THE OBSERVATORY

Vol. 130 2010 FEBRUARY No. 1214

PERIODIC BEHAVIOUR OF STARS IN THE GEOS RR LYRAE DATABASE

PAPER 1: LONG-TERM CHANGES IN THE PERIODS OF RR LYRAE

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The GEOS database O – C values for the star RR Lyrae have been used to investigate the long-term periodic behaviour of the star. It is found that over the 109 years of observations the pulsation period has varied. The data from 1910 to 1946 have a different period from the data from 1959 to 2008. Additionally, the Blazhko period of near to 40 days is poorly determined in the earlier data while in the later data it has been found that this period is variable by about 20% and that these variations show periodic behaviour. The implications of this for the origins of the Blazhko effect are discussed.

Introduction

The variable nature of RR Lyrae was discovered by Williamina Fleming[1] from photographic observations made in 1899. This class of radially pulsating star, with its 'standard candle' period–luminosity relationship, has been important to our understanding the nature and scale of the Universe. In 1907 Blazhko[2] discovered that the star RW Draconis, another RR Lyrae-type variable, showed a periodic variation of about 41·7 days as well as the shorter pulsation period. Extensive observations by Martin & Plummer[3] led to the discovery by Prager[4] that RR Lyrae also showed a longer-period variation on a time scale of about 41 days. Since then, this variation has been known as the Blazhko effect and its behaviour is that of a distortion moving through the regular pulsational light curve such that the times of maximum and minimum light are disturbed. Various attempts have been made to model the physical causes for the Blazhko effect.

These can be classified as 'magnetic models' or 'multi-pulsation-mode models'. The origins of the 'magnetic models' date back to Babcock[5], who measured the magnetic-field strength of RR Lyrae in the 1950s and claimed to have found a magnetic field which varied over the 41-day Blazhko period. More recent measurements by Preston[6] in 1963 and 1964 failed to find any magnetic field, as have several other groups (see Chadid *et al.*[7] and references therein). This means that the superficially attractive model of an obliquely-rotating, magnetic, pulsating star seems untenable. The alternative 'multi-pulsation-mode model' requires there to be both radial and non-radial modes of pulsation. Stothers[8], Kolenberg *et al.*[9], and Chadid *et al.*[10] have described non-magnetic models. However, changes in the Blazhko period, which have been seen before, require some other form of variation in the star (see Kolenberg *et al.*[9] for a thorough discussion of this problem). The present paper analyses all known times of RR Lyrae's maxima in order to investigate the long-term behaviour of both the pulsation and the Blazhko periods.

The data

The database of times of maxima in the light curves of 3380 RR Lyrae stars have been made publicly available by the Groupe Européen d'Observation Stellaire (GEOS)[11]. For RR Lyrae itself the database covers 39 910 days (over 109 years) and lists the times of 966 maxima. The GEOS database also includes many O – C (Observed minus Calculated) diagrams from which a visual representation of the stability of the periods of these stars can be quickly obtained. The O – C diagram for RR Lyrae is shown in Fig. 1. The ephemeris used to obtain these values was 2442923·41930 + 0·566837800 *E* days. Even a casual glance at this diagram shows that the period of RR Lyrae has not remained constant over the last 109 years. If we consider only the data from about HJD 2 400 000 (hereinafter omitted) +19 000 (1910) to about +31 000 (1946), then those data would be better fitted with a period of 0·5668438 days. The earliest data, prior to HJD +19 000 (1910), are clearly not compatible with that period. The later data, from about HJD +37 000 (1959) to +55 000 (2008) would indicate that over that period of time the period was 0·5668318 days. The change in period of about 0·0000120 days is about 2 parts in 10^5 of the averaged pulsation period.

It can also be seen that in addition to the obvious changes in period, which occurred around HJD +17 000 (1906), and around HJD +35 000 (1953), when there were unfortunately no data on both occasions, the behaviour of the star has changed. Before 1953 the nature of the O – C diagram is more or less a straight line with some scatter. After that epoch the O – C diagram shows clear signs of possibly periodic variations superimposed upon the long-term secular changes.

TABLE I

The best-fit 'Blazhko' periods, with standard errors, to five independent subsets of data covering the first 47 years of RR Lyrae data

Epoch (HJD)	*Period (days)*	*Standard Error*
Before +18 000	40·76	1·64
+18 000 – +21 700	49·25	0·44
+21 700 – +25 800	40·02	0·07
+25 800 – +28 000	48·36	1·19
+28 000 – +32 060	36·14	0·27

In order to quantify this we have divided the data into two independent subsets. One contains the data from about HJD +19 000 to about +32 000 and the other is the later data, which run from about HJD +37 000 to +55 000. The very early data, which are at about HJD +15 000, are insufficient for detailed period analysis but they do demonstrate the variable nature of the pulsation period.

Three methods have been used to determine any periodicities which are present in the O–C values: the Discrete Fourier Transform (DFT), the Phase Dispersion Method (PDM), and CLEANest. All the results that follow have been found by one of these methods and checked by one or both of the others.

The data before 1959

These data were detrended and then analysed over the frequency range of zero to 0·1 cycles/day. The most significant signals were in the frequency range of 0·024 to 0·026 c/d, *i.e.*, near to 40 days. It was noticed that when the whole of this data set was included the signal was weaker than when subsets of the data were used. Attempts to use arbitrary subsets of the data of 3-, 4-, or 5-year duration did not produce results which were consistent, and finally the best that was possible was to divide these 47 years of data into five subsets, the results for which are in Table I. If the formal standard errors are a good indication of the accuracy of the periods derived from these data sets then it seems that between 1890 and 1953 the value of the Blazhko period varied between about 35 days and about 49 days. This would explain why using the whole data set gives a reduced signal in the power spectrum. These data do not allow an analysis with a higher temporal resolution.

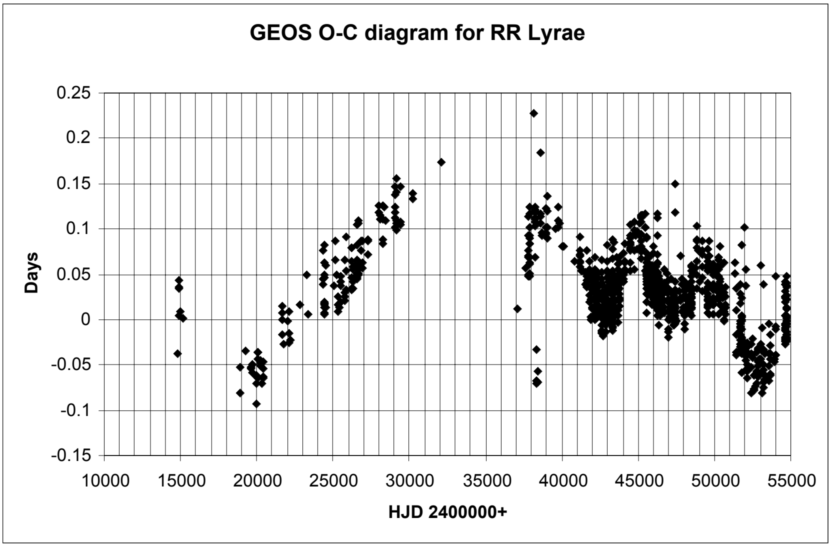

FIG. 1

The GEOS O–C diagram for RR Lyrae obtained using an ephemeris of 2442923·41930 + 0·566837800 *E* days.

The data after 1959

For this part of the analysis we have used all the data from about HJD +37000 (1959) to about HJD +55000 (2008). Inspection of Fig. 1 shows immediately that the O – C behaviour of the star has changed dramatically from that of the earlier data. Not only has the pulsational period changed but so also has the long-term behaviour of the star. The most obvious feature is the quasi-periodic behaviour with a time scale of about 5000 days. A DFT analysis of the whole of this data set gives the power spectrum in the upper panel of Fig. 2. The highest peak is at 5005 ± 312 days (13·7 years) while the lower peak is at 10373 ± 1021 days (28·4 years). The data folded with these values have mean curves with amplitudes of 0·046 days and 0·03 days respectively. The power spectrum has been calculated down to a frequency of 0·001 c/d (1000 days) as in the past there have been claims[12] of both 10- and 4-year periods in the data. There is a signal at 0·00083 c/d, 1209 ± 17·5 days (3·3 years), the mean curve of which has an amplitude of 0·014 days, but its significance and reality are uncertain.

The signal near to 5000 days is so strong in the later data that we have gone back and looked at the 1910 to 1946 data to see if there is any evidence for such a period although it is not obvious visually. The lower panel in Fig. 2 shows the result but it should be noted that the vertical scale in the lower panel is stretched by 12·5 times compared to that in the upper panel. The highest peak is at 5485 ± 1127 days and gives a mean curve with an amplitude of 0·018 days.

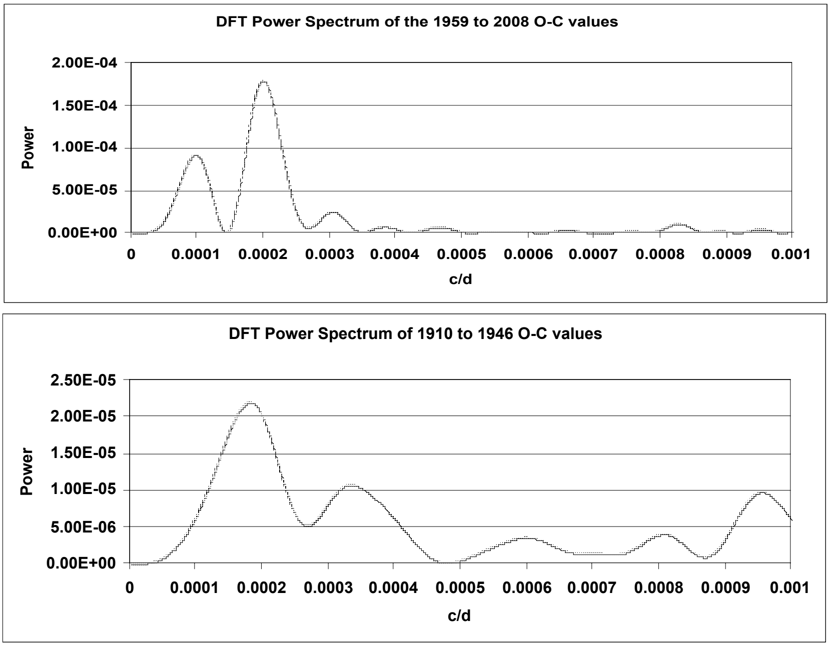

FIG. 2

DFT power spectra for RR Lyrae O – C values covering periods longer than 1000 days. The upper graph shows the results for the most recent 49-years' data. The lower graph shows the results for the 1910 to 1946 data. Note that the vertical scale of the lower graph is 12·5 times larger than that of the upper graph.

When the two periods near to 5000 and 10 000 days are removed from the later data, then the only signals which are left in the power spectrum are near to 40 days. However, rather than one peak or one broad peak the power spectrum shows a set of several narrow peaks. Previous experience in finding periods in variable stars has shown that a power spectrum with several closely spaced frequencies does not always mean that the whole data set contains these several frequencies. It can also mean that the period is not constant but varies over time with different, but similar, frequencies persisting for different lengths of time during the whole of the data run.

In order to investigate whether the approximately 40-day variation in the O – C values throughout the later part of the data are stable, the following strategies have been tried. Generally there are insufficient data in any one year to obtain a meaningful value for the '40-day' period. On the other hand, taking five consecutive years reduces the time resolution of any changes which are occurring. We have made all the following analyses. (*i*) Divide the data into five-year bins and determine the best-fit period in the range 50 days to 30 days. The five-year bin was then advanced by one year and the analysis repeated. This was done for the whole of the last 49 years of data. (*ii*) Divide the data into three-year bins and do the same type of analysis as in (*i*) above. Where years are missing, a five-year bin has been used to contain the two years each side of the year with zero data. In addition, two of the three-year bins showed no significant peak in the frequency range being investigated and in these cases five-year bins were also used. The use of five-year bins was only necessary for five of the 47 data bins used in the following analyses and in Figs. 3 and 4. (*iii*) The above two analyses were carried out on all the later data both before and after being pre-whitened with the 5000 and 10 000-day period found in the O – C values. The results were essentially the same for all forms of analysis although the five-year bins clearly had less resolution than the three-year bins. Table II contains the results of analysis (*ii*) above.

