11	+0·4	0·627	−0·2
July 15·02	470·02	+0·5	·644	+0·2
Aug. 14·03	500·03	+0·2	·655	+0·1
14·98	500·98	+0·7	·656	+0·6
Sept. 10·88	527·88	+0·3	·666	+0·3
Nov. 12·78	590·78	−0·3	·690	−0·1
Dec. 4·72	612·72	−0·3	·698	−0·1
2003 May 28·09	52787·09	+0·2	0·765	−0·1
July 13·03	833·03	+0·9	·782	+0·3
Sept. 14·91	896·91	+1·3	·807	+0·1
Nov. 15·79	958·79	+2·0	·830	0·0
2004 May 31·12	53156·12	+5·5	0·905	+0·2
June 22·06	178·06	+5·7	·914	0·0
Aug. 13·02	230·02	+6·8	·934	0·0
Sept. 13·88	261·88	+7·7	·946	+0·2
Oct. 25·80	303·80	+8·3	·962	0·0
Nov. 29·75	338·75	+8·7	·975	−0·3
Dec. 17·70	356·70	+9·4	·982	0·0
2005 May 5·11	53495·11	+11·7	1·035	−0·3
June 27·06	548·06	+12·7	·055	−0·1
July 22·02	573·02	+13·3	·065	+0·2
Aug. 16·96	598·96	+13·4	·074	0·0
Sept. 14·92	627·92	+13·7	·085	0·0
Oct. 25·85	668·85	+14·2	·101	+0·1
Nov. 29·74	703·74	+14·6	·114	+0·3
2006 Apr. 9·18	53834·18	+14·7	1·164	0·0
June 1·11	887·11	+15·0	·184	+0·4
July 3·09	919·09	+14·7	·197	+0·2
Aug. 8·05	955·05	+14·1	·210	−0·2
Sept. 26·91	54004·91	+13·4	·229	−0·5
Oct. 24·83	032·83	+13·6	·240	−0·1
Nov. 23·71	062·71	+13·4	·251	0·0
Dec. 17·69	086·69	+13·0	·261	−0·2
2007 Apr. 12·18	54202·18	+11·7	1·305	−0·1
May 19·12	239·12	+10·4	·319	−0·9
June 28·08	279·08	+11·0	·334	+0·3
July 25·04	306·04	+10·6	·344	+0·3
Aug. 31·01	343·01	+9·7	·358	−0·1
Sept. 22·91	365·91	+9·5	·367	+0·1
Oct. 23·82	396·82	+9·2	·379	+0·3
Dec. 5·70	439·70	+8·7	·395	+0·4
2008 Apr. 24·13	54580·13	+5·7	1·449	−0·4
July 1·10	648·10	+5·4	·475	+0·3
22·08	669·08	+5·1	·483	+0·3
Aug. 25·91	703·91	+4·4	·496	+0·1
30·99	708·99	+4·3	·498	+0·1
Sept. 27·86	736·86	+3·9	·509	0·0
Nov. 7·81	777·81	+3·4	·524	+0·1

TABLE V (*concluded*)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O – C) km s⁻¹*
2009 Apr. 22·16	54943·16	+0·6	1·587	−0·8
May 20·11	971·11	+0·5	·598	−0·7
June 18·10	55000·10	+1·0	·609	+0·1
2010 May 24·11	55340·11	−0·1	1·739	−0·1
2011 May 15·13	55696·13	+3·4	1·875	−0·4
June 17·10	729·10	+4·5	·887	+0·1
Sept. 12·90	816·90	+6·1	·921	0·0

*Haute-Provence *Coravel* observation[15]; weight 1

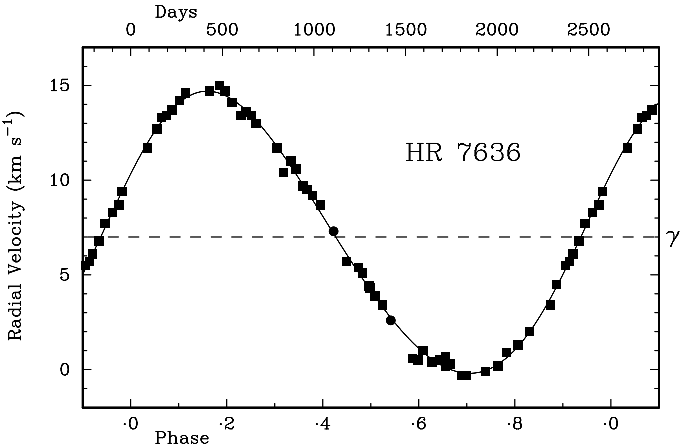

FIG. 5

The observed radial velocities of HR 7636 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. There are two OHP velocities[15] (filled circles) that were used with the Cambridge observations (squares) to derive the orbit.

6 Andromedae (*HR 8825*, *HD 218804*)

Despite its having a constellation designation, 6 And is by no means a conspicuous star to the naked eye in our light-polluted modern skies; little brighter than sixth magnitude, it is to be found near a prolongation northwards of the right-hand (as xenophobically viewed) side of the Square of Pegasus by about 1·3 times its own length. It has a large proper-motion, almost 0″·3 annually, and that seems to condemn it, just as in the case of HR 396 (treated above) to be designated in *Simbad*'s main heading, no matter under what name one may call for it, as 'LTT 16810', from its entry in one[2] of Luyten's proper-motion catalogues. (Again, Luyten was by no means the discoverer of the motion, which like that of HR 396 had been accurately measured in the 19th Century[52].) The *UBV* magnitudes of 6 And have been given by Miss Roman[53] and Johnson *et al.*[49] as $V = 5^{m}\cdot95$, $(B-V) = 0^{m}\cdot44$, $(U-B) = -0^{m}\cdot05$, and a few hundredths of a magnitude brighter in V, and with slightly different colour indices, by Imagawa[54] and Eggen[55].

Early spectral classifications of 6 And give the impression of starting early indeed and becoming successively later. The first, in the Harvard Observatory's original *Draper Catalogue*[56] of 1890, was type A. (The introduction to the *Draper Catalogue* explains that a spectrum in which only hydrogen lines and the *K* line could be seen was called type A — so it was in a sense an un-classification and indicated only that the available spectra did not show the (relatively very weak) metallic lines that could have permitted a more positive classification.) Next, in a 1915 paper from Mount Wilson reporting the first radial-velocity measurements of the star, Adams[57] called it F2. Two years later, in another Mount Wilson paper[58] giving the results on 500 stars of the application of the (then recently developed) technique of determining spectroscopic parallaxes, classifications made by two different methods were listed. In one, the type was 'estimated' in the usual way, by visual comparison of the spectrum with analogous spectra of appropriate standard stars; in the other, the type was 'measured' by explicit comparison of the intensities of certain hydrogen lines with those of nearby lines of metallic origin. For 6 And, the 'estimated' type was F5 and the 'measured' one was F4. Exactly the same types were listed in still another paper[59] in 1921. The earlier paper gave the absolute magnitude as $4^{m}\cdot1$ and the later one as $3^{m}\cdot7$. Rimmer[60], working alone with the 12-inch refractor of the Norman Lockyer Observatory but providing competition with the syndicate at Mount Wilson who used the 60-inch and later even the 100-inch telescope, derived by the same 'spectroscopic-parallax' method an absolute magnitude of $4^{m}\cdot2$ for 6 And. The star featured in the Harvard Observatory's *Henry Draper Catalogue*[61] in 1924 as F5, a type that has been more or less agreed ever since, although Adams *et al.*[62] in the final (1935) and largest listing of Mount Wilson spectroscopic parallaxes gave it as F3 and attributed the object an absolute magnitude of $3^{m}\cdot4$.

It will be noticed that all the luminosity estimates are close to those expected for main-sequence stars of the relevant types, so it is perhaps surprising that the first MK classification, by Miss Roman[53], indicated 6 And to be a subgiant, of type F5 IV. That misled Eggen[63] into including the star in a table of 'Evolved F- and G-Type Stars' in a paper on "Old-disk-population giants". Harlan[64] agreed with the subgiant luminosity class, listing the star as F6 IV, but (Anne) Cowley[65] gave it as F5 V. In a paper entitled 'A survey of F-type stars', the Jascheks & Mme. Andrillat[66] listed separately types based on the Balmer lines (F6), the G band (F5), and the metallic lines (F4). Bartkevičius & Lazauskaitė[40] concurred with the Cowley type of F5 V, and so did Gray, Napier & Winkler[67]. The parallax[10] shows the distance modulus to be $2^{m}\cdot22 \pm 0^{m}\cdot08$, so the real absolute magnitude is very near to $3^{m}\cdot8$, which is even somewhat on the faint side of the tabular[68] value for F5 V. The subgiant type was unfortunately entered in the *Bright Star Catalogue*[69], which makes it almost impossible to prevent its continued adoption in the literature.

There have been several investigations[70–77,40] of the metal abundances in 6 And; they are in substantial agreement that there is a modest under-abundance, with $[M/H] \sim -0\cdot2$. Some of the papers[70,71,74,75,77] have been particularly concerned with the abundance of lithium, which in all cases proved to be undetectably low. Others — and some of the same ones — have addressed the question of the projected rotational velocity, which is far from negligible. The earliest such paper was that of (O. C.) Wilson[78], who placed the star in his 'rotational group 1', to which he attributed projected velocities of 15–25 km s^{-1}. Danziger & Faber[79] put the rotational velocity of 6 And at 15 km s^{-1}, Boesgaard & Tripicco[70] at 12 km s^{-1}, Balachandran[71] and Wolff & Simon[80] at 14 km s^{-1}, and the OHP

Coravel syndicate (de Medeiros, do Nascimento & Mayor[81], de Medeiros & Mayor[15], and Lebre *et al.*[74]) as 17·8 km s^{-1}. The Cambridge value is 18·9 km s^{-1}.

The first of the papers from Mount Wilson[57] reported that 6 And had a radial velocity of –43·9 km s^{-1}; the text makes it clear that almost all the stars listed in the paper had been observed at least three times. Indeed, after a lapse of well over half a century (during which time no further velocity measurements were made apart from an experimental effort by the objective-prism method by Schalén[82]), Abt's listing[26] of the individual velocities showed that there were three of them, in good mutual agreement. Eventually, de Medeiros & Mayor[15], who included 6 And in their paper 'A catalogue of rotational and radial velocities of evolved stars' (in which 6 And must sit uneasily) reported two OHP *Coravel* radial velocities whose mutual discordance demonstrated the star to be a spectroscopic binary. They subsequently lodged with the Centre de Données Stellaires a listing of the individual velocities, with dates, for most of the objects in their paper, where the results had been published only as means. It was from a perusal of that listing that 6 And (among other stars) was selected by the present writer for orbit determination at Cambridge. A later paper[83] by Nordström *et al.* that also refers to OHP *Coravel* measurements indicates that there were then four of them; they presumably include the two whose details are already known, but the extra two are not available individually. In 2007 Ibanoğlu *et al.*[84] adopted 6 And as a velocity standard against which to determine radial velocities of the Algol binary V1665 Aql, crediting the information that its velocity was –33·3 km s^{-1} to the table by Nordström *et al.*[83] and seemingly overlooking the abundant evidence in immediately ensuing columns in the same table (including the one showing $P(\chi^2) = 0{\cdot}000$) that the star is a spectroscopic binary. The syndicate evidently found the standard provided by 6 And so satisfactory that they retained it for further use in their subsequent papers[85,86] on various other Algol stars.

The radial velocity of 6 And has now been followed reasonably attentively for a complete cycle from Cambridge; the 81 velocities appear in Table VI, with the three Mount Wilson[57,26] and two OHP[15] ones at the head. In an effort to keep to the usual zero-point of velocities, the Mount Wilson and OHP measures have been 'corrected' by +0·8 km s^{-1} and the Cambridge ones by –0·5 km s^{-1} from the 'as initially reduced' values. The Cambridge velocities, by themselves, yield an orbit with a period of 3438 ± 40 days. The two OHP measures stand very distinctly off that orbit, and the Mount Wilson ones (although naturally not viewed as being anything like so reliable) appear at altogether the wrong phase for points that are near the level of the velocity minimum. Inclusion of the two OHP velocities in the solution of the orbit, with the same weight as the Cambridge ones, alters the period to 3373 ± 14 days, and mends not only their own phases but also those of the Mount Wilson measurements, which then fall agreeably into place.