These '40-day' results have been analysed in two ways. In the first, all the non-independent three-year-bin values were subjected to a DFT analysis. In the second only independent three-year bins were analysed, *e.g.*, 1961, 1964, 1967, *etc.*

TABLE II

The best-fit 'Blazhko' periods, with standard errors, to three- or five-year bins of data covering the years 1960 to 2008

Central Year	*Period (days)*	*s.e.*	*5-year bin*	*Central Year*	*Period (days)*	*s.e.*	*5-year bin*	*Central Year*	*Period (days)*	*s.e.*
1961	41·27	1·00		1977	41·28	0·49		1993	39·48	0·58
1962	37·72	0·56		1978	41·02	1·11		1994	39·30	0·54
1963	37·60	0·55		1979	37·44	2·30		1995	38·78	0·39
1964	38·89	0·87		1980	39·33	0·47		1996	38·94	0·60
1965	35·08	1·27		1981	41·16	0·35	5	1997	39·82	1·03
1966	35·36	0·60		1982	42·83	0·92		1998	37·41	0·43
1967	35·36	0·71		1983	41·28	0·63		1999	34·70	0·63
1968	35·36	0·71		1984	41·01	0·47		2000	35·18	0·48
1969	36·40	0·24	5	1985	42·50	1·09		2001	35·45	0·36
1970	34·21	0·17	5	1986	39·58	0·44		2002	34·90	0·27
1971	34·40	0·73	5	1987	39·64	0·59		2003	38·64	0·51
1972	34·55	0·45		1988	39·00	1·45		2004	39·02	0·51
1973	37·34	1·92		1989	39·09	0·31	5	2005	38·23	0·39
1974	39·22	0·57		1990	39·48	1·19		2006	39·11	1·04
1975	39·05	0·34		1991	35·06	0·54		2007	38·94	3·11
1976	38·18	0·54		1992	34·87	0·60				

The first has the advantage that the one-year spacing allows the analysis to continue down to a Nyquist period of two years, thus allowing an investigation of the suggested four-year periodicity, and smoothes out some of the random variations and noise. The second lacks this resolution but has the advantage that any results cannot be due to non-independent data. The results are shown in Fig. 3. The three highest peaks in the non-independent data are at 29·3 ± 4·3, 10·35 ± 0·74, and 3·98 ± 0·11 years. In the independent data the two highest peaks are at 25·2 ± 5·1 and 11·04 ± 0·78 years. These should be compared with the values of 28·4 years and 13·7 years derived above from the raw O – C values for the same time span.

In Fig. 4 the upper panel shows the independent data folded with the 11-year period after removal of the 25-year period, while the lower panel shows the same independent data folded with the 25-year period after removal of the 11-year period. In both cases the peak-to-peak amplitude of the variations is approximately 4 days. When the non-independent data are folded with the 3·98-year period the peak-to-peak amplitude is approximately 2 days. It seems probable that the 25-year and 11-year periods found in this analysis and the 28-year and 13·7-year periods found in the earlier analysis of the shape of the original O – C diagram have the same origin. Whether this is correct or not, it seems clear that, over the 49 years covered by these most recent data on RR Lyrae, in addition to the pulsation period, there have been at least two periods present, both of which modulate the Blazhko period with peak-to-peak amplitudes of approximately 4 days. The analysis of the non-independent data

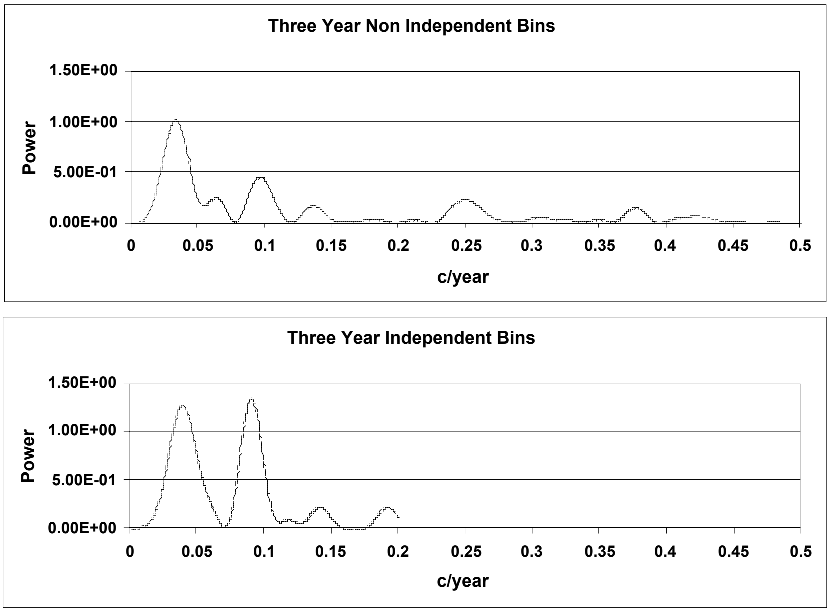

FIG. 3

DFT power spectra of the best-fit 'Blazhko' periods to three-year data bins taken from the years 1959 to 2008. The upper graph uses three-year running bins which are non-independent but which are spaced at one-year intervals. The lower graph shows the results for independent data bins spaced at three-year intervals. Both power spectra are truncated at the respective Nyquist frequency of their data sets.

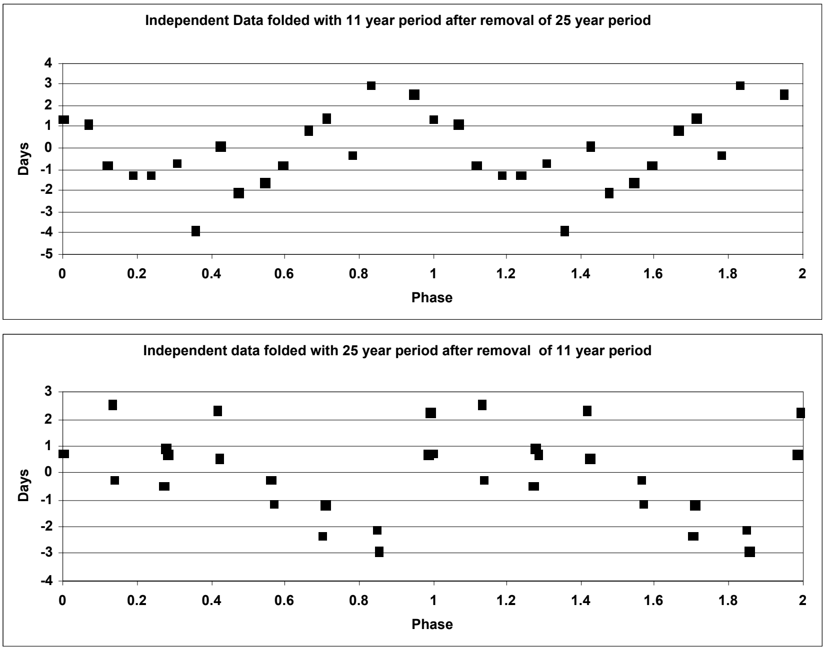

FIG. 4

Phase diagrams of the best-fit 'Blazhko' periods to three-year, independent bins. The upper graph shows the data folded with the 11·04-year period after the removal of the 25·2-year period. The lower graph shows the same data folded with the 25·2-year period after removal of the 11·04-year period. Note that the peak-to-peak amplitudes of each curve, about 4 days, is the amplitude of these long-term modulations to the Blazhko period, not O – C values associated with each period.

also supports the presence of a 3·98-year period with a peak-to-peak amplitude of approximately 2 days.

The '40-day' O – C curve

During the analysis it was noticed that the O – C values for the last year in which the data is available, 2008, had a mean curve which is very different to many of the annual mean curves in the rest of the data. All the O – C values in 2008, folded with a 39·84 day period, are shown in the top panel of Fig. 5. The extreme 'saw-tooth' nature of this curve is immediately apparent. Although it is possible to find traces of similar-shaped O – C curves in other years, the only other years in which the whole of the year's data produces a similar shape are 1994 and 1962. The folded data for these years are shown in the centre and bottom panel of Fig. 5. The discrepancy of these three years from the rest of the data has to be emphasized. Neither the whole of, nor a large subset of, any other single year of data shows the same cleanliness in a phase diagram. Indeed, most years of data are so scattered that it is impossible to determine a best-fit period to a single year of data and we have had to resort to using three-year, or even five-year, data bins before a significant period can be found. It should also be

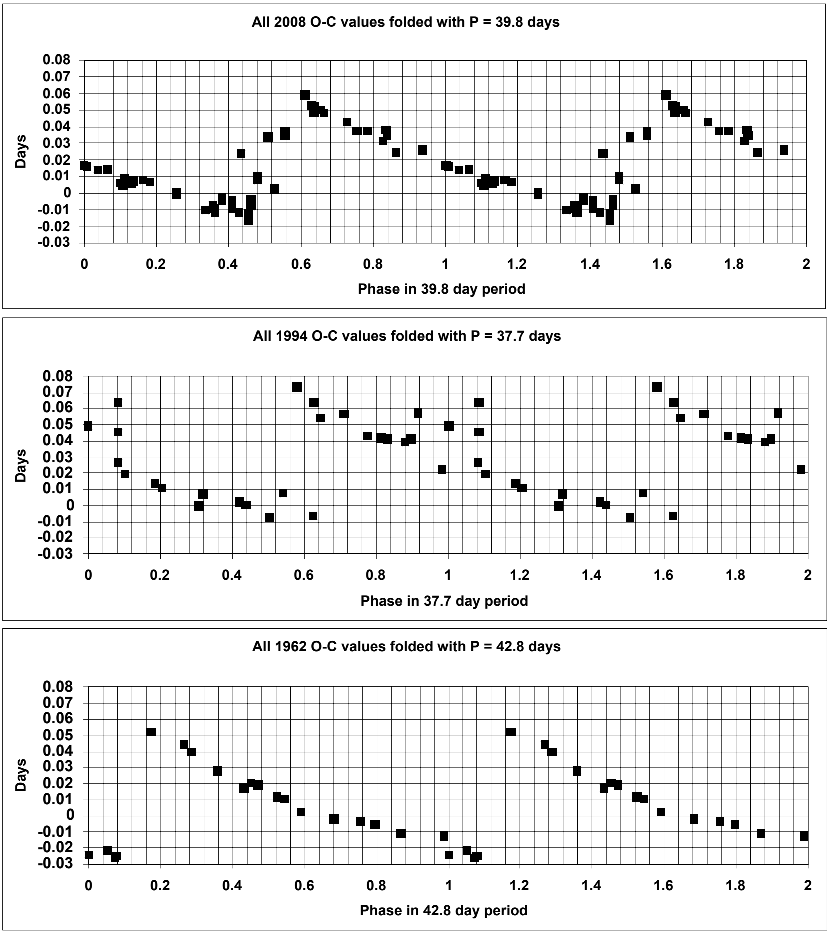

FIG. 5

Phase diagrams of all the O–C values for each of the years 2008, 1994, and 1962 folded with the best-fit 'Blazhko' period to each of those years. These three years have been chosen because of the 'clean' nature of each of these phase diagrams when compared with all other years, which show much more scatter to the extent of not having detectable periods.

noted that the similarity of these phase diagrams is not a function of observing technique as the 2008 data and the earlier data were obtained by very different technologies (CCD/photoelectric). Recalling that what is being investigated here are the departures of the times of maximum light in the pulsational light variations from a simple, single-valued period, it is clear that whatever causes these Blazhko excursions can have very different effects at different times. The situation is even worse for the pre-1959 data where many three-, four-, or five-year data bins do not even show a significant signal in the period range of 30 to 50 days. Whether this effect is influenced by the colour range to which the equipment is sensitive or by other parameters is unknown.

Implications for the understanding of the periods in RR Lyrae

The pulsation period of RR Lyrae has changed twice over the last 109 years. The earliest data in Fig. 1 have a different pulsational period to the two later data sets which form the basis for this paper. The data for the period 1910 to 1946 had a value of 0·5668438 days. The period for the most recent 49 years has been 0·5668318 days. It is unfortunate that on both occasions when the pulsation period changed there are gaps of several years in the data, so it is not clear just how rapidly the period does change. If these changes in pulsation period are periodic then it seems likely that another change will occur about 2008 – 2012. More remarkably, the behaviour of the O – C diagram has changed along with the period. The earlier data show an ill-determined, approximately 40-day modulation around the mean slope while the later data show a significant '40-day' modulation. Additionally the later data show a 5000- and a 10 000-day modulation. The 5000-day modulation is detectable in the earlier data but only by period analysis of the data. It is not visually apparent. It is possible to find one period which fits the whole of the 109 years of data. This period is 5428 ± 212 days, 14·86 ± 0·58 years, with an amplitude of 0·053 days peak to peak. It is interesting to note that this is almost the same period as is found from the 1910 to 1946 data only, but this period is not a good fit to the 1959 to 2008 data alone. Such a period with that amplitude could be caused by binary-star orbital motion, but if such were the case then radial-velocity changes would presumably have been seen by now. Whether the differences in behaviour between the early and later data sets are correlated with the change in pulsation period of the star cannot be determined from these data. The later data clearly show the '40-day' period but analysis of the changing value of this period shows it to vary between about 34 and 42 days. The modulation of this '40-day' period contains two periods, 5005 days (13·7 years) and 10373 days (28·4 years), and a possible period of 3·98 years. The amplitudes of the two certain periods are both about 4 days, peak to peak, while the 4-year period has a peak-to-peak value of about 2 days.