It is hard to know what, if any, weight to attribute to the Mount Wilson data, as the writer has little experience of similar ones. Certainly they ought to be taken rather seriously, not only because they agree well among themselves but because being ten cycles old they have very high leverage on the orbital period. The situation is made less critical by the fact that they already fit the orbit as well as they possibly can, so no matter what weight they are attributed they leave all of the elements virtually unchanged apart from the standard deviation of the period. To bring their variance into line with that of the OHP and Cambridge velocities they should be given half-weight, and the period is then computed to be 3373 ± 3 days. The writer, being unwilling to believe that they are really so good, decided arbitrarily to weight them 1/10, implicitly attributing to them

TABLE VI

Radial-velocity observations of 6 Andromedae

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

Date (UT)	*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O–C)* $km\ s^{-1}$
1911 Aug. 9·44*	19257·44	−42·5	$\overline{10}$·962	+0·3
Sept. 13·46*	292·46	−44·3	·973	−0·8
1912 Jan. 9·15*	19410·15	−43·7	$\overline{9}$·008	+1·2
1987 Aug. 31·02†	47038·02	−35·8	$\overline{1}$·198	0·0
1988 Aug. 14·05†	47387·05	−32·4	$\overline{1}$·302	−0·9
2002 July 21·10	52476·10	−32·3	0·810	−0·3
Aug. 13·15	499·15	−32·7	·817	−0·4
Sept. 11·04	528·04	−33·3	·826	−0·6
Oct. 4·93	551·93	−33·9	·833	−0·8
Nov. 12·94	590·94	−34·0	·844	−0·2
Dec. 18·83	626·83	−34·7	·855	−0·3
2003 Jan. 16·72	52655·72	−34·7	0·864	+0·3
Feb. 17·75	687·75	−34·9	·873	+0·8
Apr. 16·16	745·16	−36·6	·890	+0·4
May 12·10	771·10	−38·3	·898	−0·7
June 13·10	803·10	−37·9	·907	+0·4
July 13·10	833·10	−38·7	·916	+0·4
Aug. 9·08	860·08	−39·4	·924	+0·4
Sept. 15·98	897·98	−40·3	·935	+0·4
Oct. 11·96	923·96	−40·8	·943	+0·6
Nov. 12·92	955·92	−42·1	·953	0·0
Dec. 7·90	980·90	−43·8	·960	−1·1
28·86	53001·86	−43·3	·966	−0·2
2004 Jan. 27·75	53031·75	−44·1	0·975	−0·4
Feb. 23·79	058·79	−45·6	·983	−1·5
Apr. 23·15	118·15	−44·8	1·001	0·0
May 17·12	142·12	−44·3	·008	+0·6
June 13·10	169·10	−43·6	·016	+1·4
17·10	173·10	−45·1	·017	−0·1
July 10·10	196·10	−45·0	·024	0·0
Aug. 7·15	224·15	−44·1	·032	+0·9
Sept. 1·09	249·09	−44·4	·040	+0·4
Oct. 7·03	285·03	−45·3	·050	−0·8
Nov. 13·91	322·91	−44·4	·061	−0·4
Dec. 16·85	355·85	−44·4	·071	−0·9
2005 Feb. 8·79	53409·79	−43·0	1·087	−0·4
May 12·13	502·13	−41·0	·115	−0·1
June 23·10	544·10	−39·2	·127	+0·8
July 18·12	569·12	−39·0	·134	+0·6
Aug. 11·09	593·09	−39·1	·142	0·0
Sept. 7·07	620·07	−38·2	·150	+0·4
Oct. 5·03	648·03	−38·2	·158	−0·1
Nov. 4·97	678·97	−37·9	·167	−0·4
Dec. 8·89	712·89	−37·0	·177	0·0
2006 Jan. 28·75	53763·75	−36·6	1·192	−0·5
Feb. 25·76	791·76	−36·7	·200	−1·0
June 12·07	898·07	−33·8	·232	+0·4
July 13·12	929·12	−33·2	·241	+0·6

TABLE VI (*concluded*)

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O–C) km s⁻¹*
2006 Aug. 11·11	53958·11	−32·8	1·250	+0·6
Sept. 20·09	998·09	−32·4	·262	+0·5
Oct. 25·02	54033·02	−32·5	·272	0·0
Nov. 25·96	064·96	−31·9	·281	+0·3
Dec. 28·81	097·81	−31·5	·291	+0·4
2007 Jan. 23·83	54123·83	−32·5	1·299	−0·9
May 31·11	251·11	−30·5	·337	0·0
July 8·10	289·10	−31·1	·348	−0·9
Aug. 6·08	318·08	−29·4	·356	+0·6
Sept. 8·06	351·06	−29·8	·366	0·0
Oct. 4·99	377·99	−29·9	·374	−0·3
Nov. 1·93	405·93	−29·2	·383	+0·3
Dec. 5·90	439·90	−28·9	·393	+0·4
2008 Jan. 17·77	54482·77	−28·4	1·405	+0·6
Feb. 9·80	505·80	−29·4	·412	−0·5
July 22·12	669·12	−27·7	·461	+0·5
Aug. 30·10	708·10	−28·6	·472	−0·5
Sept. 27·04	736·04	−28·5	·480	−0·5
Oct. 21·96	760·96	−28·6	·488	−0·7
Nov. 22·87	792·87	−27·8	·497	+0·1
Dec. 26·83	826·83	−27·5	·507	+0·3
2009 Feb. 3·75	54865·75	−26·6	1·519	+1·1
July 25·12	55037·12	−27·5	·570	+0·1
Aug. 20·13	063·13	−27·8	·577	−0·2
Sept. 15·06	089·06	−27·9	·585	−0·3
Oct. 11·98	115·98	−28·0	·593	−0·4
Nov. 9·00	144·00	−27·2	·601	+0·4
Dec. 20·83	185·83	−27·6	·614	0·0
2010 Jan. 30·76	55226·76	−27·7	1·626	0·0
May 23·12	339·12	−27·8	·659	+0·2
July 30·14	407·14	−28·2	·679	0·0
Aug. 24·10	432·10	−28·8	·687	−0·5
Sept. 15·98	454·98	−28·0	·694	+0·4
Oct. 20·04	489·04	−28·4	·704	+0·2
Nov. 25·96	525·96	−28·7	·715	+0·1
2011 Jan. 14·78	55575·78	−29·6	1·729	−0·4
Aug. 8·12	781·12	−30·5	·790	+0·6
Sept. 13·03	817·03	−30·8	·801	+0·7

* Mt.Wilson photographic observation[57,26]; wt. 1/10.
† Haute-Provence *Coravel* observation[15]; weight 1.

a standard deviation of 1·7 km s⁻¹ per observation: then the standard error of the period becomes 6 days. Even if that proves in the future to be excessively optimistic, there will be almost *no* repercussions on the uncertainties of the other elements, or indeed on the elements themselves, whose adopted values are listed below, while the orbit is illustrated in Fig. 6.

P	= 3373 ± 6 days	$(T)_1$	= MJD 53116 ± 16
γ	= −33·62 ± 0·06 km s⁻¹	$a_1 \sin i$	= 385 ± 4 Gm
K	= 8·75 ± 0·09 km s⁻¹	$f(m)$	= 0·200 ± 0·007 $M_\odot$
e	= 0·317 ± 0·009		
ω	= 165·2 ± 2·0 degrees	R.m.s. residual (wt. 1)	= 0·54 km s⁻¹

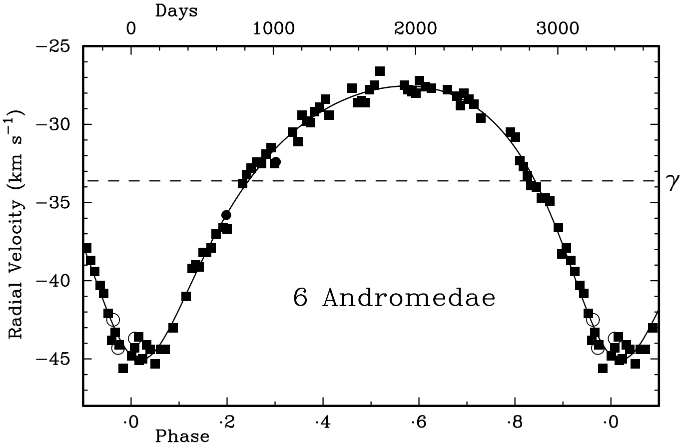

FIG. 6

The same caption as that of Fig. 5 could apply to this figure for 6 And, but in this case there are in addition three Mount Wilson observations[57] that are a hundred years old; they have been attributed a weight of 1/10 and plotted as open circles.

The most striking feature of the elements is the large mass function to which they give rise. The mass of the F5 main-sequence primary must be very near to 1·2 $M_{\odot}$, so the mass function of 0·2 $M_{\odot}$ requires the secondary to have a mass scarcely less than 1 $M_{\odot}$ even if the orbital inclination is practically 90°. A main-sequence secondary of that minimum mass could be at most one magnitude fainter than the primary, and at the nodal passage near periastron its velocity would differ from that of the primary by 25 km s^{-1}, so its signature should be quite apparent, causing the radial-velocity traces to appear double-lined. No significant asymmetry in the traces was ever noticed, although they always needed to be integrated to quite high photon-count levels to obtain tolerable precision on the velocities given by the broad-lined primary star. As has happened in quite a number of previous instances of otherwise inexplicably large mass functions, it seems necessary to postulate that the companion object is itself a binary system*. That would enable its components to have the necessary combined mass but to associate it with a total luminosity far smaller than if the same mass belonged to a single object. For dynamical stability the orbital period of the putative sub-system should not be much more than one year, but it could be much shorter than that. If it were only a few days or even less, evidence of activity would probably have been seen in ultraviolet sky surveys, especially since, as stars go, 6 And is quite a 'nearby' star. The period of the secondary might therefore be expected to be between a week and a year. The mean linear separation from the F5 primary must be something like 5 AU, which could at certain phases therefore subtend an angle of the order of five times the parallax,

*A referee, Dr. D. Latham, has very properly pointed out the alternative possibility that the companion might be a white dwarf. That does not seem likely, because at the astronomically modest distance of 6 And a white dwarf could be expected to have been conspicuous in ultraviolet sky surveys, and also to have left chemical evidence of its evolution as a giant in the form of 'barium-star' anomalies in the photospheric elemental abundances of the star that we now observe. Several abundance studies have not shown any such anomalies.

viz., $0''\cdot18$. Thus, as far as separation is concerned, the secondary should be easily resolved by speckle or other types of interferometry; the difficulty must lie in the magnitude difference between the components of the system. It may be noted that the orbit of the postulated sub-system could itself be large enough to be resolved. If Kepler's Third Law[87] is expressed in the form $a^3 \propto P^2\Sigma m$, where a, P, and Σm are the orbital radius, period, and the total mass, then if in the case of the sub-system P were 0·1 times that of the outer system and Σm is a half, a would be $\sqrt[3]{200}$ times smaller, or about one-sixth, making it still as much as $0''\cdot03$, so, for instance, speckle interferometry on a sufficiently large telescope might even 'see' the system as triple directly.

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TYC 1404–1687–1, AN EXTREME-MASS-RATIO BINARY?

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High-precision $UBVR_cI_c$ CCD photometry shows that the newly discovered variable, TYC 1404–1687–1, has a W UMa-type light-curve with a moderate amplitude averaging $0^{m}\cdot40$ in all bands. However, a brief, but discernible, time of constant light is present at phase 0·5. It is possible that a third stellar component or other phenomenon is contributing additional light that 'flattens' the light-curves. Beginning with a substantial third-light model (~30%) as determined from BINARY MAKER, a *UBVRI* simultaneous synthetic-light-curve analysis was initiated which converged to a solution with very small third-light values (up to 2%). From that point, a non-third-light solution was calculated. The lowest-residual solution prescribes a mass ratio of 0·22. Thus, the photometry indicates that a new solar-type extreme-mass-ratio binary (EMRB) may have been discovered. Radial-velocity curves are needed to confirm that prediction. In addition, a period study was conducted which yielded nine new times of minimum light, and the first high-precision ephemeris for this system. Also, BVR_cI_c standard magnitudes are presented for the variable, comparison, and check star. The variable is of spectral type F0 V. The light-curve solution is that of an over-contact binary of A type (the more massive component is the hotter), with a fill-out factor of 45%, all fairly usual for EMRBs and A-type W UMa binaries. No spots are needed in the solution.

Introduction

The discovery of the *Tycho* variable, TYC 1404–1687–1 [GSC 01404–01687, 2MASS J09142593+1853543, GGM2006–10196343, $\alpha(2000) = 09^{h}\ 14^{m}\ 25^{s}\cdot932$, $\delta(2000) = +18°\ 53'\ 54''\cdot39$] was announced in *Reports of New Discoveries*[1]. It was identified as an EW-type (W UMa contact) variable with a magnitude range of 11·35–11·75 and an ephemeris of:

$$\mathrm{HJD}\ T_{\min\ \mathrm{I}} = 2452723\cdot6127 + 0\cdot39858\ E \qquad (1)$$

Over ninety observations were presented from which we obtained two eclipse timings. The curves show an amplitude of $0^{m}\cdot4$ and reveal a possible time of totality in the secondary eclipse. These facts, taken together with *IJK* 2MASS photometry, suggest that it may be an extreme-mass-ratio solar-type binary

(EMRB). Our astronomy group has a particular interest in this transitional state[2–5], which appears to be the final stage in binary-star evolution — that of coalescence into a single, rapidly rotating, A-type star[6]; another possibility is that the light detected from the binary is contaminated by third-light. Both are worth exploring.

Observations

Our $UBVR_cI_c$ light-curves of TYC 1404–1687–1 were obtained on 2008 December 21 and 26, and 2009 March 10, 11, 13, and 14, at Lowell Observatory, under the auspices of the National Undergraduate Research Observatory (NURO), with the 0·81-m reflector, and on 2009 January 16 *via* remote observing at Kitt Peak using the Southeastern Association for Research in Astronomy (SARA) 0·9-m reflector. NURO observations were taken with the CRYOTIGER-cooled (T <–100°C) 2K×2K CCD NASACAM. SARA images were taken with the thermoelectrically-cooled (–21°C) 2K×2K U42 CCD camera. The images were calibrated in a standard way with biasses, darks, and *UBVRI* flats which were taken each night. The calibrations and magnitude determinations were carried out with AIP4WIN 2·31. The data used in the light-curve solutions consisted of our 2009 March images and included 172 *B*, 189 *V*, 176 *R*, 177 *I*, and 109 *U* measurements. The standard error of a single observation is $\pm 0^{m}\cdot006$ in *B*, *V*, *R*, and *I*, and $\pm 0^{m}\cdot007$ in *U*. Our *UBVRI* observations are given in a table which may be found at usclancaster.sc.edu/faculty/faulkner/TYC1404-1687-1.pdf.

Period study

Seven times of minimum light, for five primary and two secondary eclipses, were determined using parabolic fits to each of the *U*,*B*,*V*,*R*, and *I* curves and then averaged. They are the last seven given in Table I, with the standard errors given in parentheses. Two additional times of minima were calculated from the Geneva Observatory discovery data[1], by the same method. The first minimum listed is the ephemeris given in the same source. The following improved linear ephemeris was calculated from all ten eclipse timings:

$$\text{HJD } T_{\text{min I}} = 2454902{\cdot}6912 \pm 0{\cdot}0009 + (0{\cdot}39858742 \pm 0{\cdot}00000037)\,E. \quad (2)$$

TABLE I

O–C residuals

	Epochs (2400000+)	*Cycles*	*Weight*	*Linear Residuals*	*Note*
1	52723·6127 (23)	−5467·0	1·0	−0·0010	1
2	52721·4226 (01)	−5472·5	0·5	0·0011	2
3	52728·3972 (06)	−5455·0	0·5	0·0004	2
4	54823·9678 (17)	−197·5	0·5	−0·0023	3
5	54827·9618 (05)	−187·5	1·0	0·0058	3
6	54848·8844 (14)	−135·0	1·0	0·0026	3
7	54901·6927 (05)	−2·5	1·0	−0·0020	3
8	54901·8924 (06)	−2·0	1·0	−0·0016	3
9	54902·6903 (14)	0·0	1·0	−0·0009	3
10	54904·6790 (58)	5·0	0·5	−0·0051	3

1 *IBVS*, no. 5500.
2 Minima from ROTSE I data.
3 Present observations.

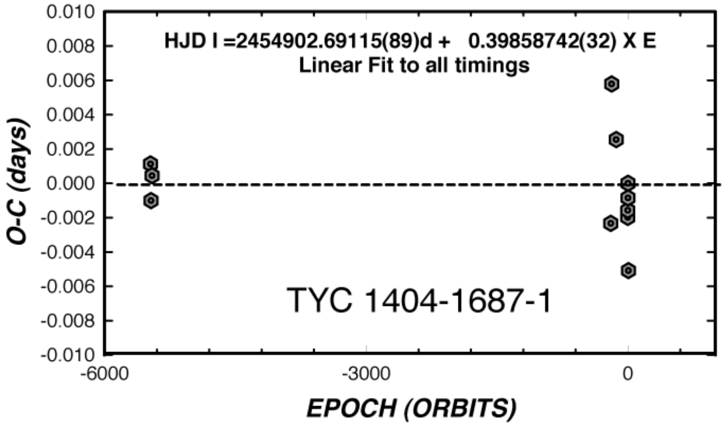

FIG. 1
TYC 1404–1687–1 O – C residuals from equation (2).

An O – C plot of the linear residuals is shown in Fig. 1 with the data for our O – C plot given in Table I. The system needs to be monitored during the next decade or so with CCDs to detect its orbital evolution. We suspect that the overall trend will be a period decrease owing to magnetic braking, but nothing of the sort is indicated by the data at present.

Light-curves

The phased light-curves of TYC 1404–1687–1, differential magnitude *versus* phase, are shown in Fig. 2. Light-curve amplitudes in all bands average $0^{m}\cdot40$ and are given in Table II. The binary is seen to be a low-amplitude EW system with a fairly symmetrical light-curve, *i.e.*, no large spots are affecting the light-curve. Also, it appears to have a time of constant light in the secondary eclipse, the same as shown in the discovery curves, so there is apparently an occultation of the smaller component at phase 0·5. Thus, from visual inspection, TYC 1404–1687–1 is an A-type W UMa system (the less-massive component is the cooler one). Previous modelling of other binaries (for example[7]) reveals that this binary is similar to other EMRBs, but the possibility existed that it might be a typical totally-eclipsing, shallow-contact binary with a third-light.

TABLE II

Light-curve amplitudes

Filter	*Phase (0·0–0·25)*	*Phase (0·25–0·5)*
ΔU	0·463	0·403
ΔB	0·460	0·398
ΔV	0·433	0·381
ΔR	0·426	0·385
ΔI	0·409	0·397

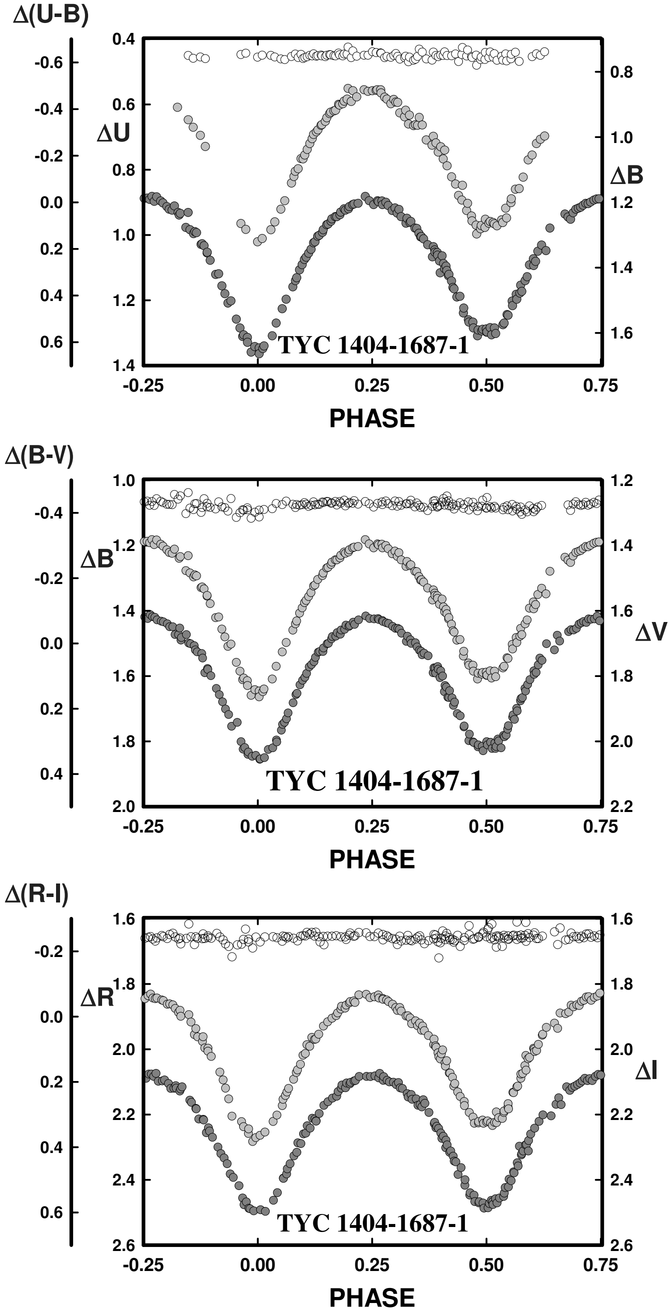

FIG. 2

TYC 1404–1687–1 colour and light-curves phased with equation (2). Top: U, B; middle: B, V; lower: R, I.

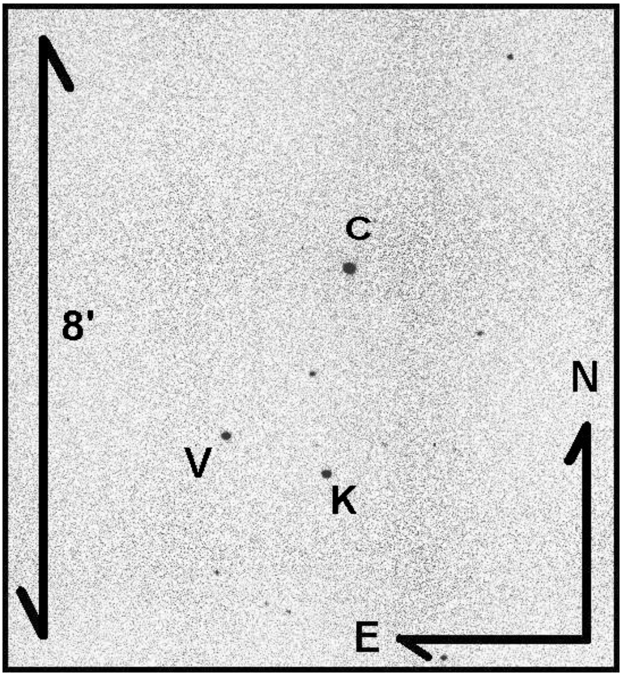

FIG. 3
Finding chart showing variable (V), comparison (C), and check stars (K).