Whatever the mechanism, or mechanisms, which cause the '40-day' Blazhko effect, they have to be capable of modulation with more than one period. The phase coherence of these long periods is sustained over about 50 years. The three possible periods, 28·4, 13·7, and 3·98 years do not seem to have a common denominator but it should be recognized that the determination of the two longer periods from only 49 years of data means that they are not accurately determined. The amplitudes of these three periods are, respectively, 4 days, 4 days, and 2 days. This means that they cannot be due to light-travel times in a multi-star system.

There is a further problem which also constrains models for the origin of the Blazhko effect and that concerns the nature of annual '40-day' mean curves for the folded data. These curves, which represent the modulation of the times of the pulsational maxima, are well defined for the years 1962, 1994, and 2008. No other year's data, or large subset of one year's data, shows the same 'clean' variation over the 109 years covered by these data. Of particular note is the fact that the three phase diagrams, shown in Fig. 5, have essentially identical shapes, amplitudes and durations. The form of these three phase diagrams suggests an important constraint on models. Note that in all three cases the O – C value becomes more negative in an approximately linear fashion by about 0·08 day within the Blazhko period before rapidly returning to its original value. The value of 0·08 days is approximately 14% of the pulsation period. The number of Blazhko cycles covered in each of the three years is four in 1962, four in 1994, and three in 2008, so when this effect occurs it continues over several Blazhko periods.

The correct interpretation of these variations is likely to act as a useful constraint on models to explain the Blazhko effect but there are problems. The first is to understand why these 'clean' variations are so rare. Many subsets of the 109 years of data show similar gradients and yet they never persist for as long as a full Blazhko period, so one question which arises is: (*i*) are the variations shown in Fig. 5 the true shape of the underlying changes and is there generally some other variation superimposed upon them? This leads to two further questions: (*ii*) what was special about the years 1962, 1994, and 2008 which suppressed the hypothetical additional variations? It is possible that there was some particular phasing of the 28·4-, 13·7-, and 3·98-year periods but as the two longer periods are not well constrained it would be speculative to try to find such a phase connection. However, the 14·86-year period which fits the whole of the 109-years' data, but which is not a good fit to only the more recent 49-years' data, is approximately a common denominator to the intervals between these years. (*iii*) If the curves in Fig. 5 are the correct variations, then what is the source of the additional variations which normally mask the underlying changes? The effects are much too large to be due to observational errors.

There are additional problems with the interpretation of these diagrams. The effect could be interpreted as though the pulsation period of the star, 0·5668 days, becomes shorter by about 0·0003 days for 200+ pulsation cycles, but when the phase lag becomes about 14% of the pulsation period something constrains the pulsations to revert to their original phase. Note that the period resuming its original value would only lead to a levelling off of the O – C diagram, not a reversion to its original O – C value. Alternatively the phase diagrams could be interpreted as suggesting that the pulsation period remains constant but that some effect linearly retards the apparent time of maximum until such time as the retardation is 14%, at which time the retardation mechanism is either overcome or removed and the star recovers its original phase within between one and six pulsation cycles. The rapidity of this return to the original O – C value is something that any successful model will have to explain. The following additional questions are therefore raised: (*iv*) should the shapes of the curves in Fig. 5 be interpreted as a change in period with a 'memory' of the 'correct' phase or as a progressive distortion of shape of the pulsation light curve until such time as that retardation reaches about 14% of the pulsation period? And (*v*) what caused the rapidity of the return to the original O – C value?

Acknowledgements

None of this research would have been possible without the dedication of observers over the last 109 years who have observed this star, measured its variations, and published their results to allow them to be archived. Without the enthusiasm and labours of the members of GEOS[11] who have made these data publicly, and easily, accessible none of this would have been possible. It is a particular pleasure to thank Dr. Chris Lloyd who drew my attention to some of the references used. Finally it is a pleasure to thank Tonny Vanmunster, of the Belgium Center for Backyard Astrophysics, who has collected the many period-finding techniques which have been used in this analysis and made them readily available through his PERANSO package.

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DOES THE RR LYRAE VARIABLE DY AND SHOW THE BLAZHKO EFFECT?

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Data taken on the University of Sussex 0·46-m telescope in 2006 and 2007 are combined with previously published data to obtain a better-defined light curve for the RRab-type variable DY And, a slightly improved period of $0{\cdot}6030897^{+0{\cdot}0000006}_{-0{\cdot}0000002}$ days, and a new time of maximum. Evidence is presented that may indicate the Blazhko effect in this system. In addition, a new time of maximum has been obtained for VX Tri.

Introduction

The University of Sussex operates a 0·46-m telescope at the Isle of Thorns Observatory in the Ashdown Forest (longitude 0° 01′ 16″ E, latitude 51° 03′ 23″ N) which is used for final-year MPhys projects; further details of the telescope and CCD can be found in an earlier paper[1]. During 2006–07, a study was made of a number of RR Lyrae stars, including the RRab-type star DY Andromedae (J2000: $23^{h}\ 58^{m}\ 42^{s}{\cdot}2$, +41° 29′ 19″), which was followed up in the next observing season, enabling a good light curve and an improved period to be obtained.

Observations and data reduction

Observations of DY And were obtained on the night of 2006 November 4–5 (for an MPhys project[2]) and subsequently on six nights in 2007 September and October (Table I), comprising 1549 CCD images, each of relatively short exposure to avoid image smearing by the slight periodic error in the drive. Similar observations of VX Tri (J2000: $02^{h}\ 10^{m}\ 01^{s}$, +32° 24′ 11″; this position was obtained by comparing the *Aladin* image with a finding chart, and is not

TABLE I

Journal of observations for DY Andromedae

Start date	*Start time (UT)*	*Finish time (UT)*	*No. of images*	*Exposure length (sec)*
2006 Nov. 4	2246	0042	105	45
2006 Nov. 5	0043	0345	158	30
2007 Sep. 10	2127	2259	42	40
2007 Sep. 11	2057	0358	546	40
2007 Sep. 12	2043	2200	99	40
2007 Oct. 4	2055	2201	89	40
2007 Oct. 5	2005	0257	296	40
2007 Oct. 14	2027	2309	214	40

quite the same as given by *Vizier*) were taken on the nights of 2006 November 6, December 9 and 10, and 2007 January 10 and 11.

Because the filter wheel was not working, all observations were taken in white light. The CCD is Peltier-cooled and was never warmer than −5° C. Times were taken from the computer clock, whose difference from UT was determined at the start of each night, and then corrected to give the heliocentric time of mid-exposure. Dark frames were subtracted automatically from each image to minimize the thermal background.

The raw images from the SBIG ST-7 camera were first converted to FITS format by a freeware program available from SBIG. Flat fields were then obtained and applied with the IRIS software[3] (version 5·55) to stack and average many images so as to blur out the star images, following the method used in the Sussex 2nd-year astronomy laboratory[4]. The initial data reduction to obtain differential magnitudes was also carried out with IRIS. Subsequently, the entire post-flat-fielding reduction process was repeated for DY And with IRAF, and it was the IRAF results that were used in the period analysis reported here. Three reference stars were used for DY And; their positions are indicated in Fig. 1 and their identities and magnitudes are given in Table II. Errors in the final differential magnitudes were estimated as in the earlier paper[1]. Two nearby but unidentified reference stars were used for VX Tri; again, only differential magnitudes were obtained.

Previous work on DY And

The star was picked out as a potential target because the period given in the 1971 edition of the *GCVS* was not very well determined at 0·604 days (no error stated). However, later papers gave a variety of other estimates: 0·6030 ± 0·001 days[5], 0·603087 ± 0·000005 days[6], and 0·60298 days (no error quoted)[7]. The aim of the observations was either to confirm or to improve on the most precise of those periods.

TABLE II

Data for reference stars for DY And

	GSC number	*Magnitude**	*Comments*
Ref. star 1	3241–0174	12·84	Blended image
Ref. star 2	3241–0490	14·13	
Ref. star 3	3241–0054	13·68	

**Magnitudes taken from GSC on V system. However, only differential magnitudes were used, since our data were unfiltered.*

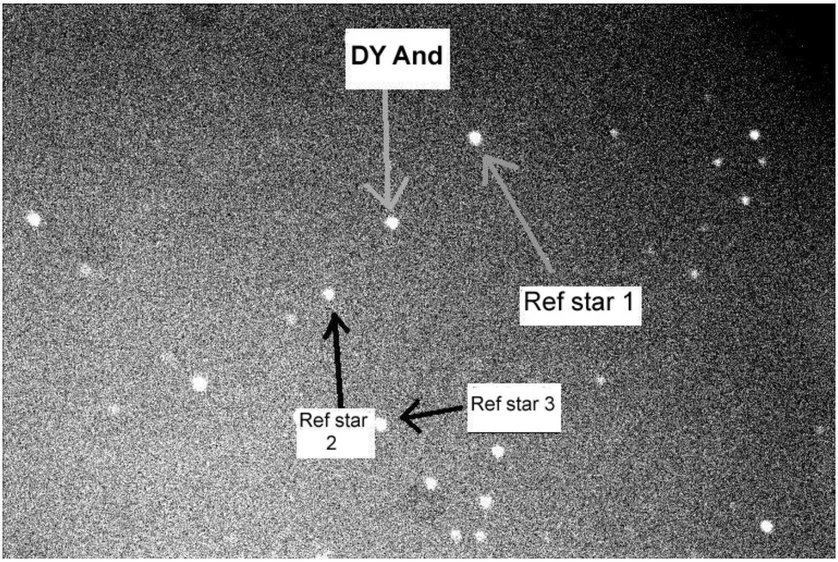

FIG. 1

A CCD image of DY And, taken on 2006 November 4, showing the reference stars used to obtain the differential magnitudes. Star 1 was the main reference star, with stars 2 and 3 primarily used as check stars (star 1 has a very close companion, whose magnitude cannot be measured separately, but both stars were included in the aperture when doing the photometry).

Results for DY And

The data obtained in 2006 November showed almost no variation over the five hours of observation, so it was necessary to supplement them with additional observations, obtained in 2007 September and October. A period analysis was carried out with the 'string-length' option in the *Starlink* package PERIOD[8] and the 2007 data alone yielded a period of 0·6030 ± 0·0001 days, consistent with most previous estimates. We were also able to find a new time of maximum, at HJD 2454355·5732 ± 0·0001 days. However, a light curve for the combined 2006 and 2007 data, phased on the period of 0·6030 days, showed that the 2006 data did not fit the curve. We therefore reanalysed the combined data set and found the slightly longer period of 0·603189 days; neighbouring periods were also present, with a frequency spacing corresponding to the roughly 11-month gap between the data sets, but a light curve with this period fitted both data sets well. To resolve the difference between this period and the one published by Schmidt[6], we needed additional data.

Dr. Chris Lloyd (Open University) kindly made available to us the ROTSE-1 data used by Wils *et al.*[7], and 33 points from the Schmidt data[6] were available as an on-line table. Since the Sussex data were available only as differential magnitudes, we first had to add a constant to all the Sussex magnitudes to bring them onto a scale compatible with the ROTSE-1 data. There was some uncertainty about this because there was a larger range in the ROTSE-1 data; we chose to make the maxima have the same magnitudes. Adding the ROTSE-1 data alone also gave a slightly longer period, of 0·603219 days, but in this case there was also a shorter period of nearly the same significance, namely 0·603091 days, close to Schmidt's period. The frequency difference between the two periods corresponds to a time-scale of about 2800 days, which is approximately the time interval between the ROTSE-1 data and the Sussex 2007 data. This suggests that the longer period is actually an alias of the true period, perhaps introduced by the small 2006 data set.