Standard magnitudes

Standard magnitudes were calculated from observations of Landolt standard stars on 2008 December 26 and 27 and standard procedures were used in their determination[8]. Extinction and transformation coefficients were calculated and standard magnitudes were derived for the variable, comparison, [GSC 1404 0119, $\alpha(2000) = 09^{\mathrm{h}}\ 14^{\mathrm{m}}\ 18^{\mathrm{s}}{\cdot}885$, $\delta(2000) = +18^{\circ}\ 56'\ 08''{\cdot}75$], designated 'C', and check star [GSC 1404 0587, $\alpha(2000) = 09^{\mathrm{h}}\ 14^{\mathrm{m}}\ 20^{\mathrm{s}}{\cdot}242$, $\delta(2000) = +18^{\circ}\ 53'\ 22''{\cdot}97$], designated 'K'. The results of our calculations are given in Table III. We find[9] that the variable, comparison, and check are early-F-, late-G-, and mid-F-type main-sequence stars, respectively. Both transformation and standard-star errors are included in the uncertainties of the table. A finding chart is included as Fig. 3 for the convenience of future observers.

TABLE III

Standard magnitudes

	V	$B-V$	$V-R_c$	R_c-I_c	$V-I_c$	*Ave. Sp.*
Variable						
Phase 0·00	12·34±0·05	0·24±0·03	0·10±0·04	0·24±0·03	0·37±0·04	F0±3
Phase 0·25	11·94±0·02	0·241±0·007	0·10±0·03	0·24±0·02	0·34±0·02	
Comp.	10·33±0·07	0·69±0·04	—	0·43±0·02	0·77±0·03	G8±3·5
Check	12·00±0·07	0·43±0·03	0·19±0·05	0·29±0·03	0·49±0·04	F5±3

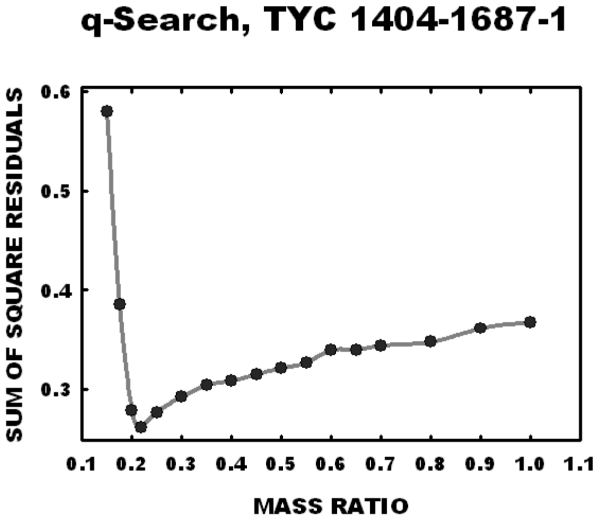

FIG. 4
Mass-ratio search for TYC 1404–1687–1.

Light-curve solutions

A *UBVRI* simultaneous synthetic-light-curve calculation was undertaken. The temperature of the primary was chosen according to its F0 spectral type (~7500 K). It is interesting that many EMRBs are of F-type, particularly, F8 ± 5 V[10]. BINARY MAKER 3·0[11] was used initially to explore the character of the light-curves and determine fits to each of the *U*,*B*,*V*,*R*, and *I* light-curves. Our original set of parameters included ~30% third-light with a mass ratio of ~0·37. They fitted the light-curves quite well, at least to the eye. Using the average starting values from the BINARY MAKER fits, we proceeded to compute simultaneous five-colour light-curve solutions. We used the 2004 version of the Wilson code[12–16], which includes Kurucz atmosphere fluxes, rather than black bodies, and a detailed reflection treatment along with 2-D limb-

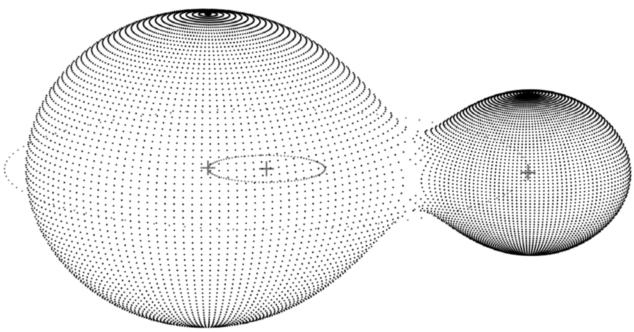

FIG. 5
Geometrical representation of light-curve solution without third-light.

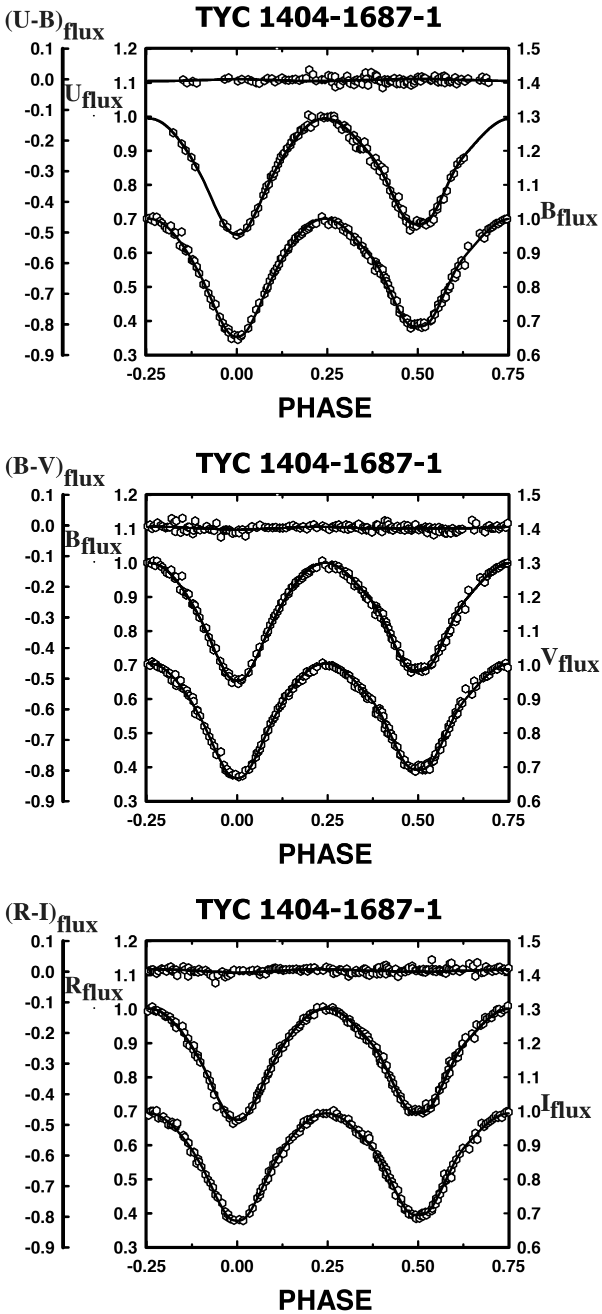

FIG. 6

Normalized fluxes overlaid by our light-curve solution without third-light. Top: *U*, *B*; middle: *B*, *V*; lower: *R*, *I*.

darkening coefficients. Intermediate modelling iterations were done with the PHOEBE[17] interface which runs the same Wilson code in the background and makes it possible to view the light-curve fit as the iterations progress. Spots were not needed. The final solutions were performed with the Wilson code directly, which ultimately indicated parameter convergence. Our initial solution showed appreciable third-light and a mass ratio of 0·37. Since solutions are ambiguous unless they have a conclusive total eclipse, a mass ratio or q-search was performed. This included a series of seventeen solutions with the mass ratio fixed at values between 0·15 and 1.0. The sum of square residuals, $\Sigma(res)^2$, minimized at $q \sim 0{\cdot}2$ as shown in Fig. 4, which immediately took us into the range of the EMRBs. The final iterations were begun with the above q-value and stabilized from then on. As the calculation progressed, the third-light diminished and converged within the range 0–2%. From the low third-light values, one would conclude that there was a very similar solution without them, and that proved correct. The third-light parameters were turned off, and the mass ratio, again, remained fairly constant throughout the iterations. The solution was achieved: the $\Sigma(res)^2$ was essentially the same for both models. The geometrical representation of the simpler system is given in Fig. 5. The normalized curves overlain by our light-curve solutions are given as Fig. 6. As suggested by the observations, the model confirms a total phase of secondary eclipse, now calculated to be 8·5 minutes.

Conclusion

The solution leads us to conclude that TYC 1404–1687–1 belongs to the class of EMRBs[7]. Its moderately high fill-out factors and small secondary component indicates that it is evolving toward coalescence. The fill-outs of EMRBs average 55 ± 20%, which our present calculations include. In the non-conservative case, magnetic braking of a binary with a convective atmosphere will tend to cause the system to coalesce over time, producing a continuous decrease in the orbital period owing to angular-momentum loss[18]. The main driving mechanism for this process is the torque supplied by out-flowing winds along 'stiff' field lines originating from such solar-type stars, which eventually lead to coalescence.

High-precision radial-velocity curves are needed to help fix the mass ratio of TYC 1404–1687–1 and give absolute dimensions and masses. Further light-curves are needed to follow the time evolution of the orbital period.

Acknowledgements

We acknowledge NURO and SARA for their allocation of observing time, as well as NASA and the American Astronomical Society for their support of travel expenses. We also wish to thank USC, Lancaster, for annually supporting our association with NURO.

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NOTES FROM OBSERVATORIES

A NEW, INTERESTING, MULTIPERIODIC VARIABLE STAR

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In the field of the globular cluster NGC 2298, Kryachko *et al.*[1] discovered several new variable stars. Here we report another object discovered by us from the same observations, USNO–A2·0 0525–03526442 ($\alpha = 06^{h}\ 49^{m}\ 47^{s}{\cdot}12$, $\delta = -36°\ 20'\ 48''{\cdot}7$, J2000·0, 2MASS). The finding chart for the new variable is presented in Fig. 1. The discovery set of observations (JD 2455475–2455486) consisted of 315 frames taken with an 80-mm *f*/6 refractor with an SBIG ST-2000XM CCD at Tolar Grande, Argentina. Our reductions of these data identified the star as a δ Scuti variable and suggested an interesting multiperiodic behaviour.

To check this suspicion, we undertook two additional observing runs using the 410-mm *f*/10 Schmidt-Cassegrain Meade reflector of the Observatorio Cerro Armazones (Chile), operated by the Universidad Catolico del Norte. These observations, made on JD 2455589–2455594 and 2455655–2455660, were made with an SBIG ST-10XME CCD. In all three observing runs, performed with small telescopes, we used no filters. The CCD detectors being red-sensitive, we calibrated our observations using *R* magnitudes of comparison stars from the USNO–B1·0 catalogue. All our reductions made use of the VAST software developed by Sokolovsky & Lebedev[2].

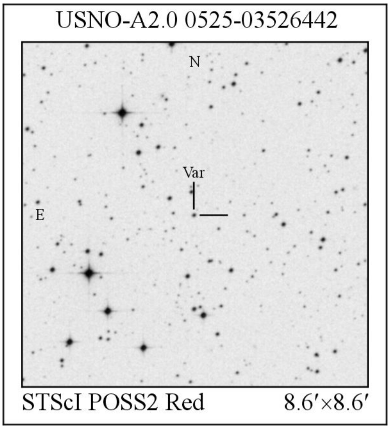

FIG. 1
The finding chart for the new variable.

The comparison star in the reductions of the first (Tolar Grande) observing run was USNO–B1·0 0536–0072222 (α = 06^h 50^m 29^s·28, δ = –36° 22′17″·2, J2000·0), its 2MASS infrared colour indices, $J - H$ = 0^m·347, $H - K$ = 0^m·098, being not very different from those of the variable ($J - H$ = 0^m·212, $H - K$ = 0^m·042, rather typical of F stars). The R magnitude adopted for calibration of our observations, R_{comp} = 13^m·40, is the mean of the two R magnitudes provided in the USNO–B1·0 catalogue. The field of view in the second and third observing runs was much narrower, so we had to choose a new comparison star with similar photometric parameters. Our choice was USNO–B1·0 05370073046 (α = 06^h 49^m 42^s·25, δ = –36° 17′32″·1, J2000·0), with $J - H$ = 0^m·268 and $H - K$ = 0^m·155. For this star, we adopted R_{comp} = 14^m·31.