We therefore combined all three data sets, making a shift (by eye) of 0·2 in the magnitude scale to bring the unfiltered ROTSE-1 and Sussex data onto a scale compatible with Schmidt's *V* data. Analysing just the published Schmidt data[6] first, as a check, led to a period consistent with, but very slightly different from, his published value[6]; the slight difference probably arose because he also included 16 earlier data points[5], not available on-line. We then analysed the combined data set (Schmidt + ROTSE-1 + Sussex) and found a well-defined period of 0·6030897 days; we estimate the uncertainties to be +0·0000006 and –0·0000002 days, based on the shape and width of the asymmetric minimum in the string-length/frequency plot. The nearest alternative period, considerably less significant, was again 0·603219 days, supporting the idea that this longer period is an alias.

A combined light-curve with our new period is shown in Fig. 2. The 2007 Sussex data (the filled diamonds) provide the best-defined light curve so far published. There are three features of interest in the combined curve: (*i*) There is a reasonably well-defined curve for all the data, except that the 2006 Sussex data do not fit the mean curve. Since they were obtained with the same instrumental set-up as the 2007 data, and have been reduced in the same way, the mis-fit is real, suggesting a possible change in the light curve on a time-scale of a year. (*ii*) There appear to be two branches of the curve in the phase range 0·75 to 0·9; the two branches correspond to the 2007 September and 2007 October data, as can be seen in the detailed plot in Fig. 3. This may be evidence for a small change in the light curve on a timescale of 3–4 weeks. (*iii*) There is a great deal of scatter in the ROTSE-1 data, which were taken over an interval of about 8 months; this may suggest changes in the light curve on an intermediate

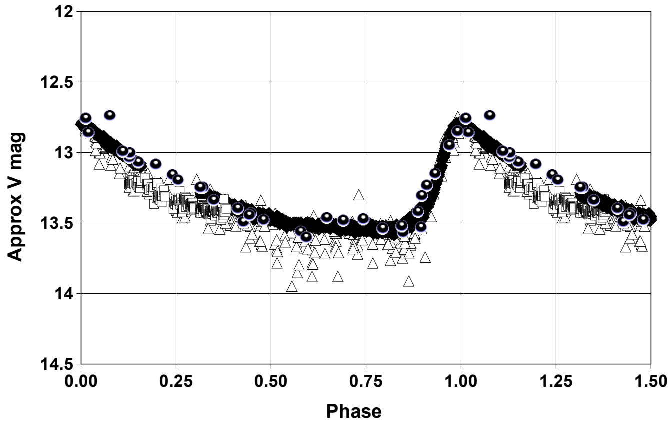

FIG. 2

The light curve of DY And, folded on a period of 0·6030897 days. Filled circles with a white spot are data from Schmidt[6], open triangles are the ROTSE-1 data, open squares are the 2006 Sussex data, and filled diamonds are the 2007 Sussex data. By eye, the asymmetry in the light curve is 0·15 ± 0·05, confirming the RRab classification[5,6].

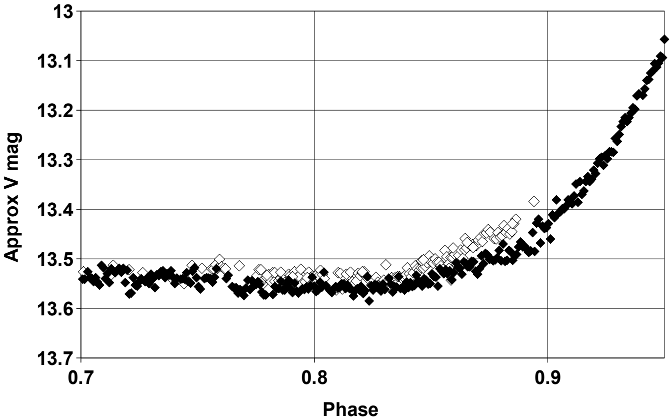

FIG. 3

Detail of Fig.2, for the Sussex data alone, to demonstrate the two branches of the light curve in the phase range 0·75–0·9. The solid diamonds are from 2007 September, and the open diamonds from 2007 October. Note that this feature is only detectable because of the large number of observations, closely spaced in time.

time-scale of months, although ROTSE-1 data for other stars show a similar scatter.

Taken together, these three features suggest that this variable may be an unrecognized member of the class of RR Lyrae stars that show the Blazhko effect. Against this is the fact that Schmidt[6] looked for the Blazhko effect in stars in his survey, found it in some of the stars, but found no evidence of it in DY And; our suggestion is therefore rather tentative and intended mainly to flag the star as worth monitoring.

Results for VX Tri

The currently accepted period for VX Tri, given by Meinunger[9], is 0·633076 days. It had been hoped to combine the results of the 2006–07 project with those from a previous project in 2003–04 in order to improve the period. However, it became clear that the results from the earlier project were too noisy to be useful. Analysis of the 2006–07 data alone proved completely consistent with Meinunger's result, so the only new result reported here is a new time of maximum, at HJD 2454079·526 ± 0·005 days. The O–C diagram from the GEOS website[10] has been updated with this additional point and is shown in Fig. 4. There is no evidence of secular period change.

Conclusions

Additional observations of DY Andromedae have produced a better light curve than previously published and, in conjunction with previous data, have enabled a slight refinement of the published period. Comparison of our data with other data available in the literature suggests that DY And may show the Blazhko effect, although there is insufficient evidence to show any periodic changes in the light curve. Clearly this is a very tentative suggestion until more data are available; we recommend further monitoring of this star.

A new time of maximum is reported for VX Tri, whose period seems to be stable.

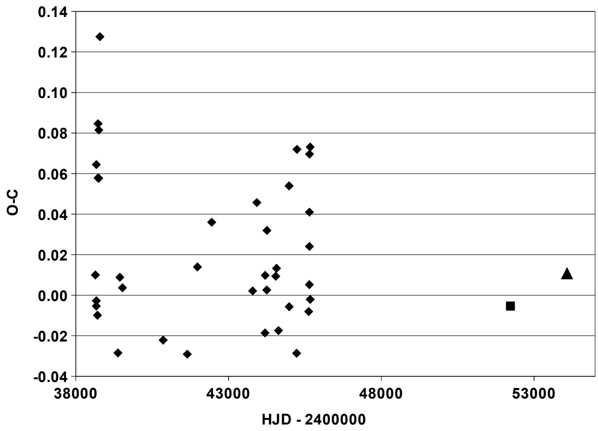

FIG. 4

The O – C diagram for VX Tri. The diamonds (from Meinunger; photographic observations) and the square (CCD observations) are taken from the GEOS database[10] and the triangle is our point.

Acknowledgements

The *Simbad*, *Vizier*, and *Aladin* services of CDS (Centre de Données Astronomiques de Strasbourg) were used to obtain finding charts and other information; we also made use of the GEOS RR Lyrae Database. We thank Chris Lloyd for providing the ROTSE-1 data, and a referee for helpful comments.

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 210: ψ^6 AURIGAE AND 34 PEGASI

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ψ^6 Aurigae is a fifth-magnitude late-type giant which is here shown for the first time to be a spectroscopic binary; it has a period of some 16 years and a near-circular orbit. 34 Peg is a fifth-magnitude F8 star a magnitude or so above the main sequence. It has a rich literature, having been drawn to attention as a probable member (which it probably is not) of the 'Hyades group'; despite such attention, until recently its radial velocity had not been measured since 1922 and the star had not been recognized as a spectroscopic binary. It is now found to have a moderately eccentric orbit with a period of about 2½ years.

ψ^6 Aurigae (HR 2487, HD 48781) — introduction

About 10° following β Aur is a small cloud of 5^{m}–6^{m} stars. Bayer's atlas[1] plots them — ten of them — as representing the Charioteer's whip, but it does not actually have the letter ψ there, although Bayer evidently intended it to be there because in his *Explicatio*[2] he remarked on it, "*Decem stellulae flagellum constituentes*". Bayer himself did not give the superscript numbers that have subsequently come into use to assign the same Greek-letter designation to more than one star (mostly in cases where it was impossible to tell to which of two or more stars Bayer intended his designation to apply). Baily[3], who is usually regarded as the authority for star identifications, has a footnote on his p. 67, saying that although the "usual manner of annexing the numerals is according to the right ascensions of the stars . . . [in the case of ψ Aurigae they] appear to be reckoned in the order of their north polar distances." But that is not so: the ten stars are in fact numbered in right-ascension order*, although it was not Baily, but seems to have been Argelander[6], who actually made the assignments. If indeed numbers had already been assigned to the stars in polar-distance order in Baily's time, they have been so thoroughly superseded by the Argelander numbering that they seem to have sunk without trace. Baily himself, after referring to the matter in the cited footnote, did not deign to designate any star as ψ Aur, either with or without a superscript numeral, in the body of his catalogue. That is the more surprising, given that, in another footnote on the same page, he mentions, seemingly disparagingly, that "The group of 10 stars, designated by BAYER as ψ Aurigae, has been wholly overlooked by FLAMSTEED, as there is no star designated by that letter in the British Catalogue." The writer's concern with ψ^6Aur was touched upon in Paper 193[7] of this series, in connection with the interesting double-lined system HD 47467 which is in the part of the sky that is so thickly populated by the ψ Aur clan: the hope

*Almost! — ψ^2 and ψ^3 are 'wrong'. ψ^{10} is no longer in Auriga but was transferred, when the constellation boundaries were defined[4], to Lynx, in which constellation Flamsteed[5], with more than 200 years of foresight, had already invested it with the designation 16 Lyncis in seeming defiance of Bayer.

is there expressed that ψ^6 would feature in the series in due course, "perhaps around no. 210". So that hope is being honoured here, although the much more muted possibility that was indicated at the same time, that ψ^1 might also feature hereabouts, is not.

The magnitude and colours of ψ^6 Aur have been published by Argue[8] and Eggen[9], with results close to $V = 5^{m}\cdot21$, $(B-V) = 1^{m}\cdot13$, $(U-B) = 1^{m}\cdot04$. The spectral type is given as K0 in the *Henry Draper Catalogue*[10], and that type was agreed at Mount Wilson, where Adams *et al.*[11] also provided a luminosity estimate of $M_V = +0^{m}\cdot1$. The earliest spectroscopic luminosity estimate, however, came from the Dominion Astrophysical Observatory in Victoria, B. C. (the DAO), where Young & Harper[12], working collaboratively but independently, gave estimates of $+0^{m}\cdot7$ and $+1^{m}\cdot2$, respectively. (In their paper the star is identified as Boss[13] 1728 and as 57 Aur but not as ψ^6 Aur.) The first classification on the MK system was published by Miss Roman[14], as K1 III 'strong-line'. Nearly 30 years later, Keenan & Pitts[15] returned to the *HD* temperature type with their K0 III. That type was reaffirmed by Keenan and his collaborators subsequently[16,17], but in his final reconsideration[18] Keenan made a compromise with Miss Roman's type by putting it at K0·5 III.

Meanwhile, astronomers had been concerned to establish the metallicities of stars by means both of spectroscopy and of narrow-band spectrometry. Mme. Cayrel[19] obtained spectra of ψ^6 Aur at 9·7 Å mm^{-1} (blue) and 12·4 (red) with the OHP 1·93-m telescope; she found abundances of the elements from sodium to silicon and from calcium to zinc, plus strontium and zirconium, all very uniformly enhanced by 0·2 dex with respect to the Sun. Williams[20], on the other hand, found iron and sodium to be depleted by about 0·3 dex on the basis of narrow-band observations made with the present author's spectrometer at the Cambridge 36-inch telescope. The star was on a number of programmes carried out with that instrument, and seemed to be quite a normal late-type giant. Hansen & Kjærgaard[21] deduced $M_V = -0\cdot2$ and [Fe/H] $= -0\cdot14$ from photometric indices obtained in the Copenhagen narrow-band system[22] by Dickow *et al.*[23].

ψ^6 Aurigae — radial velocities and orbit

The radial velocity of ψ^6 Aur (as of so many other bright stars) was first measured at the Lick Observatory with the *New Mills Spectrograph*[23] on the 36-inch refractor nearly a century ago. Only three observations[24] were made; their mutual agreement is much worse than normally characterizes Lick velocities, but no announcement was made of variability, probably owing to the paucity of measurements. That most of their scatter is due to actual variation of the velocity is demonstrated by the fact that the sum of the squares of their deviations from the orbit found below is 1·6 (km s^{-1})^2, whereas the sum obtained from their discrepancies from their own mean is 11·5 (km s^{-1})^2.