All the three observing runs reveal rapid variations of USNO–A2·0 0525–03526442, on a time scale of about 0^d·09 and with a peak-to-peak amplitude up to 0^m·08. We searched for periodic signals in the observations with the PERIOD04 code[3] in the frequency range between 3 and 20 cycles per day that was selected following recommendations by Breger[4]. Three apparently significant frequencies were detected; their parameters, corresponding to eq. (1), and determined by least squares, are collected in the table below.

$$m(t) = 15{\cdot}0983 + \sum A_i \sin(2\pi(f_i\, t + \Phi_i)) \qquad (1)$$

Detected frequencies

f, c/d	*Φ*	*A, mag*
f_1 10·5714	0·9863	0·027
f_2 11·1460	0·8829	0·021
f_3 10·4304	0·4421	0·010

Fig. 2 presents the variable's amplitude spectrum (a) and the theoretical light-curve (approximating function) with superposed data points corresponding to individual observations from the second observing run (b). Light-curve variations are easy to notice; they are reproduced with the model rather well.

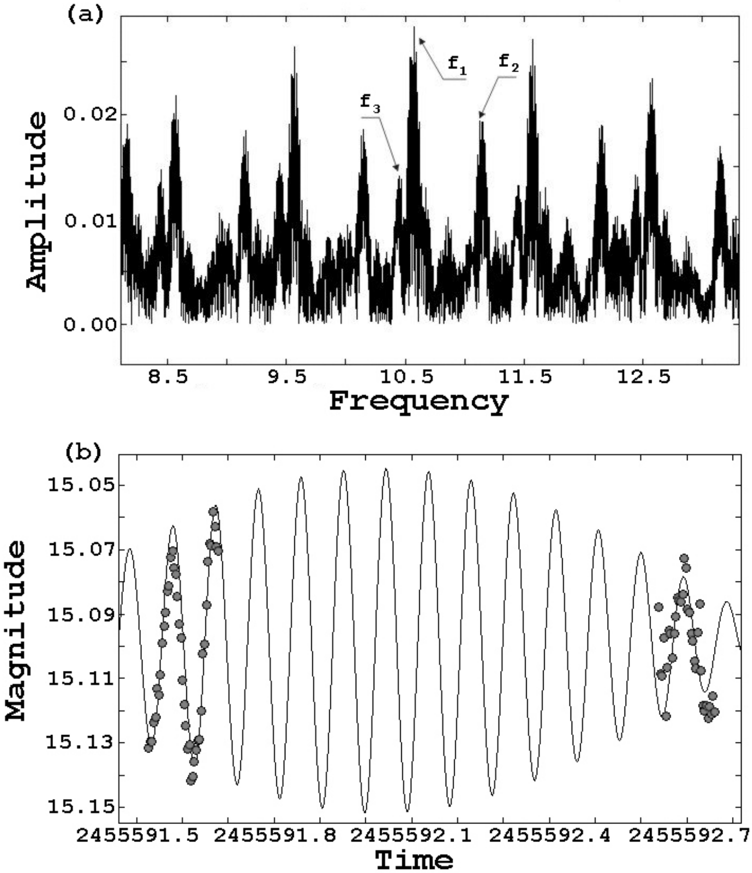

FIG. 2

The amplitude spectrum (a) and the model light curve with superposed observations from the second run (b).

In order to check for the presence of possible additional frequencies and to attempt mode identification, new high-precision photometry in several standard photometric bands is needed. We appeal to observers in the southern hemisphere to continue observations of this new and interesting variable star.

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CORRESPONDENCE

To the Editors of 'The Observatory'

Footprints of Pre-Big-Bang Intelligence

Far in the future, a highly advanced civilization may face its termination when its universe ends up in black holes, consuming everything before they evaporate. The only way they may survive is by sending the information of their knowledge and technologies into another universe, perhaps the next stage of their own universe if it has one. They may even send the required information for reviving their race (*e.g.*, their DNA sequence) in the hope that one day an advanced civilization in the other universe may find their information. But has our Universe had a history of consecutive Big Bangs? And if so, is it possible to send information from one aeon to the next?

Recently, Gurzadyan and Penrose have proposed that concentric circles in the cosmic microwave background (CMB) may provide some evidence of pre-Big Bang history[1–3]. They suggest that our Big Bang was not the first one in its series and thus our Universe has experienced several aeons during its consecutive Big Bangs. When an aeon reaches its final period, the remaining mass of universe concentrates into several super black holes. Those black holes engrave massive gravitational waves on the fabric of space and it is possible to observe them as some circles in the CMB of the next aeon even after the Big Bang.

Now, let us assume that our Universe's previous aeon was a life-friendly universe which ultimately resulted in some scientifically and technologically advanced civilization. If they are faced with the unavoidable annihilation of their own aeon, it is very probable that they may send some information regarding their existence and knowledge to the next aeon. They may do this by manipulating mass flow and the formation of black holes in the final stages of their aeon. Consequently, we may be able to extract that information by searching for correlated patterns in the concentric circles of our CMB.

In a possible scenario, that civilization will use available energy in galaxies and move matter in the Universe in order to specify the time and location of black holes' formations. In this way, the gravitational-wave interferences of these black holes can produce meaningful patterns in some regions of the CMB sky in the next aeon.

Gurzadyan *et al.* have demonstrated that the random Gaussian component in the CMB is only around 0·2 in the total CMB signal[4]. Therefore, this amount of noise still permits the possibility of sending information from one aeon to the other one. I suggest that by looking into pre-Big Bang evidence, we may have a higher chance of detecting footprints of some sort of intelligent existence. In this way, we are looking at the whole history of a universe in one single shot.

I would like to thank Dr. Gurzadyan for valuable discussions.

Yours faithfully,

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REVIEWS

Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy, by Barbara J. Becker (Cambridge University Press), 2011. Pp. 380, 25·5 × 18 cm. Price £65/$110 (hardbound; ISBN 978 1 107 00229 6).

The differences between Sir William Huggins, OM, KCB, FRS (1824 – 1910), of 90 Upper Tulse Hill, South London, and today's pioneers of observational astrophysics could not be greater. Where is Huggins' list of degrees? He did not have any 'real' ones (I discount the collection of honorary degrees he got in later life). Where is the university or observatory affiliation? Huggins' telescope was in his own back garden. What was the source of his funding? Huggins lived privately off the rents of property left him by his father, a silk mercer and linen draper from Shoreditch. Fortunately he did not have to pay for his own telescope; that was funded by the Royal Society and then lent to him for as long as he could put it to "full and proper use".

Huggins was an amateur — a true lover of astronomy; in fact he was one of the last pioneering amateurs. But it is wrong to think of Huggins as the last of anything. He should really be remembered as one of the world's first great astrophysicists. In 1863 he was in the vanguard of the spectroscopic analysis of the chemical composition of stars, building on the work of Bunsen and Kirchhoff. A year later he observed NGC 6543, obtaining the first planetary-nebula spectrum. Comparing what was then known as the Andromeda Nebula with the Orion Nebula, he realized that the former had a stellar spectrum whilst the later had a gaseous-emission spectrum. In 1868 he was the first astronomer to measure a stellar radial velocity, using the Doppler shift of spectral lines. Huggins was the first to identify spectroscopically hydrocarbons in cometary comae, the first to capture ultraviolet hydrogen lines photographically, and the first to observe solar prominences outside eclipses.

But like all astronomers life wasn't all positives. He spent years trying to photograph the solar corona outside eclipses, something that was not achieved until the days of Bernard Lyot in 1930. Like others at the time he searched in vain for changes in lunar topography. Being an inveterate 'gadget man' and a skilled manipulator of temperamental instruments he also tried unsuccessfully to measure stellar radiation with bolometers.

Barbara J. Becker, a recently retired professor of the history of science at the University of California, Irvine, has not only produced an excellent, highly readable, and erudite biography of one of England's greatest astrophysicists, she has also provided the reader with a detailed insight into the progress of astrophysics during the last half of the 19th Century. By considering correspondence, observational and experimental notebooks, and research publications, the truth of Huggins' battle with a new science slowly rises to the surface. (It is interesting, in passing, to note that historians of today's astrophysicists will not have the first two of these sources available.)

Becker also examines in some detail the rôle of Mrs. Huggins. At the then ripe old age of 51 William got married, for the first time, to a 27 year-old Irish lady, one Margaret Lindsay Murray. How did they meet? Why did William wait so long? How much influence did she have on the quality and rate of progress of his later research? Much is still veiled in mystery. Clearly Lady Margaret was a formidable help-mate. Her loyalty to her husband's memory was amazing. When William died, the astrophysical playing field was becoming somewhat crowded. Also the cutting edge of endeavour was moving from Europe to the USA. Margaret did much to ensure that William's pioneering work was not forgotten. Woe betide anyone who tried to muscle in on William's claims of priority.

I loved this book. I recommend it unequivocally. Read it — you will learn a lot. — DAVID W. HUGHES.

Cosmic Heritage: Evolution from the Big Bang to Conscious Life, by P. Shaver (Springer, Heidelberg), 2011. Pp. 275, 23·5 × 15·5 cm. Price £31·99/$34·95/€34·95 (paperback; ISBN 978 3 642 20260 5).

I wish this book had existed a few years ago, when colleagues were involved in planning an education and public-outreach activity in which all the 9th-grade (age *c.* 14) students in a large area were to read the same book at the same time and discuss it. When I complained about the book chosen (*To Kill a Mockingbird*), they asked for alternatives, and I couldn't really think of anything, except perhaps Bill Bryson on the origin of everything. *Cosmic Heritage* would have been a very good choice. The explanations are generally clear, the language straightforward, and the mistakes few, at least in the territories I know something about. There are things in it to be learned at any age from 14 to 114 — for me a definition of methylation, and that females of some species (fruit flies and mice, at least) will exhibit male courtship rituals under some circumstances. I hate to think what those opposed to women doing science, *etc.*, will make of that.

And, of course, a few complaints: the handful of colour plates are indeed colourful, but none of them has any scale bars; I know roughly the size of a star-formation region and a honeybee, but how big is a jellyfish, let alone a hippocampal axon? At least a bit of the English is in someone else's dialect (the author is primordially Canadian). For instance, slug is synonymous with slime mould (and a product of many amoebæ aggregating when food is in short supply), while an American slug is a homeless snail*. The claim of 94 naturally-occurring elements on Earth leaves me missing some fingers. Up to Uranium, minus technetium and promethium would seem to be 90. And you must make allowances for some folklore (Einstein's biggest blunder) and analogies ("December 30th was the terrible day when a large asteroid collided with the Earth", which is not the same as the world having been created on October 29th).

All in all, a book to read, share, and check. The need for this last is perhaps indicated by the fact that five of the six distinguished folk saying nice things on the back cover are also among the larger number thanked in "acknowledgements" for input. I am neither, but Shaver was my immediate predecessor as president of the Division of Galaxies and Cosmology of the International Astronomical Union and set a very high standard for the task. — VIRGINIA TRIMBLE.

*Or possibly a naked snail.

Transit of Venus, by N. Lomb (New South Books, Sydney), 2011. Pp. 228, 24 × 24 cm. Price AU$49·95 (about £32) (hardbound; ISBN 978 1 7422 3269 0).

On 2004 June 8, observers in the UK were blessed with a fine day for the first of two transits of Venus in the latest series. Plate I in the 2005 February issue of this *Magazine* carried an excellent photo of the event, which spawned significant public interest and a number of books on the subject, one of which I reviewed in these pages (**124**, 406, 2004). On that occasion, the whole 'show' was visible from Britain, but on 2012 June 6, only (relatively) early risers here will have a chance to see the closing stages of the second transit of this pair.

However, for folk in most of Australia (excluding the western edge), together with the western side of New Zealand, an opportunity to view the entire sequence only comes with this second transit. To prepare potential observers, and to get everyone up to speed on the history and significance of transits, Nick Lomb of Sydney Observatory has produced a beautifully illustrated volume covering past transits, from the time of Jeremiah Horrocks up to that of 2004, when the first observations from spacecraft were taken. The significance of the transits of 1761 and 1769, and 1874 and 1882, for the determination of the Astronomical Unit is explained, together with the extraordinary efforts made by astronomers to record those events accurately. The stories of transit observations made in the Antipodes will certainly be of interest to the readers 'down under'. Along the way, snippets of history outside of astronomy are included to help place the narrative in context. Local circumstances for observers (not just in Australia and New Zealand) are given for the 2012 transit, along with good advice on how to view the transit safely. The volume concludes with a useful glossary and a comprehensive index.

The illustrations are splendid, especially those relating to the historical aspects, but including the wonderful pictures of the 2004 transit from the Swedish Solar Telescope on La Palma (page 189). Perhaps those from space in the recent era are given, in my view, a bit too much room (including several pages of monochrome images from *Magellan*), but then again they do help with another feature of the book which is to update our knowledge of Venus itself. There is one strange illustration, however, unless I have missed some vital piece of information: on pages 20–21 we find a double-page spread showing what, according to the index, is "Venus in front of Moon"; if our *Here and There* section carried pictures, then surely this would be a candidate for a future issue. It must be said, however, that the "Moon" doesn't look much like our familiar Moon. (But see also p. 71 of this issue!)

The text is very readable with nothing to quibble about, except perhaps for the subtle movement of one of the early observation sites at Bencoolen from India (on page 43 — wrong) to Indonesia (on page 58 — correct). It was sad to note that one thing has not changed over the years: that the US Naval Observatory transit campaigns of the 19th Century, while able to collect observations, were frustrated in their efforts to reduce the data by lack of funding (page 158). How often are expensive projects brought into being only to be denied the means to be fully exploited; certainly this was (and probably still is) a regular feature of UK astronomy.

All in all an excellent volume and a fine souvenir of our privileged age, during which such an event could be seen. — DAVID STICKLAND.

Stars and Their Spectra: An Introduction to the Spectral Sequence, by J. B. Kaler (Cambridge University Press), 2011. Pp. 394, 25 × 18 cm. Price £30/$50 (hardbound; ISBN 978 0 521 89954 3).

Already hailed as a classic in its first edition of 1989, Kaler's book has now undergone substantial revision and expansion. The quality and application of the first edition were acclaimed by numerous reviewers at the time, and the same epithets can be applied just as convincingly to this second edition. An excellent foundation for descriptions and a qualitative understanding of stellar spectra, *Stars and Their Spectra* will doubtless continue to stand the test of time for another couple of decades, and it deserves to be on the book-shelf of all who pursue stellar spectroscopy actively or even those who just like to read about it without needing to delve too deeply into the details of what is actually a highly complex subject.

The revision of the first edition has been extremely thorough. Chapter headings are mostly unchanged, though two entirely new chapters dealing with L and T stars — barely on the map in 1989 — have been introduced. Section headings are also similar, though more have been included in the new version, and while most of the figures are also the same some have been replaced and several additions made. But within each section the paragraphs have been re-written rather than just revised, and rarely has a sentence been left as it was, demonstrating the striving of a conscientious author towards a perfect text. In some cases (*e.g.*, the λ Boo stars) the topic has been rewarded with a sub-section to itself whereas earlier it was dismissed with a brief mention that occupied only two short sentences. The few mistakes that I spotted were in such newly-introduced wording, one obvious one being a description of the spectrum of Arcturus as G1 instead of K1 (as written elsewhere on the same page).

The only real criticism which reviewers levelled at the first edition was its lack of references, and the second edition does not change that. While the professional might find such a lack slightly irritating, I think Kaler is right to omit them. This is not intended to be a professional textbook; the sub-title claims only an *introduction* to the spectral sequence, though in practice it is a fairly comprehensive description of it, but inasmuch as it is a reading book rather than a textbook the inclusion of references would equally irritate the non-professional reader who did not have ready access to an astronomy library or the ADS.

One small point in disfavour of the second edition is its length. The increase is substantial, from ~280 to ~380 pages; any fatter, and it begins to look like a tome rather than a handy reference book. I also noticed some changes of attitude which had crept in. For example, early astrophysics depended upon photographic observations, and were universally trusted, and the subject was not re-developed with the advent of the CCD as the workhorse detector. In his first edition Kaler merely mentions that photography was slow, but in the second he goes further, claiming that photography was poor for quantitative analysis and implied imprecise measurements of intensity and line strengths, notwithstanding his retention of a number of figures depicting photographic spectra. But that is more a matter of opinion. Kaler's treatment of the subject contains something for all levels of interest; it is comprehensive and thorough, and his style very readable, almost conversational, with smatterings of wry humour. It is unreservedly recommended. — ELIZABETH GRIFFIN.

Astronomical Spectroscopy for Amateurs, by K. M. Harrison (Springer, Heidelberg), 2011. Pp. 254, 23·5 × 15·5 cm. Price £23·99/$34·95/€26·95 (paperback; ISBN 978 1 4419 7238 5).

The intention of this book was to provide enough history and background to stellar spectroscopy and instruction in the principles of the requisite instrumentation, the basics of obtaining and analyzing spectra, and the design and construction of appropriate instruments to engage the reader and keen amateur.

It was an attractive, and clearly much needed, proposition but unfortunately the book is not well written, or even well prepared. The first section — 'The theory of spectra' — skids through the history and then attempts potted descriptions and definitions of the terms and their meanings but mostly succeeds in trivializing them. Terms like 'black body curve' wander into the pages with no explanation, while 'Quantum Theory' is dismissed in a single sentence. The middle section — 'Obtaining and analysing spectra' — devolves into an off-line hand-holding guide through the VSPEC package, and although the last section — 'Spectroscope design and construction' — reveals the author in his natural element it reads more like an engineer's handbook than a student textbook. The author found it difficult to describe "obtaining and analysing spectra" without first mentioning the different types of likely equipment, so there is considerable overlap between the sections, and the phrase "... but see later" occurs persistently.

Even more unfortunate is the plethora of mistakes, and not just typographical ones. The best examples, it seems, of the Doppler effect are seen in the rotation of the Sun and planets, Pickering's stellar-classification team apparently consisted of only three people, the carbon stars are an offshoot of the G types, differentiation is needed between main-sequence and dwarf stars, and the original spectral types B9, A1, G1, G7 and a host more have since been omitted (yet Sirius is nevertheless quoted as type A1). Several spectroscopic facts are confused, as if some sentences had been omitted for brevity. Then ... the lines in the solar spectrum. We learn that the magnesium triplet is in the green at 430·0, 431·0, and 431·2 nm, and that identifying the "magnificent seven" Fe lines between the sodium doublet makes a good test for a spectroscope with $R = 5000$ [or 500,000?]. At this point in my reading the pages of much of Section I dislodged themselves from the binding and fell to the floor. I wondered whether it was even worth picking them up.

The mistakes did not stop there. Incorrect or misleading formulae, that 'S' stands for sodium, that the Swan bands are composed of any carbon molecule and not just C_2, that ESO stands for European Space Agency and that *A&A* means "Astronomical Astrophysics", were only some of the many potholes in this rough road, one of the most puzzling being the statement that "spectral lines can appear doubled by the Earth's annual rotation, where it may be approaching or receding from the star at up to 30 km/s".

While the author clearly has a passion for, and doubtless considerable expertise in, small-telescope and DIY hardware, the analysis of observations follows exclusively a free software system (VSPEC), and the discussion of how to analyse one's observations is simply cut-and-pasted from the VSPEC manual. It would have been better to direct the reader to that source and to bypass the synopses of the selected sections; the diagrams, copied from interim screen output, would have been easier to understand in their proper context, and easier to read. The reproduced spreadsheets are too small to see properly.

The style is simple but at the same time over-simplifying. Ideas are not properly explained, and the diagrams are copied from sources whose notation and symbols do not necessarily match those being used by the author. Somewhat irritatingly, the author does not know the difference between '*i.e.*' and '*e.g.*', and in using the former exclusively when the latter is meant makes nonsense of the text in many places. The whole is written in American English. There are also numerous grammatical errors, such as 'due' instead of 'owing' and frequently starting a sentence with 'This', but those are (sadly) all too common in publications by professional scientists too.

I find it astounding that a book which intends to instruct can contain so many mistakes, and equally baffling that a publisher of such high international standing could transmit them in one of its publications. But I am also quite seriously worried for my science. Amateurs have deservedly become the dominant contributors in the field of photometry, and professionals rely upon them rather than seek precious telescope time for those purposes. Amateurs are already making substantial inroads into the realms of stellar spectroscopy, and have the potential and the energy to make extremely useful contributions, particularly when nightly monitoring of an object is needed. But there is more finesse to attend to in spectroscopy than in photometry; at present there is rather little overlap there between professionals and amateurs, and practising bad habits like ignoring the need to flat-field or measuring velocities from tilted spectral lines is not going to help anyone, nor is supplying the amateur community with incorrect 'instruction'.

The back-cover blurb admits that "spectroscopy currently receives scant attention in astronomical texts", and that "this book answers that need" and is the "book that amateur astronomers have been waiting for!" I earnestly hope they will heed my comments, and have the patience to wait a bit longer. — ELIZABETH GRIFFIN.

The Cambridge Photographic Star Atlas, by A. Mellinger & R. Stoyan (Cambridge University Press), 2011. Pp. 176, 34·5 × 25·5 cm. Price £30/$48 (hardbound; ISBN 978 1 107 01346 9).

This is a whole-sky colour atlas produced from images taken with an SBIG STL-11000 digital camera. This camera gives a field of 40° × 27°, and 70 field centres were chosen to give a nearly twofold coverage of the sky. Each field was exposed through red, green, and blue filters with three different exposures to increase the dynamic range. To improve the signal-to-noise ratio, each exposure was repeated five times with diurnal tracking. Whole-sky coverage was achieved from dark sites in the USA or South Africa.

The combination of the 70 fields into a seamless mosaic required three operations. Firstly, the backgrounds of the images varied because of geophysical activity and zodiacal light. They were made consistent over the whole sky by appealing to images exposed during the *Pioneer* missions in the 1970s. Secondly, a selection of stars were identified with their counterparts in the *Guide Star Catalogue* and used to derive a mapping between positions in the image and positions on the sky. Finally, the photometric intensities were homogenized to replace saturated pixels by scaled values from a shorter exposure. This was necessary to provide a realistic map, accurate in both intensity and colour.

The atlas consists of 82 stereographic maps 25° × 34°, distributed on an equatorial grid. On the right-hand page is the map itself with a black background. The scale is 1° to a centimetre; it is impossible to give a limiting magnitude to a polychromatic atlas but 14 is typical for white stars. On the left is the image, through the red filter only, with black stars on a white background. The overlaps around the periphery have a blue background. The naked-eye stars are joined by conventional constellation lines. Emission, dark, and reflection nebulae are colour-coded. Most are given realistic boundaries but the smallest are little squares. Open clusters are marked by yellow circles and globular by orange, the diameter depending on the size of the cluster. Extragalactic nebulae are marked as ellipses of the correct size and orientation.

Both left and right pages are printed in half-tone at about 180 dots per inch, which corresponds to 50″ between dots. Double stars separated by more than 60″ are resolved and some closer ones appear elongated. The labelled double stars are based on the *Cambridge Double Star Atlas* and include all pairs that are resolvable in amateur telescopes, even when they cannot be resolved in the atlas. With the limiting magnitude and scale of this atlas, some crowding is unavoidable. A 3× magnifier is a help but a higher magnification makes the half-tone process obtrusive.

When open, the atlas measures 51 × 34 cm which is inconveniently large to use at the eyepiece of a telescope. The atlas is best consulted on a desk, especially when used in conjunction with a computer-controlled telescope with remote imaging. It should prove a valuable reference to the advanced-amateur community. — DEREK JONES.

The Complete Guide to the Herschel Objects: Sir William Herschel's Star Clusters, Nebulae and Galaxies, by Mark Bratton (Cambridge University Press), 2011. Pp. 584, 25 × 19·5 cm. Price £45/$70 (hardbound; ISBN 978 0 521 76892 4).