Shortly after the first Lick measurement was obtained, Plaskett *et al.*[25] measured the velocity of ψ^6 Aur six times in the course of the first observing programme with the then-new 72-inch DAO reflector. The observations agreed with one another about as well as measurements made there normally did, and in fact their scatter is not significantly reduced when referred to the orbit because they were all made at nearly the same phase, within an interval of less than a year — scarcely more than 5% of the orbital period. The DAO paper[25] was published several years before the catalogue[24] of Lick observations and was therefore the first to present any radial velocities of ψ^6 Aur.

A mean velocity from three Mount Wilson plates was given by Christie & Wilson[26]; these measurements were published individually much later by Abt[27].

No fewer than 18 observations were made of ψ^6 Aur by Beavers & Eitter[28] with the photoelectric radial-velocity spectrometer that they constructed and operated at the Fick Observatory of Iowa State University. Their paper shows that the r.m.s. deviation from the mean of their measurements was 3·2 km s^{-1}, whereas the value to be expected from their assessment of their errors of observation was only 1·2 km s^{-1}. Where the ratio of those two quantities exceeded 3, the star concerned was declared variable in velocity; in the case of ψ^6 Aur, where the ratio did not quite reach the critical value, the star was noted as 'VAR?' in the summary Table 5. It also features in a table (Table III) of 'Probable Variable Velocity Stars', with the comment 'Slow', in a paper that Beavers[29] presented at an *IAU Colloquium*.

Two velocities obtained with the Haute-Provence (OHP) *Coravel* were reported as a mean by de Medeiros & Mayor[30]; they were subsequently made available as individual measurements through the Centre de Données Stellaires. In the listing by Famaey *et al.*[31] of nearby late-type giant stars, ψ^6 Aur is shown as being a binary with an undetermined orbit and a mean velocity of –6·51 ± 0·30 km s^{-1}. Their information came from the unpublished data base, held in Geneva, of the radial velocities measured with the OHP *Coravel*. Since the only published *Coravel* velocities of ψ^6 Aur are the two from de Medeiros & Mayor[30], which are not in serious mutual disagreement, it seems very likely that the evidence upon which Famaey *et al.* relied came from such of the present author's radial velocities as were to be found on the Geneva data base.

All of the radial velocities thus published are listed in chronological order in Table I here (two Mount Wilson ones made on the same evening have been averaged and treated as one); in an effort to place them on the Cambridge zero-point they have all been adjusted by +0·8 km s^{-1}, and the DAO and Mount Wilson ones have additionally been altered by the corrections noted in the *Radial Velocity Catalogue*[32] (Table 3 on p. vi) for measurements of K-type stars at those observatories. They are followed in the Table by the writer's own observations that were deliberately made to determine the orbit, starting in 1993 when the star was belatedly selected for observation from the work of Beavers & Eitter[28]. There are 15 measurements that were made on a guest-investigator basis with the OHP *Coravel*, two made at the DAO similarly, and 49 obtained with the *Coravel* instrument at the 36-inch reflector on the home site at Cambridge.

Only the Cambridge measurements have been given full weight in the solution of the orbit. To bring the variances of the different sources into approximate equality, the OHP and recent DAO velocities have been given half-weight, the Lick ones ⅛, and the Ames ones 0·02 (halved in the cases of those marked as quality B by their authors). The DAO and Mount Wilson velocities have not been utilized in the solution at all. The orbit that results is illustrated in Fig. 1, and its elements are as follows:

P	=	5996 ± 26 days	$(T)_1$	=	MJD 52556 ± 310*
γ	=	–6·62 ± 0·04 km s^{-1}	$a_1 \sin i$	=	267 ± 4 Gm
K	=	3·24 ± 0·04 km s^{-1}	$f(m)$	=	0·0211 ± 0·0009 $M_\odot$
e	=	0·044 ± 0·014			
ω	=	222 ± 19 degrees	R.m.s. residual (wt. 1)	=	0·23 km s^{-1}

*The epoch of periastron is poorly defined owing to the smallness of the eccentricity. The value of T_0, MJD 54862 ± 21, is therefore given as well as that of T.

TABLE I

Radial-velocity observations of ψ^6 Aurigae

Except as noted, the sources of the observations are as follows:
1976–1984 — Iowa State University[28] *(weighted 0·02 in orbital solution);*
1997–2009 — Cambridge Coravel (weight 1)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
1917 Dec. 31·42★	21593·42	−9·3	$\bar{5}$·836	+0·4
1919 Dec. 2·46†	22294·46	−7·5	$\bar{5}$·953	+2·2
1920 Jan. 6·35†	22329·35	−7·6	$\bar{5}$·959	+2·0
Feb. 10·14†	364·14	−12·3	·965	−2·7
21·17†	375·17	−9·8	·967	−0·2
24·16†	378·16	−8·8	·967	+0·8
Oct. 9·57†	606·57	−6·4	$\bar{4}$·005	+2·7
1921 Mar. 3·28★	22751·28	−9·0	$\bar{4}$·029	−0·3
1923 Mar. 6·28★	23484·28	−5·0	$\bar{4}$·152	+1·1
1926 Nov. 17·41‡	24836·41	+4·3	$\bar{4}$·377	+7·8
1928 Nov. 2·51‡	25552·51	−1·1	$\bar{4}$·497	+3·2
1976 Dec. 12·31	43124·31	−3·8	$\bar{1}$·427	−0·2
15·41	127·41	+0·2	·428	+3·8
1978 Jan. 23·28	43531·28	−5·2	$\bar{1}$·495	−1·0
Mar. 9·10	576·10	−0·6	·502	+3·7
Nov. 8·41	820·41	−6·6	·543	−1·7
Dec. 10·33	852·33	−3·5	·549	+1·5
1979 Mar. 15·11	43947·11	−4·6:	$\bar{1}$·564	+0·6
Dec. 15·31	44222·31	−2·5	·610	+3·6
1980 Dec. 19·26	44592·26	−7·8	$\bar{1}$·672	−0·6
1981 Feb. 5·20	44640·20	−4·3	$\bar{1}$·680	+3·1
1982 Jan. 14·24	44983·24	−8·0	$\bar{1}$·737	+0·4
Feb. 2·22	45002·22	−8·4	·740	+0·1
27·13	027·13	−8·0	·744	+0·6
1983 Jan. 27·21	45361·21	−9·0:	$\bar{1}$·800	+0·4
Feb. 1·18	366·18	−9·2:	·801	+0·2
1984 Jan. 6·25	45705·25	−10·0	$\bar{1}$·858	−0·1
25·24	724·24	−10·2	·861	−0·3
Feb. 14·16	744·16	−8·8:	·864	+1·1
1989 Feb. 16·88¶	47573·88	−6·0	0·169	−0·2
Nov. 28·13¶	858·13	−5·2	·217	−0·3
1993 Feb. 12·95§	49030·95	−3·7	0·412	−0·1
Mar. 24·92§	070·92	−3·5	·419	+0·1
Dec. 27·06§	348·06	−3·7	·465	+0·2
1994 Feb. 17·04§	49400·04	−3·7	0·474	+0·3
May 1·82§	473·82	−4·0	·486	+0·1
Aug. 5·15§	569·15	−3·9	·502	+0·4
Dec. 13·13§	699·13	−5·0	·524	−0·4

TABLE I (*continued*)

Date (UT)		MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
1995	Dec. 27·07§	50078·07	−6·1	0·587	−0·5
1996	Apr. 3·89§	50176·89	−5·9	0·603	0·0
	Dec. 16·11§	433·11	−6·9	·646	−0·2
1997	Jan. 25·07§	50473·07	−6·9	0·653	0·0
	Mar. 2·95	509·95	−6·6	·659	+0·4
	May 2·88	570·88	−7·1	·669	+0·1
	July 20·13§	649·13	−7·9	·682	−0·5
	Sept. 11·19§	702·19	−8·0	·691	−0·4
	Dec. 22·11§	804·11	−8·4	·708	−0·5
1998	May 1·82§	50934·82	−9·0	0·730	−0·7
1999	Apr. 2·24‖	51270·24	−8·7	0·786	+0·5
	Nov. 4·47‖	486·47	−9·4	·822	+0·2
	Dec. 29·09	541·09	−9·5	·831	+0·2
2000	Feb. 11·99	51585·99	−9·8	0·838	−0·1
	Mar. 1·92	604·92	−9·5	·841	+0·3
	Apr. 6·90	640·90	−9·6	·847	+0·2
	Sept. 25·19	812·19	−10·2	·876	−0·3
	Nov. 14·14	862·14	−10·3	·884	−0·3
2001	Jan. 7·07	51916·07	−9·9	0·893	+0·1
	25·82	934·82	−9·8	·896	+0·2
	Mar. 10·97	978·97	−9·8	·904	+0·2
	Apr. 28·84	52027·84	−9·6	·912	+0·3
	Aug. 21·15	142·15	−10·1	·931	−0·2
	Oct. 4·18	186·18	−10·3	·938	−0·5
	Nov. 1·14	214·14	−9·8	·943	0·0
2002	Jan. 1·10	52275·10	−10·0	0·953	−0·3
	Mar. 7·93	340·93	−9·3	·964	+0·3
	Sept. 28·21	545·21	−9·3	·998	−0·1
	Nov. 15·05	593·05	−9·0	1·006	+0·1
2003	Jan. 5·13	52644·13	−9·0	1·015	−0·1
	Feb. 15·04	685·04	−8·8	·022	0·0
	Apr. 4·90	733·90	−8·5	·030	+0·2
	Sept. 24·20	906·20	−8·2	·058	−0·1
	Nov. 28·09	971·09	−8·0	·069	−0·1
2004	Jan. 17·12	53021·12	−7·5	1·078	+0·2
	Mar. 13·91	077·91	−7·7	·087	−0·2
	May 3·85	128·85	−7·1	·096	+0·2
	Sept. 14·19	262·19	−7·1	·118	−0·2
	Nov. 13·20	322·20	−6·7	·128	0·0
2005	Jan. 6·09	53376·09	−6·5	1·137	0·0
	Mar. 18·93	447·93	−6·0	·149	+0·2
	May 14·86	504·86	−5·9	·158	+0·1
	Sept. 29·22	642·22	−5·5	·181	0·0
	Nov. 19·14	693·14	−5·4	·190	0·0
2006	Jan. 28·98	53763·98	−5·0	1·201	+0·2
	Apr. 3·91	828·91	−4·9	·212	+0·1
	Sept. 21·20	999·20	−4·5	·241	0·0
	Nov. 26·15	54065·15	−4·1	·252	+0·3

TABLE I (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2007 Jan. 23·02	54123·02	−4·4	1·261	−0·2
Mar. 21·90	180·90	−4·1	·271	0·0
May 24·88	244·88	−3·9	·282	+0·1
Oct. 5·22	378·22	−4·3	·304	−0·5
Dec. 8·14	442·14	−3·7	·315	0·0
2008 Feb. 11·02	54507·02	−3·6	1·325	0·0
Apr. 1·89	557·89	−3·5	·334	+0·1
Oct. 9·22	748·22	−3·9	·366	−0·4
2009 Jan. 3·07	54834·07	−3·6	1·380	−0·1
Mar. 5·95	895·95	−3·4	·390	+0·1
May 3·87	954·87	−3·3	·400	+0·2

*Lick observation[24]; weight ⅛.
† DAO observation[25]; weight 0.
‡ Mount Wilson observation[26,27]; weight 0.
§ Observed with Haute-Provence *Coravel*; wt. ½.
¶ ditto, observation by de Medeiros & Mayor[30].
‖ Observed with DAO 48-inch telescope; wt. ½.

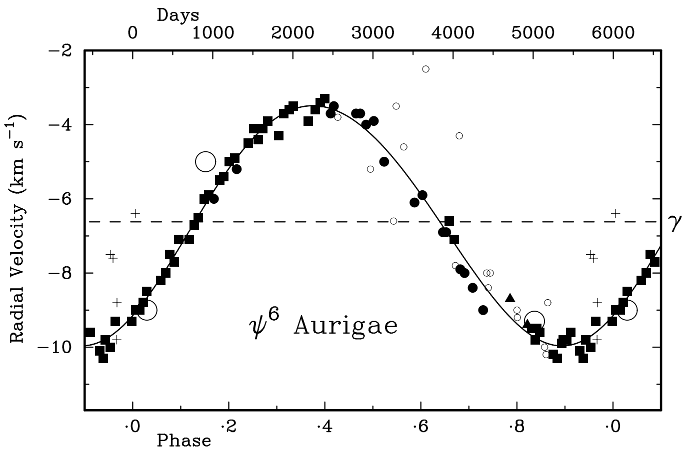

FIG. 1

The observed radial velocities of ψ^6 Aurigae plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The principal contributions to the solution of the orbit are from the measurements plotted with filled symbols, *viz.*, Cambridge *Coravel* (squares), OHP *Coravel* (circles), and DAO spectrometer (triangles) (the last two sources half-weight). Also included in the solution are the three early Lick velocities[24] plotted as large open circles (weight ⅛) and the 18 obtained by Beavers & Eitter[28] at Ames (weight 0·02), plotted as small open circles (two are off the top of the plot). Not used in the solution are the six DAO photographic velocities[25] (plusses; one is off the bottom of the plot) and the Mount Wilson measures[26,27], neither of which is within the limits of the graph.

The writer is a bit apologetic over the non-uniform phase coverage of the orbit — the rising branch, which has been traversed during the past ten years since the observer had the routine use of his own *Coravel*, is obviously much better observed than the descending one. However, both nodes have been well covered, and the period is quite accurately determined, so the trajectory of the velocity's descent is already so well determined that little more than cosmetic improvement could be gained from retaining the star on the observing programme for the further 2500 days that would be required. It may be mentioned that the period obtained just from the author's own observations together with the two earlier *Coravel* velocities listed by de Medeiros & Mayor[31] is 5915 ± 67 days; when plotted on that period, all three of the Lick measurements[24] fall decisively to the left of the velocity curve, fully warranting the change (by a little over 1 σ) and improved formal precision of the finally adopted period.

It may be noticed that the orbital eccentricity is barely three times its standard error. The point has been pursued by comparing the sums of the weighted squares of the deviations of the total of 89 accepted observations with the eccentricity allowed as a free parameter as in the adopted solution (4·62 (km $s^{-1})^2$) and with zero eccentricity imposed (5·13 (km $s^{-1})^2$). Application of Bassett's second statistical test[33] to those numbers shows that $F_{2,83} \sim 4{\cdot}40$, which though significant at the 2½% level ($F = 3{\cdot}86$) is not so at 1% (4·87). Thus it could be argued that there is slight doubt as to whether the orbit really departs from the circular form, but (especially since there is no possible reason to suppose that zero eccentricity is in any sense favoured at periods as long as that of ψ^6 Aur), there is no hesitation on the part of the author in adopting the eccentric solution.

34 Pegasi (HR 8548, HD 212754) — introduction

At a declination of less than +5°, 34 Peg is the next-to-southernmost Flamsteed-numbered star (after 11 Peg) in its constellation; it is well to the south-west of the Great Square. It arose on the writer's observing programme as one of many stars that were placed on it, when the Cambridge *Coravel* became operational in late 1999, to make an observational check on the proposal by Suchkov & McMaster[34] that the *Hipparcos Catalogue* included very many unrecognized double-lined F stars. Not a few F stars were found by those authors to exhibit considerable 'over-luminosity', in the sense that their *Hipparcos* parallaxes indicated absolute magnitudes significantly brighter than would be predicted by uvbyβ photometry. An obvious source of such over-luminosity would be duplicity, which would make the objects brighter without involving a corresponding change in their Strömgren indices derived from the photometry.

Among a set of 111 bright examples of objects whose over-luminosity was as much as half a magnitude or more, and of which 83 were the subject of new radial-velocity observations made with the *Coravel*, 58% proved[35] to be binaries. However, not all the binaries were double-lined, and most of the remainder of the sample showed constant velocities, so it seemed that duplicity was not the whole story about over-luminosity although it did account for a substantial proportion of the sample. One of the stars discovered to be binary, albeit single-lined, was 34 Peg. At the conclusion of the initial programme, which lasted only two years, it was one of six binaries whose orbits had not yet been seen round a complete cycle, and it was therefore retained on the ordinary spectroscopic-binary programme to be watched systematically and written up later at the author's convenience. Now, after almost ten years, it has been seen round nearly four cycles and its orbit is quite well determined. In the interim, Goldin & Makarov[36] have managed to derive an astrometric orbit from the original data from which the *Hipparcos* catalogue was produced. They found the orbital period to be 878^{+65}_{-57} days, the same as is found in the present paper within its uncertainty. Most of the other elements have such large uncertainties as to be effectively indeterminate, apart from the inclination, which is close to edge-on (93^{+6}_{-5} degrees). The time of periastron is given as 420 days; the zero-point of the time-scale appears not to be specified, and seems unlikely to be that of the Julian-Day (or even MJD) era.

34 Peg has a very faint visual companion which is definitely associated with the principal star because it shares the large proper motion of just over 0″·3 annually. The faint star was discovered by Burnham[37] in 1874, almost casually, when on a visit to Washington he was invited to observe for a single night with the then-new 26-inch USNO refractor. (His account of the power and excellence of the telescope makes inspiring reading!) Merely *en passant* to the object (now called HD 212923, less than 20′ distant from 34 Peg) that he really intended to scrutinize because when observing with his own 6-inch refractor he had suspected its duplicity, he noticed that 34 Peg possessed what for others would be an invisible companion! The system carries his 'discoverer's designation' β 290, and features in his great 1906 catalogue[38] of double stars as BDS 11716 and in Aitken's subsequent one[39] as ADS 15935. The more extravagant estimates of the Δm between the components of the double star are probably to be discounted, because Kuiper saw it well enough at one time to try to obtain its spectrum, which he classified 'K4::' according to the posthumous listing of his (Kuiper's) very numerous classifications that was public-spiritedly compiled by Bidelman[40]. Vaughan & Preston[41] also referred to the companion as K4, but since they were not obtaining spectra they must have been quoting it — presumably they were aware then of Kuiper's classification. They were able to see it well enough with the Mount Wilson 60-inch reflector to attempt a measurement with their '*HK* spectrometer'.

Photometry of 34 Peg has been obtained by Cousins[42], Johnson *et al.*[43], Eggen[44], and Penston[45], who gave mutually accordant values close or equal to $V = 5^{m}{\cdot}75$, $(B-V) = 0^{m}{\cdot}52$, $(U-B) = 0^{m}{\cdot}03$. The measurements doubtless include the light of the visual companion, but since there is a brightness difference of something like five magnitudes the effect of the companion is practically negligible. There are also in the literature *dis*cordant values of $V = 5^{m}{\cdot}48$, $(B-V) = 0^{m}{\cdot}38$ published by Häggkvist & Oja[46]. That fact was noted already by Penston in the paper[45] on her own photometry. It was subsequently listed by Mermilliod[47] as one of a large number of errors that he came across, but could not correct, in the compilation that was eventually published as a large and useful book[48]. He[47] stated that the errors "cannot be corrected" — but the one of present concern can! The offending paper certainly gives the constellation name, Bright Star number, and position of 34 Peg, and the spectral type of dF5 that was often listed for it at that time, probably copied from the *Radial Velocity Catalogue*[32] — but the magnitude and colour are exactly those of the adjacent star 37 Peg, which is less than a degree following and differs by only two minutes of arc in declination from 34 Peg: it is an obvious case of misidentification.

Even before the relevant volume of the *Henry Draper Catalogue* had been published, 34 Peg had been classified both at Mount Wilson[49] and at the DAO[12]. Adams & Joy[49], in their earliest work (1917) on spectroscopic parallaxes, found the star to have an absolute magnitude of $+4^{m}{\cdot}1$. They put the spectral type at F5 by 'estimation' and at F6 by 'measurement'; the first method was what has since been regarded as the usual one, of visual comparison of the spectrum with standards, whereas the latter involved comparison of the strengths of the Balmer lines Hλ and Hδ with specified nearby Fe I lines on microdensitometer tracings of the spectra. An enlarged and revised Mount Wilson catalogue in 1921 gave both the estimated and measured types as F7, and listed the absolute magnitude as $+3^{m}\cdot9$. In 1923 Rimmer[50], working with a telescope of only 12 inches' aperture at the Norman Lockyer Observatory, found the spectroscopic luminosity to be $+3^{m}\cdot5$ and gave the spectral type as G0; shortly afterwards Young & Harper[12], at the DAO, gave estimates of $+4^{m}\cdot1$ and $+3^{m}\cdot5$ for the luminosity and F8 for the type. A further catalogue[11] from Mount Wilson in 1935 gave $+3^{m}\cdot5$ and F5, and it was no doubt on that basis that the *Radial Velocity Catalogue*[32], which was compiled at Mount Wilson, recorded the type as dF5.

In more recent times a substantial literature has accumulated on 34 Peg, largely (it seems) because van Bueren[51] listed it, with 50 other stars, in a table of stars — other than recognized members of the Hyades cluster — "with velocity vectors pointing into a sphere of 10 km.sec^{-1} around the velocity of the Hyades". Van Bueren himself did not claim as original the idea of the existence of a 'Taurus stream' distributed all over the sky, and indeed attributed it to Strömberg[52]; it seems possible that a sufficiently careful historical review might trace the seeds of the idea back to Kapteyn if not indeed beyond.

Eggen, of course, was keen to include 34 Peg in his various papers on the 'Hyades group' or 'Hyades supercluster'. In 1960 he[53] determined that, if a member of the group, it had to have a parallax of $0''\cdot032$ and a corresponding absolute magnitude of $+3^{m}\cdot3$. He considered its 'observed' absolute magnitude (a weighted mean of trigonometrical measurements and spectroscopic estimates) as $+3^{m}\cdot1$ — satisfactorily close — although it is difficult to see how he could have obtained a spectroscopic M_V of $+2^{m}\cdot8$ (which we now realize to be exactly correct!) from the spectral type of dF5 that he quoted. He used the radial velocity of $-17\cdot8$ km s^{-1}, with quality b, listed in the *Radial Velocity Catalogue* as a mean of the available data (slightly 'corrected'), from the DAO and Mount Wilson.

Breger[54] obtained an M_V of $3^{m}\cdot6$ from the Strömgren c_1 index, and agreed that "the motion is close to that of the Hyades cluster". He also remarked, in a *Note added in proof* that was galvanized by his receipt of a preprint from Eggen, that "it is now clear that the kinematical method of finding Hyades group members results in a large number of spurious members ...".

In 1970, and again in 1971, Eggen[55–57] reaffirmed the inclusion of 34 Peg in the Hyades group, although the 'computed' absolute magnitude required for membership had changed to $+3^{m}\cdot6$. In the latter year, too, he seemed to say (his Table III) that 34 Peg stood $1^{m}\cdot8$ above the 'zero-age main sequence' — it looks as if the relevant main sequence was being defined by Strömgren indices and was not the normal M_V–type or M_V–$(B-V)$ sequence. Returning to the issue in 1982, Eggen[58] gave the distance modulus of 34 Peg as $2^{m}\cdot21$ and its absolute magnitude as $+3^{m}\cdot55$; in 1984 (in a paper[59] littered with mistakes, one of which was to call the star of present interest 35 Peg), he gave almost the same numbers, and listed the radial velocity corresponding to group membership as -22 km s^{-1} and the observed value as -18. In 1992[60] those numbers had changed, the required value becoming $-20\cdot6$ and the 'observed' one $-20\cdot0$ km s^{-1}, although no additional radial velocities had been published in the interim. It has been carefully documented elsewhere[61] how not only theoretical but even 'observed' quantities could change in Eggen's hands in such a way as to support whatever theory he wished to advance. The needed ($+3^{m}\cdot65$) and observed ($+3^{m}\cdot3$) absolute magnitudes were, however, almost unchanged. The parallax that has now been determined by *Hipparcos*, close to $0''\cdot025$, corresponds to a distance modulus of $2^{m}\cdot98 \pm 0^{m}\cdot15$, and so to $M_V = +2^{m}\cdot77$, with the same uncertainty: the star *is*, therefore, more than a magnitude above the main sequence, especially as its received type is now about F8 and not F5, and the much higher transverse velocity indicated by its large proper motion at the unexpectedly great distance ought surely to imply that the star has nothing to do with the Hyades at all. All the same, Montes *et al.*[62], writing post-*Hipparcos*, in assessing membership of the group, gave 34 Peg a 'yes' on the correctness of what they termed its 'peculiar velocity', by which they meant its proper motion *perpendicular to the convergent point*, and rejected it only on the radial component of its motion.

There have been several independent MK classifications of 34 Peg. The earliest appears to be that by Harlan[63], of F8 IV; there followed types of F7 V by Cowley & Bidelman[64], F8 IV–V by Abt[65], and that same type by Gray, Napier & Winkler[66]. In seeming support for the ideas that the star was a Hyades member and that the Hyades are metal-rich, substantial enrichments ([Fe/H] ~ +0·4) were at first found[67,68] for 34 Peg; later investigations, however, put the logarithmic metallicity at[69] or close[70] to zero, or even slightly below[71,72].