Long-time Webb Society member and visual observer Mark Bratton has taken up the challenge first achieved by Father Lucien Kemble in the 1980s to observe personally all the 2500 or so objects discovered by William Herschel during his great sky survey — a quest that has taken the best part of 20 years. This book is the result of that quest. It opens with a short biography of William Herschel and his telescopes along with a survey of what was known about the deep sky before Herschel started his project. The following chapters contain a description of how the observations for the book were carried out and a description of the guide format. The main part of the book (540 pages) is a listing by constellation of all the objects that William found. Some of them are illustrated with images taken from the Deep-Sky Survey (DSS) in black and white, and some with sketches. Each object has the pertinent positional information and Herschel's original catalogue number, and includes a description of the object from the DSS and a combined visual description of what might be seen through a medium-sized (30–35-cm) telescope. There are also small snippets of information on Herschel's observations and more modern data.

The book itself is nicely produced and although not a guide in the traditional sense the layout of the material makes it easy to select a constellation and go looking for the objects in it. I think it will be an excellent guide for anyone thinking of taking on the Astronomical League's Herschel observing projects (I, II, and 300) and is a good companion to the O'Meara *Herschel 400 Observing Guide* book, also by CUP. It is also an excellent reference to some of the less-famous deep-sky objects. Perhaps the only quibble I have is that I would like to have seen Herschel's own descriptions for each object included in the information. This book can be recommended to anyone with an interest in what Herschel did, and to all deep-sky observers. — OWEN BRAZELL.

Choosing and Using a Dobsonian Telescope, by N. English (Springer, Heidelberg), 2011. Pp. 245, 23·5 × 15·5 cm. Price £31·99/$34·95/€34·95 (paperback; ISBN 978 1 4419 8785 3).

This is a welcome addition to the popular *Patrick Moore's Practical Astronomy Series* and is equally useful to the first-time buyer of a Dobsonian telescope and the existing owner of an older instrument.

The first part briefly covers John Dobson's history and the development of the telescope that bears his name, together with Isaac Newton's invention of the Newtonian reflector and how it evolved. As the book progressed I felt that the chapters reviewing the design and field testing of the available models were focussed on the USA, but this impression was soon corrected by frequent references to the Crayford focuser and the inclusion of independent evaluations from observers in the UK. These practical reports from a wide range of locations are easily translated into everyday use and cover a wide range of objects imaged. From 3-inch first scopes to 16-inch apertures for the serious observer, self-assembly to ready-made instruments, and solid-tube to truss-tube design, this section gives a detailed description for the amateur who is looking for a good portable 'scope. If you want a visually pleasing telescope as well as good optical quality, the author has taken this into account and awesome 36-, 40-, and 50-inch instruments with equally awesome price tags are also mentioned. Controversial issues such as reflectors *versus* refractors and the use of Dobsonians for planetary imaging are dealt with adeptly, enabling the reader to make an informed decision.

Part two enables you to get the best use from your Dobsonian, with information on eyepieces, the Barlow lens, and filters. The section on star testing to evaluate the optics is particularly instructive. If, like me, you purchased your Dobsonian some years ago and feel that time has passed you by, you will be pleased to discover that there are a variety of ways to update your scope with go-to technology and equatorial platforms for tracking. Although Dobsonians were not considered camera-friendly, innovations have paved the way for astrophotography and the problems and challenges faced by photographers together with their solutions are a very useful guide to the subject.

On occasions the illustrations do not agree with the text but that is a minor detail. Whether you are looking for simplicity or wish to embrace modern technology this book gives you all the information you need to make the right choice and to get the most out of your observations. — VALERIE STONEHAM.

Patrick Moore's Yearbook of Astronomy 2012, edited by P. Moore & J. Mason (Macmillan, London), 2011. Pp. 474, 22·5 × 14·5 cm. Price £20 (hardbound; ISBN 978 0 230 75984 8).

The *Yearbook of Astronomy* was started by Dr. J. G. Porter following his retirement from the Nautical Almanac Office and the first issue was for the year 1962, so 2012 marks the 50th anniversary of publication. I was amazed to find that I'd been buying it for almost 40 years. Compared with the first edition (of only 216 pages), the 51st is a monster. It's always good to welcome the *Yearbook* with its mixture of maps, monthly notes, and topical essays.

Of the articles on offer for 2012, many appropriately review the last 50 years of research in various fields, and in this respect I particularly liked David Harland's 47-page piece on Solar System exploration by robotic probes: that will surely be a useful one for reference. Elsewhere, in another very useful piece, Martin Mobberley gives sage and witty advice for the would-be telescope owner and rightly concludes that any instrument that takes more than ten minutes to set up won't get used much. There are some interesting historical articles, and details of the transits of Venus observed during the Victorian era. For this special edition there are also five reprints of previous articles, one from each decade, including a piece on the Barwell Meteorite of Christmas 1965 by Howard Miles, and David Allen's 'Brighter than a Million Suns' from 1979 (which discussed Eta Carinae). Comments have been added to bring these articles right up to date. Following the articles section, we have lists of variable stars and several useful charts, predictions of maxima for Mira-type stars, and a list of double stars.

As ever the *Yearbook* concludes with a list of UK astronomical societies (18 pages this time, compared with just a few for 1962). I do recommend the publisher to start this list again with a clean sheet, or to become more pro-active in ensuring its accuracy. It will be fruitless to write to one local secretary who has been dead for years, and it is ages since the BAA last held its monthly meetings in Savile Row, London. A casual look disclosed several other mistakes. Today, however, it's more than likely that any search for the existence of a local astronomical society will begin on the internet rather than in these pages.

The 2012 *Yearbook* fully maintains the level of interest of its predecessors. I warmly commend this new edition — and long may it continue! — RICHARD MCKIM.

An Introduction to Astrobiology, Revised Edition, edited by D. A. Rothery, I. Gilmour & M. A. Sephton (Cambridge University Press), 2011. Pp. 360, 26·5 × 21 cm. Price £35/$65 (paperback; ISBN 978 1 107 60093 5).

Astrobiology is a relatively new field of science, concerned with the possibility of life beyond the Earth. You could argue that the maturation of a research field is measured by the appearance of first-rate textbooks devoted to training new students. So now, with the publication of this updated version of CUP's *An Introduction to Astrobiology*, astrobiology is surely in a very healthy state indeed.

Astrobiology, as the name might already suggest, is a deeply interdisciplinary subject. It combines studies of the survival tolerances of life on Earth and its origins with planetary science and the exploration of extraterrestrial environments and astronomical observations of stars and their planetary systems. Astrobiology sits in the central Venn-diagram overlap of a great number of distinct research fields, and it is the fusion of different ideas and techniques that makes the subject so exciting. But it's this interdisciplinary nature of astrobiology that also makes writing good textbooks so difficult. You can't assume anything about the background or prior knowledge of your readers — they could just as easily be geologists as biologists or astrophysicists. It is all the more impressive, then, that Rothery, Gilmour & Sephton have pulled together such a comprehensive and readily understandable introductory textbook as this.

The book follows a clear logical structure, building from the biological basics and what sort of world is needed to support life, through a tour of the other planets and moons in our Solar System that are considered likely candidates for extraterrestrial life, and finishing with the detection of exoplanets orbiting other suns and how to read biosignatures of life from so far away. The text is extremely well supported with carefully chosen photographs and illustrations, and many of the figures have been created bespoke for the book (no dodgy 'Wiki-rip-offs' here!).

This *Introduction* serves perfectly for both undergraduate and postgraduate courses, as well as more established researchers looking to read-up on other fields, and is equally approachable for non-scientists interested in finding out a bit more about this young field. I've already recommended this book to a new student! — LEWIS DARTNELL.

Annual Review of Astronomy and Astrophysics, Volume 49, 2011, edited by S. M. Faber, E. van Dishoeck & J. Kormendy (Annual Reviews, Palo Alto), 2011. Pp. 593, 24 × 19·5 cm. Price $227 (print only for institutions; about £144), $89 (print and on-line for individuals; about £56) (hardbound; ISBN 978 0 8243 0949 9).

Vera Rubin begins this volume of *ARA&A* with an eclectic selection of memories (personal as well as astronomical) from a long and distinguished career in science. Then follow twelve masterly reviews on a range of topics, perhaps not quite as wide as in previous volumes, but produced and illustrated to a very high standard, as we have come to expect.

Two articles on comets show just how far we have progressed in recent years through the employment of a technologically advanced arsenal of observational facilities, especially those in space, to the point where our understanding of the chemistry of comets has reached a quite sophisticated stage (Mumma & Charnley), and the rôle of comets in the development of planetary systems can be argued with authority (A'Hearn).

Two reviews on the evolution of proto-planetary discs (Williams & Cieza and Armitage) chime with the current enthusiasm for extra-solar planetary systems, while the pre-cursor to this activity, in the interstellar medium, is discussed in two further articles: on laboratory studies of the chemistry likely to be important there (Smith), and on the nature of the ISM in our neighbourhood (Frisch, Redfield & Slavin).

Then we go further afield to the 'realm of the nebulae' — 'galaxies' in modern parlance. The earliest galaxies to form, around 10^8 years after the Big Bang (if that's really what happened), are thoughtfully considered (by Bromm & Yoshida), including seeing what they might look like to *ALMA* and *JWST*. The physical characteristics of slightly older galaxies, formed at $z = 2$–4, is the topic addressed by (Alice) Shapley, while van der Kruit & Freeman outline, in the longest review in the book, our current understanding of the discs of galaxies.

Then on to the cosmological parameters revealed by whole clusters of galaxies (Allen, Evrard & Mantz), which overlaps with the search for dark matter, tackled in the review on the contribution astroparticle physics makes in that direction (Porter, Johnson & Graham). Quite where the ultrahigh-energy cosmic rays fit in is still work in progress, but an update is provided by Kotera & Olinto.

It goes without saying that your library should have a copy. — DAVID STICKLAND.

Russian Space Probes: Scientific Discoveries and Future Missions, by B. Harvey & O. Zakutnyaya (Springer, Heidelberg), 2011. Pp. 543, 24 × 16·5 cm. Price £40·99/$44·95/€44·95 (paperback; ISBN 978 1 4419 8149 3).

At the time of writing, Russia's *Phobos-Grunt* spacecraft is stranded in low Earth orbit and out of touch with its controllers, instead of heading towards a rendezvous with the larger of the Martian moons. This dramatic failure of a flagship mission is symptomatic of the ailing condition of the Russian space-science programme, formerly a dynamic leader in the exploration of the cosmos.

The country's descent from technological and scientific dominance is clearly demonstrated by this book, which summarizes in considerable depth the scientific missions and discoveries made by the former Soviet Union. In fact, an appropriate subtitle might be 'The Rise and Fall of the Russian Space-Science Programme'.

Almost the entire book is taken up with descriptions of scientific endeavours undertaken during the 1960s and 1970s. All aspects of space science are covered, including balloons and sounding-rocket flights, Earth-orbiting satellites, missions to the Moon, Venus, and Mars, and experiments conducted on Soviet space stations. Each chapter contains numerous references, but the quality of the illustrations is often disappointing.

This well-researched volume provides a valuable account of many experiments and missions which have previously been poorly documented in the West. There is also some coverage of recent attempts to revive the Russian scientific programme, including *Koronas-Foton*, *Spektr-R/Radioastron*, and the *Phobos-Grunt* mission. One noticeable trend as time goes by is the introduction of international contributions on missions such as *Foton* and *Phobos-Grunt*, although the results in recent decades have often been disappointing. — PETER BOND.

[*Phobos-Grunt* re-entered Earth's atmosphere on 2012 January 15. — Ed.]

Computational Star Formation (IAU Symposium No. 270), edited by J. Alves, B. G. Elmegreen, J. M. Girart & V. Trimble (Cambridge University Press), 2011. Pp. 556, 25 × 18 cm. Price £73/$125 (hardbound; ISBN 978 0 521 76643 2).