In the wake of the discovery of the extraordinary dip in lithium abundances among Hyades early-F stars in comparison with both earlier and later spectral types, much interest developed in lithium abundances, and then in beryllium too; those interests are reflected in the case of 34 Peg in a number of investigations. The first of them, in 1988, was by Boesgaard & Budge[70], who showed that lithium was heavily depleted ($\log N(\mathrm{Li}) = 1{\cdot}67$ on the usual scale in which $\log N(\mathrm{H}) = 12$) although it had an effective temperature (6160 K) just where, in the actual Hyades, lithium abundances reach a maximum, at $\log N(\mathrm{Li}) \sim 3$, on the cool side of the 'lithium gap'. Analogous conflicts arose for other stars, and those authors concluded that "The Hyades Moving Group does not appear to be a cohesive or coeval group linked to the Hyades, as judged by the scatter in the Li and the Fe abundances." The 'writing was on the wall', therefore, if not for the Hyades group as a whole at least for 34 Peg's membership of it. Deliyannis *et al.*[73] (a consortium that included Boesgaard) later derived a still lower $\log N(\mathrm{Li})$, of 1·17, for 34 Peg, and also found the λ 3130-Å Be II feature to be substantially weakened; actual tracings of the Li and Be regions of their spectra of 34 Peg appear as illustrations in their paper.

Much interest has also been shown in the rotational velocity and period of 34 Peg. In the era of photographic spectroscopy (recalled with due nostalgia by the present writer, who could also claim to have been one of the first to forsake it, at least for some purposes), it was a 'rule of thumb' that the smallest projected rotational velocity that could be recognized and measured by its effect in widening the spectral lines was numerically equal to the dispersion in Å mm^{-1}. The veracity of that rule is neatly illustrated by the fact that whereas Wilson[74], working with the excellent 10·4-Å mm^{-1} camera of the Mount Wilson coudé, could do no more than place 34 Peg in his 'rotation group 0', meaning $v \sin i \leq 10$ km s^{-1}, shortly afterwards Kraft[75] was able to give a $v \sin i$ of 7 km s^{-1} on the basis of a spectrogram taken at 4·5 Å mm^{-1}. Later, a careful investigation by Soderblom, Pendleton & Pallavicini[76], based on reticon spectra obtained with the ESO coudé auxiliary telescope at a nominal resolving power of 10^5, yielded for 34 Peg a $v \sin i$ of $7{\cdot}9 \pm 0{\cdot}7$ km s^{-1}.

From the late 1960s, 34 Peg was observed on the '*HK* project', begun by O. C. Wilson at the mountain observatory of the same name, that monitored photoelectrically the strengths of the Ca II emission lines in the spectra of many late-type stars. In an initial report, after a decade of observation at a frequency of several per season, Wilson[77] reported that in the case of 34 Peg there was no significant variation. Later, the project became the full-time occupation of the 60-inch reflector at Mount Wilson; stars could then be monitored almost nightly, and (as Wilson had clearly foreseen) the observations could then not only demonstrate analogues of the solar sunspot cycle but also demonstrate stellar rotational periods through azimuthal non-uniformity in probable plage-like regions of the stellar surfaces. The first report[78] of such rotational periods said that 34 Peg showed a period of 13 days, which was not visible just upon inspection of a graph of *HK* intensity against time but was brought up out of the noise by an auto-correlation analysis. Later, however, that period was not confirmed: the authors[79] (a syndicate largely overlapping, but not identical to, that of ref. 78), referring to 34 Peg and one other star, said, "Both these standard stars have extremely weak chromospheric emission and the periods which were marginally significant are now considered insignificant". It is easier to start a hare than it is to catch it! The originally proposed rotation period of 13 days has been repeatedly quoted and misquoted in the literature, sometimes[80] just as 13, but in other cases with exaggerated precision as 13·0 days[81,82] or even 13·00 days[83], and in the Eggen paper[59] that is "littered with mistakes" entirely erroneously as 30 days.

Next, however, a 'calculated' rotation period of 11·1 days was listed[84] on the basis of an (admittedly rather close) empirical relationship between rotation periods (where they could be established observationally), the mean nett chromospheric emission (written as $<R'_{HK}>$), and $(B-V)$. Much later a greatly enlarged syndicate[85], led by Baliunas, discussing the Mount Wilson results, claimed that the seasonal means of the emission intensities of 34 Peg showed a rising trend, the implication being that the star might yet show an analogue of the solar cycle. Then, in a very short paper in the *Letters* section of the *Astrophysical Journal*, Baliunas, Sokoloff & Soon[86] listed in a table, without comment, a *measured* rotational period of 12 days. That is where the matter seems to rest at the moment, save that Saar & Brandenburg[87] rejected the idea of there being a rising trend in the emission levels, saying that in their view "Long-term trends were rejected for HD … and 212754 [*i.e.*, 34 Peg]. In all these cases, the trend amplitude seems negligible, or so small as to be unreliably detected."

34 Pegasi — radial velocities and orbit

The first radial velocities measured for 34 Peg came from the same authors at Mount Wilson, Adams & Joy[88], as had been concerned with the first spectroscopic parallaxes — indeed, the same plates must have been used for both purposes. The mean velocity of 34 Peg, from five plates, was found to be $-18·2$ km s^{-1}, with a 'probable error' of the mean of 1·2 km s^{-1}. Nearly 50 years later Abt[89] listed the five measurements individually. (Their mean, from Abt's listing, appears to be $-18·5$ km s^{-1}.) Three measurements, with a stated mean of $-19·0$ km s^{-1} (although the present writer's arithmetic indicates $-19·7$), were made by Harper[90] at the DAO — again, doubtless on the same plates as were used to determine spectroscopic parallaxes[12]. Although the mean values were in agreement, the individual velocities were not in very good accord; the Mount Wilson ones had a range of about 10 km s^{-1}, and DAO ones of six, but by the standards of the day they were acceptable and did not clearly demonstrate any real variation of velocity. There were enough of them to warrant the assignment of quality b to the overall mean of $-17·8$ km s^{-1} that was given, after small corrections, in the *Radial Velocity Catalogue*[32].

There, astonishingly enough, the matter seems to have rested right up to the time (2003) of Griffin & Suchkov[35]: after the DAO plates were taken in 1922, it appears that no further velocities were measured for 34 Peg until the writer

Table II

Radial-velocity observations of 34 Pegasi

Except as noted, the observations were made at Cambridge

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O–C)* *km s*$^{-1}$
1912 Aug. 27·31*	19641·31	−16·0	$\overline{35}$·874	+0·7
1913 July 19·44*	19967·44	−22·0	$\overline{34}$·224	−8·6
Aug. 22·42*	20001·42	−16·5	·260	−3·6
1917 Sept· 4·37*	21475·37	−11·7	$\overline{33}$·843	+3·9
Oct. 7·27*	508·27	−19·8	·879	−2·9
1922 Aug· 29·41†	23295·41	−19·4	$\overline{31}$·798	−5·0
Sept. 14·30†	311·30	−18·9	·815	−4·1
Oct. 1·26†	328·26	−15·4	·833	−0·1
2000 Jan. 15·71	51558·71	−15·0	0·147	+0·2
Sept. 4·04	791·04	−11·6	·397	+0·3
17·06	804·06	−12·2	·411	−0·4
Oct. 8·94	825·94	−11·7	·434	+0·1
Dec. 6·79	884·79	−11·8	·498	0·0
2001 Jan. 6·73	51915·73	−11·6	0·531	+0·2
May 29·13	52058·13	−12·2	·684	+0·5
July 1·10	091·10	−13·6	·719	−0·5
Aug. 1·09	122·09	−13·4	·752	+0·2
Sept. 29·95	181·95	−14·6	·817	+0·3
Oct. 9·00	191·00	−15·8	·826	−0·7
30·89	212·89	−15·4	·850	+0·5
Nov. 22·81	235·81	−16·0	·875	+0·8
Dec. 14·82	257·82	−18·0	·898	−0·2
2002 Jan. 2·76	52276·76	−18·5	0·918	+0·3
June 23·09	448·09	−16·9	1·102	+0·1
July 21·07	476·07	−15·9	·133	−0·2
Aug. 13·06	499·06	−15·0	·157	−0·1
28·99	514·99	−14·2	·174	+0·2
Sept. 23·96	540·96	−13·5	·202	+0·3
Oct. 18·97	565·97	−13·2	·229	+0·1
Nov. 12·89	590·89	−13·5	·256	−0·6
Dec. 9·83	617·83	−12·5	·285	+0·1
2003 Jan. 5·73	52644·73	−12·3	1·314	0·0
June 28·09	818·09	−12·2	·500	−0·4
July 21·07	841·07	−12·0	·524	−0·2
Aug. 20·09	871·09	−12·1	·557	−0·2
Sept. 15·99	897·99	−12·0	·586	0·0
Oct. 16·95	928·95	−12·1	·619	+0·1
Nov. 12·88	955·88	−12·5	·648	−0·1
Dec. 7·79	980·79	−12·4	·674	+0·2
2004 Jan. 2·71	53006·71	−12·9	1·702	0·0
June 22·10	178·10	−17·2	·886	+0·1
July 5·11	191·11	−17·5	·900	+0·4
Aug. 8·14	225·14	−20·4	·937	−0·7
17·12	234·12	−20·3	·947	−0·1
31·03	248·03	−21·2	·961	−0·3
Sept. 14·00	262·00	−21·3	·976	+0·1
25·98	273·98	−21·2	·989	+0·5
Oct. 5·98	283·98	−21·9	2·000	−0·2
18·93	296·93	−21·4	·014	0·0

TABLE II (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O–C)* *km s⁻¹*
2004 Nov. 4·90	53313·90	–21·0	2·032	–0·2
13·85	322·85	–19·8	·042	+0·5
26·81	335·81	–19·7	·056	–0·2
Dec. 5·78	344·78	–19·1	·065	–0·1
16·76	355·76	–18·2	·077	+0·1
26·73	365·73	–18·0	·088	–0·3
2005 June 23·09	53544·09	–12·3	2·279	+0·3
Sept. 3·03	616·03	–12·0	·357	0·0
Oct. 1·93	644·93	–11·8	·388	+0·1
2006 Oct. 21·84	54029·84	–14·5	2·801	0·0
Dec. 2·82	071·82	–16·5	·846	–0·8
3·80	072·80	–15·7	·847	+0·1
2007 July 27·11	54308·11	–17·1	3·100	0·0
Sept. 8·04	351·04	–15·5	·146	–0·2
2008 June 26·11	54643·11	–11·8	3·460	0·0
2009 Aug. 28·05	55071·05	–19·1	3·919	–0·3
Sept. 4·03	078·03	–19·3	·927	–0·1
10·05	084·05	–19·3	·933	+0·2
13·00	087·00	–19·6	·936	+0·1

* Mount Wilson observation[88,89]; weight 0.
† DAO observation[90]; weight 0·0067.

began observing it in 2000, unless the undated mean velocity of –14·1 km s⁻¹ given in a table referred to by Nordström *et al.* in their 2004 paper[91] stems from measurements made in that interval. Despite all the interest in its abundances, emission lines, and rotation, therefore, 34 Peg was not even recognized as a spectroscopic binary until the fact was published[35] in 2003. The star has continued under observation with the Cambridge *Coravel* since that paper went to press; there are now 60 observations from it, listed in Table II after the Mount Wilson and DAO measurements. Those published velocities have been adjusted by +0·8 km s⁻¹ to take account of the offset noticed (*e.g.*, ref. 92) between the Cambridge and former IAU zero-points, plus the amounts recommended in Table 3 of the *Radial Velocity Catalogue* for F-type stars measured at the respective observatories.