Despite being a little tardy in writing my review, I was actually very pleased to be asked to review a volume on computational star formation, an area that I find very interesting, and I wasn't disappointed. The book is the Proceedings of the 270th IAU Symposium held in Barcelona, from 2010 May 31 to June 4; and, judging by the author list, it really did seem to be attended by the great and good of the field. It made me regret not putting more effort into going to this meeting.

The opening two papers, by Richard Larson and Mike Norman, gave an excellent overview of the history of the field. Computational star formation is a field that has a number of interesting controversies. One revolves around the different numerical methods, and this debate can become quite vitriolic, as highlighted in Dan Price's contribution. Another is the process through which high-mass stars form. I have seen this debate become quite heated in the past, but it wasn't as obvious in this volume, so possibly the different views are starting to converge.

I also found many other excellent contributions, including papers that my students and postdocs would find interesting and relevant. Well worth a read if this is an area of interest. — KEN RICE.

Active OB Stars: Structure, Evolution, Mass-Loss, and Critical Limits (IAU Symposium No. 272), edited by C. Neiner, G. Wade, G. Meynet & G. Peters (Cambridge University Press), 2011. Pp. 664, 25 × 18 cm. Price £73/$125 (hardbound: ISBN 978 0 521 19840 0).

This volume presents the papers given at an IAU Symposium held at Paris–Meudon in 2010 July, attended by about 150 participants drawn from the research communities studying massive OB and related stars. The main aim of the organizers was to present and discuss recent progress, on both observational and theoretical fronts, in delineating and understanding the nature, structure (both internal, and atmospheric and winds), rotation, magnetic fields, and evolutionary links between OB, Be, LBV, and WR stars. The organizers certainly succeeded in this endeavour, with excellent and informative papers dealing with many key topics in this field. These include: (*i*) pulsations, rotation, magnetic fields, and transport processes affecting the internal structure of OB stars; (*ii*) OB-star formation and evolution, their circumstellar environment, binarity, and final stages as supernovae and GRBs; (*iii*) discs, magnetospheres, wind clumping, and the Be phenomenon; (*iv*) the use of active OB stars as test beds for the theory of mass loss, radiative transfer, and critical rotation and fundamental stellar parameters; and (*v*) stellar-population studies and the use of massive stars as tracers of galaxy structure and cosmic evolution.

Coverage of each area is provided by a healthy combination of papers dealing with the latest theoretical developments and new observations across the electromagnetic spectrum. The proceedings embrace review and contributed papers together with two-page summaries of the posters presented. Most of the sessions finished with extensive discussion and these are recorded in the proceedings. The editors are to be congratulated in getting the proceedings out so swiftly.

The proceedings will be of interest to all those working in the field of massive-star research, to get people, including new students, up to speed in the latest developments, both in theory/modelling and observations, and is a must for libraries. — ALLAN WILLIS.

THESIS ABSTRACTS

ON THE OBSERVABLE PROPERTIES OF DEBRIS DISCS

By Laura Churcher

Studying planetary-system formation is a growing area of astronomical research that endeavours to answer fundamental questions about the Universe and our place in it. Planetary systems contain both planets and planetesimal belts, such as the warm asteroid belt and the cold Kuiper Belt in the Solar System. These remnants of planet formation are known as debris discs. Debris discs offer an alternative pathway for indirectly examining planetary systems because planets are responsible for shaping the structure of the disc.

This thesis is on modelling debris-disc observations and relating them to planetary-system evolution. I apply advanced modelling techniques to synthesize all available observational constraints into a coherent, self-consistent picture of the debris-disc system. These models include dynamically based models in which planets impose structure on the disc and models in which the distribution is that expected for a system with on-going planet formation.

Resolved images of discs offer an alternative method of constraining the architecture of possible planetary systems — gaps in belts or truncation of the disc point to the dynamical influence of planets. We can also examine the discs in the context of planet-formation models; for example, do we see large amounts of hot dust that might be due to collisions during terrestrial-planet formation or is the disc distribution consistent with that expected from on-going planet formation? I have also used models in which comets on very eccentric orbits are coming in from a cold outer reservoir and being sublimated close to the star, creating small dust particles and a hot excess.

By studying discs around stars at ages of a few tens of Myrs, we are examining discs after the gas has dispersed, but while planet formation may still be ongoing. Models can be used to diagnose the state of planet formation in these systems. In this thesis I consider four young debris discs: HR 4796, η Tel, HD 191089, and β Leo. The discs around HD 191089 and η Tel are resolved for the first time in the work presented here, both imaged in the mid-IR. Two of these systems, HR 4796 and HD 191089, show a brightness asymmetry which is fitted with a pericentre-glow model, suggesting that the discs could be being perturbed by a planet or binary companion on an eccentric orbit. η Tel and β Leo have debris discs with multiple components, both showing evidence of hot dust which could be linked to terrestrial-planet formation. I also fit both these discs with delayed-stirring models in which dust production in the cold planetesimal disc is increased by the formation of Pluto-sized bodies. I further consider a model of an eccentric planetesimal swarm in which the emission around η Tel and β Leo is produced by a single planetesimal population. This model is also applied to η Corvi and HD 69830, two older (> 1 Gyr) debris discs that have large amounts of hot dust. — *University of Cambridge; accepted 2011 August.*

A full copy of this thesis can be requested from: ljc51@ast.cam.ac.uk

Source Modelling of Extreme- and Intermediate-Mass-Ratio Spirals

By Eliu A. Huerta

Black holes, neutron stars, and white dwarfs have always stirred a great deal of fascination in the general public. They have inspired countless sci-fi books and films based on their intriguing, yet usually misunderstood, properties. The aura of Einstein is responsible for this social phenomenon. He set in motion one of the greatest scientific revolutions of the 20th Century when, in 1915, he put forward a relativistic theory of gravitation in which he blended space and time into a single concept, space–time, and from which the existence of extreme objects was an inevitable consequence. This prediction was not initially welcome by most astrophysicists, including Einstein himself, but subsequent research showed that neutron stars and black holes are the end-points of stellar evolution, and hence merger observations of these compact objects can provide information about the distribution of masses of stars and their stellar evolution. Additionally, these 'high-energy laboratories' provide the necessary conditions to test the nature of gravity in the strong-field, high-curvature régime — a situation in which Einstein's theory has not yet been tested. Because many of these extreme compact objects do not emit light, it is the gravitational radiation emitted from them which will allow us to study their astrophysical properties.

In Chapter I of this thesis I present a summary of the development of gravitational-wave astronomy, both from observational and theoretical standpoints.

In Chapter II, I investigate the precision with which future low-frequency, space-based, gravitational-wave detectors will be able to measure the fundamental properties — mass and spin — of supermassive black holes that exist in the centres of galaxies. This study has two different aspects. The first one consists of developing an accurate waveform template to study the in-spiralling of stellar-mass compact objects into supermassive black holes. This study suggests that space-based detectors, such as the *Laser Interferometer Space Antenna* (*LISA*), will be able to perform a very accurate census of the mass and spin distributions of supermassive black holes. Furthermore, by augmenting the waveform template with corrections that take into account the interaction of the in-spiralling body with the curvature of the background space–time, I have found that for *LISA* the systematic errors that arise from omitting these conservative self-force corrections are generally smaller than the parameter errors that arise from instrumental noise. However, parameter-estimation results also suggest that the second-order radiative part of the self-force may be as important as the first-order conservative part. Hence, conservative self-force corrections can probably be ignored in search templates, but it may be necessary to follow-up with more accurate templates to get more precise parameter estimates.

In Chapter III, I present the second investigation, which involves the modelling of the in-spiralling of stellar-mass and intermediate-mass black holes into supermassive black holes. I have studied whether the inclusion of small-body spin effects is of any relevance for this type of event. I have found that these corrections are important for mergers that involve bodies with masses $\gtrsim 10^3\ M_\odot$ that spiral into central objects with masses $\sim 10^6\ M_\odot$. By including spin–orbit and spin–spin couplings in waveform templates, gravitational-wave observations may allow an accurate determination not only of the properties of the central supermassive black hole, but also of an intermediate-mass black hole that spirals into it.

Given the recent funding upheaval at NASA, ESA has been forced to explore ESA-only concepts for the *LISA* mission. In Chapter IV, I examine a few alternatives that ESA is currently exploring for such a low-frequency detector. I present results on the accuracy with which these de-scoped detectors will be able to measure the astrophysical properties of extreme-mass-ratio in-spiralling objects.

The second part of this thesis, Chapters V and VI, deals with intermediate-mass black holes in the context of ground-based-detector networks. The in-spiralling of stellar-mass compact objects into intermediate-mass black holes — events which may take place in core-collapsed globular clusters — will generate gravitational waves that could be detected with ground-based detectors. I have modelled these sources using the best information currently available from the extreme- and comparable-mass-ratio régimes. The waveform models I have developed include the in-spiralling, merger, and 'ring-down' phases in a consistent way. In order to cross-check the accuracy of my predictions, I have built two alternative models. One of them is valid for intermediate-mass black holes of arbitrary spin, whereas the second model is valid for non-spinning sources. I have used these models, in the context of the proposed *Einstein Telescope*, to compute signal-to-noise ratios and parameter-estimation errors for a sample of binary systems, assuming a variety of ground-based-detector networks. The two models make predictions that are consistent to better than ten per cent. Using these models, I have explored the dependence of parameter-estimation errors on the network configuration, and the improvement that may be achieved if this instrument achieves good low-frequency sensitivity. — *University of Cambridge; accepted 2011 August*.

A full copy of this thesis can be requested from: eahuerta@syr.edu

Measuring the Properties of Active Galactic Nuclei

By Sandra I. Raimundo

Active galactic nuclei (AGN) are observed at various redshifts and in various environments, spreading over orders of magnitude in power, obscuration, and mass. The energetic output observed from such sources is generated by accretion onto a supermassive black hole, a process which, although not resolved by our current instruments, can be inferred by multi-wavelength observations of the emitted radiation. Studies at various redshifts have shown that, similarly to galaxies, the AGN population also shows evolution with time. In the local Universe, the mass of the black hole is related to properties of the galaxy in which it lies, suggesting that there is a link between the evolutionary process of AGN and host galaxies.

This thesis is focussed on the study of AGN properties, from the physical parameters that control the accretion process, such as the mass to energy conversion, to the directly observable properties, such as the luminosity, and to their rôle in the surrounding gas and on the host galaxy. In the following chapters, I will first describe what the current understanding of AGN activity is, and then present an observational and theoretical research study to determine the main AGN properties. The first research chapters, Chapters 2 and 3, are focussed on determining the accretion parameters and observable properties of AGN activity. In Chapter 2 the growth of supermassive black holes by mass accretion is modelled using observables such as the luminosity function and the obscuration, to reproduce the supermassive-black-hole distribution in the local Universe. Chapter 3 describes the use of an accretion-disc model and two AGN samples, to explore the accretion-efficiency measurements for individual sources and discuss in detail the associated uncertainties.

The second research section of this thesis moves from the accretion disc and black-hole system to the larger-scale effects of the AGN. Chapter 4 studies a large sample of X-ray-detected AGN, to measure the obscuring density of material surrounding the black hole, and the relation between the AGN output energy and obscuration. Chapter 5 is focussed on a specific galaxy, MCG–06–30–15, for which there are observations able to probe its inner regions, and hence the environment of the central black hole. I present the main results on the stellar and gas dynamics and discuss the possible links between the AGN activity and the host galaxy. Finally, Chapter 6 summarizes the main conclusions of this thesis, and outlines some of the future work that follows from the results presented here. — *University of Cambridge; accepted 2011 September*.

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

Here and There

NO NEED TO MAKE A SONG AND DANCE ABOUT IT

I revue the project and introduce our target sample … — Extreme Solar Systems II, Conference Abstracts, p. 13.

EVIDENCE FOR INTELLIGENT LIFE IN THE ASTEROID BELT?

Vesta has a visible and infrared mapping spectrometer … — *Astronomy & Geophysics*, 2011, August, p. 4.9.