An orbit determined from the Cambridge observations alone has a period of 930·5 ± 1·3 days. The question arises as to whether any improvement might be effected by the inclusion in the solution of the old observations, made about 34 cycles previously. Those observations have almost negligible 'weight', but their age gives them a lot of leverage on the orbital period. In the case of the Mount Wilson ones, the answer is clearly no. They are scattered seemingly at random with respect to the orbit, and indeed the sum of the squares of their deviations from the orbit is much more than the sum from their own mean! — it has risen from about 62 to 101 (km s⁻¹)². (That is not at all significant statistically, since even the 10% point of $F_{5,4}$ is as much as 4·05.) The DAO measures present a more difficult problem, since it is obvious from their positions just to the left of the descending branch of the orbital velocity curve that their residuals could be materially improved by a small change to the period. If they are given the same weight as the Cambridge observations, they shift the period to 933·5 days, an increase of 3·0 days or 2·3 standard deviations, something that would happen with a chance little more than 2%, and they would still have a variance about 60 times worse than the Cambridge data. To go that far would obviously be imprudent. If their weighting is adjusted to bring their variance into equality with that of the Cambridge measurements (it needs to be 0·0067 to do that), the period is shifted a little way — about a quarter of the way to where the DAO observations would really like it — without appreciable harm to the fit of the Cambridge data, so *that* is the solution adopted for the orbit. It is illustrated in Fig. 2 and has elements as follows:

P	=	931·3 ± 1·1 days	$(T)_2$	=	MJD 53283·9 ± 3·3
γ	=	−14·60 ± 0·04 km s^{-1}	$a_1 \sin i$	=	57·3 ± 0·9 Gm
K	=	4·96 ± 0·07 km s^{-1}	$f(m)$	=	0·0087 ± 0·0004 $M_{\odot}$
e	=	0·432 ± 0·010			
ω	=	184·4 ± 1·9 degrees	R.m.s. residual (wt. 1)	=	0·30 km s^{-1}

The rotational velocity of 34 Peg is found from the Cambridge traces to be 8·6 km s^{-1}, the r.m.s. scatter of the 60 individual observations being 1·0 km s^{-1}; the formal standard error of the mean is therefore only 0·13 km s^{-1} but, because differences between stars in respect of other sources of line-broadening are not taken into account in the Cambridge estimates, the mean value is not claimed to be as accurate as its formal uncertainty might suggest. If the star really rotates in 12 days, as Baliunas *et al.*[86] have said (after a good deal of vacillation previously), then a $v \sin i$ of 8·6 km s^{-1} corresponds to a projected radius, $R_\star \sin i$, just marginally over 2 $R_{\odot}$. In the light of Goldin & Makarov's astrometric determination[36] of an *orbital* inclination of 93^{+6}_{-5} degrees — so for practical purposes we could take $\sin i$ as unity — we might adopt as a working hypothesis

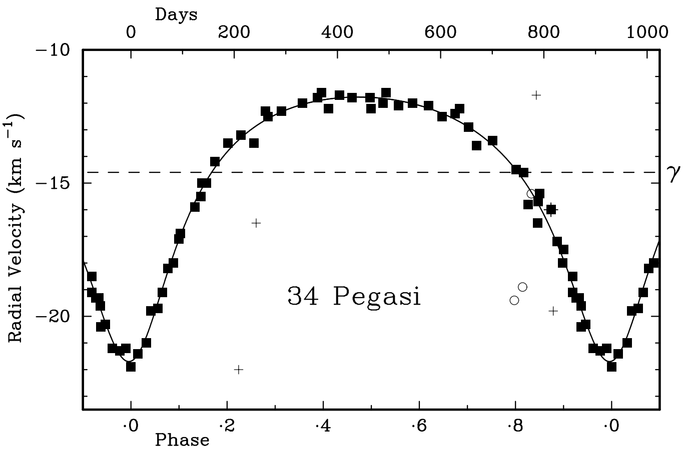

FIG. 2

The observed radial velocities of 34 Pegasi plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The Cambridge observations are plotted as filled squares. The three velocities obtained[90] at the DAO in 1923 are shown by open circles; they have been weighted 0·0067 in the solution of the orbit. The five Mount Wilson measurements[88,89] (weight 0) are shown as plusses.

that we could do the same for the axial inclination and thus to consider that the rotational velocity implies an actual stellar radius of 2·0 $R_\odot$. A *main-sequence* star with the temperature type (F8) of 34 Peg could be expected[93] to have a radius of about 1·1 $R_\odot$ and an absolute magnitude of $4^{m}\cdot0$. The parallax of 34 Peg puts its absolute magnitude at $2^{m}\cdot77 \pm 0^{m}\cdot15$, implying that its surface area must be larger than that of the corresponding main-sequence star by a factor of 3·1 ± 0·4, and the calculation leads finally to an expected radius of 1·94 ± 0·14 $R_\odot$ — exactly as we might have hoped!

We can enter, with reasonable assurance, into the expression for the mass function the quantities $M_1 = 1{\cdot}1\ M_\odot$, $\sin i = 1$, and thereby obtain $M_2 \sim 0{\cdot}25\ M_\odot$, showing that the spectroscopic secondary star is far down the M-dwarf sequence; it is no surprise that it has not been detected in the radial-velocity traces or in any other manner.

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UBV PHOTOMETRY FOR HD 1

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Reading Griffin & McClure's[1] first paper in their new series of spectroscopic-binary-star orbits for *Henry Draper Catalogue* stars reminded the author that he had unpublished *UBV* photometric data from years ago. He had decided to obtain photometry of HD 1 just for curiosity: what were the magnitude and colour indices of the first star in the then-most-used and, perhaps, famous astronomical catalogue?

The star HD 1 has been found to be a spectroscopic binary with a period of 2315·9 days by Griffin & McClure[1], who noted that HD 1 is a K giant, perhaps something like a K3 III, in a binary orbit whose eccentricity they determined to be 0·5. According to Perryman *et al.*[2], HD 1 has a small proper motion of $\mu_\alpha = 7{\cdot}13$ and $\mu_\delta = -7{\cdot}08$ mas/year; they also quote a parallax value of $0''{\cdot}00253 \pm 0''{\cdot}00069$.

The star HD 1 was observed over a time interval of 5553 days between 1970 October 5 and 1985 December 18. The data were obtained at the then-named KPNO No. 3 16-inch, No. 4 16-inch, No. 1 36-inch, and No. 2 36-inch telescopes. None of those telescopes exist today at KPNO. The data were all taken during the author's standard-star data-acquisition programmes, which meant all-sky photometry. Hence, there was no use of a comparison star.

The data from 1970 and 1971 January 30 were obtained during the standard-star programme that produced the results presented by Landolt[3]; those data were tied into Johnson's system[4], as were those obtained between 1976 November 30 and 1976 December 4. The data obtained between 1971 September 23 and 1972 January 20 were tied into the system of Johnson & Harris[5]. Lastly, the night of 1985 December 18 was tied into Landolt's system[6]. Thus seventeen separate data sets were obtained, each set containing deflections in the order *VBUUBV*, obtained on 15 different nights over the 15·2-year time frame. These data cover 2·40 orbits, based on Griffin & McClure's[1] period of 2315·9 days.

Table I contains the photometric information found for HD 1. Column one identifies the UT date for the data. Column 2 identifies the KPNO telescope at which the data were obtained. The heliocentric Julian Day (HJD) of mid-observation is given in column 3. The last three columns list the transformed magnitudes and colour indices.

Table II lists the photometric errors for a single observation for different HJD time intervals. These errors are, in essence, based on the all-sky photometric reductions of which these data are a part. Errors for the first line have the values listed since those observations were all made during the preparation of the standard-star results by Landolt[3]; those errors were summarized by Landolt[7] in his Table 7. The errors for the three nights HJD 2443112–2443116 and for 2446417 resulted from those nights' all-sky-photometry data reductions.

TABLE I

UBV magnitudes and colour indices for HD 1

UT	*Tel. No.*	*Diam.*	*HJD*	*V*	*B – V*	*U – B*
1970 Oct. 5	1	0·9 m	2440864·73178	7·326	+1·320	+1·128
1970 Oct. 6	1	0·9 m	2440865·73505	7·412	+1·338	+1·118
1970 Oct. 7	1	0·9 m	2440866·83801	7·378	+1·330	+1·131
1970 Oct. 8	1	0·9 m	2440867·74781	7·400	+1·335	+1·146
1970 Oct. 9	1	0·9 m	2440868·75215	7·406	+1·326	+1·139
1970 Oct. 10	1	0·9 m	2440869·76370	7·388	+1·321	+1·130
1971 Jan. 30	2	0·9 m	2440981·59338	7·373	+1·324	+1·101
1971 Sept. 23	2	0·9 m	2441217·81030	7·404	+1·311	+1·104
1971 Sept. 25	2	0·9 m	2441219·80231	7·393	+1·308	+1·108
1971 Nov. 14	3	0·4 m	2441269·73734	7·386	+1·309	+1·106
1972 Jan. 20	4	0·4 m	2441336·58467	7·372	+1·320	+1·141
1976 Nov. 30	4	0·4 m	2443112·71670	7·370	+1·320	+1·111
1976 Nov. 30	4	0·4 m	2443112·71948	7·378	+1·312	+1·134
1976 Dec. 1	4	0·4 m	2443113·61351	7·393	+1·304	+1·139
1976 Dec. 4	4	0·4 m	2443116·59724	7·395	+1·311	+1·128
1985 Dec. 18	2	0·9 m	2446417·73182	7·368	+1·304	+1·099
1985 Dec. 18	2	0·9 m	2446417·74718	7·371	+1·299	+1·089

These data are confined by observation interval to four time periods: HJD (1) 2440864–2440981, (2) 2441217–2441336, (3) 2443112–2443116, and (4) 2446417. If one looks at the entire data set, the 17 measures provide $V = 7{\cdot}383 \pm 0{\cdot}022$, $(B-V) = +1{\cdot}320 \pm 0{\cdot}011$, and $(U-B) = +1{\cdot}123 \pm 0{\cdot}020$. If one determines the average magnitude and colour index by observation interval, one finds the values indicated in Table III. These results may be compared to the *Hipparcos Catalogue*[8] values of $V = 7{\cdot}41$ and $(B-V) = +1{\cdot}29$, which values are more indicative, than systematically accurate, as described in volume one of the *Hipparcos and Tycho Catalogues*. The *Hipparcos Catalogue* contains the flag "C", indicating HD 1 was not found to be variable in light.

The single measurement of HD 1 on 1970 October 5 is brighter in the *V* magnitude by $0^{m}{\cdot}057$ than the overall average brightness. However, the colour indices agree with the overall average colour-index values. A thorough perusal of the Brown chart recording, observing notes, and reductions shows no reason to doubt the measurement. The last measurements, made on 1985 December 18, are very slightly brighter and a bit bluer than the photometry from the other three time intervals. It should be mentioned that the two measurements of 1985 December 18 were taken about 15 minutes apart, and hence are but a point in time, not an average over days or months, similar to the other three time intervals.

The data, all tied into this author's standard-star work, appear to show that HD 1 is constant in magnitude and colour indices to within the errors of observation. One might be tempted to say that HD 1 has become a bit bluer with time. Again, though, the last line of Table III represents measurements made on one night.

TABLE II

Photometric errors for a single observation (magnitudes)

HJD Dates	δV	$\delta(B-V)$	$\delta(U-B)$
2440864 – 2441336	0·015	0·016	0·025
2443112 – 2443116	0·020	0·013	0·015
2446417	0·007	0·009	0·012

TABLE III

Average photometry for stated HJD intervals (magnitudes)

HJD Dates	*V*	*(B – V)*	*(U – B)*	*n*
2440864 – 2440981	7·383	+1·328	+1·128	7
2441217 – 2441336	7·389	+1·312	+1·115	4
2443112 – 2443116	7·384	+1·312	+1·128	4
2446417	7·370	+1·302	+1·094	2

Fig. 1 illustrates a *UBV* colour–colour plot. Filled circles indicate the location of the main-sequence stars. The giant stars are identified by open circles, while HD 1 is marked with a cross.

Using $(U-B)$ = +1·123 and $(B-V)$ = +1·320, the dust maps by Schlegel, Finkbeiner, & Davis[9] were used to determine a colour excess of 0·836 for the Galactic coordinates of HD 1 (l = 118°·6, b = +5°·4). This value is an upper limit for the line-of-sight colour excess in this direction. Perusal of the *Palomar Observatory Sky Survey* (POSS) prints O-555 and E-555 shows that HD 1 is in the direction of a mixture of dust and nebulosity, albeit some 30 minutes of arc north of the most opaque part of the mixture.

According to a compilation in *Allen's Astrophysical Quantities* (Drilling & Landolt[10]), the colour indices for a K0 III star are $(B-V)$ = +1·00, and $(U-B)$ = +0·84. For a K2 III, the values are $(B-V)$ = +1·16 and $(U-B)$ = +1·16. The colours for a K5 III are $(B-V)$ = +1·50 and $(U-B)$ = +1·81. As evident in Fig. 1, HD 1 certainly is reddened. Its position lies 0·15 magnitude redward of either the luminosity class V or III sequences in the *UBV* colour–colour plot, and 0·34 magnitudes above the giant sequence.

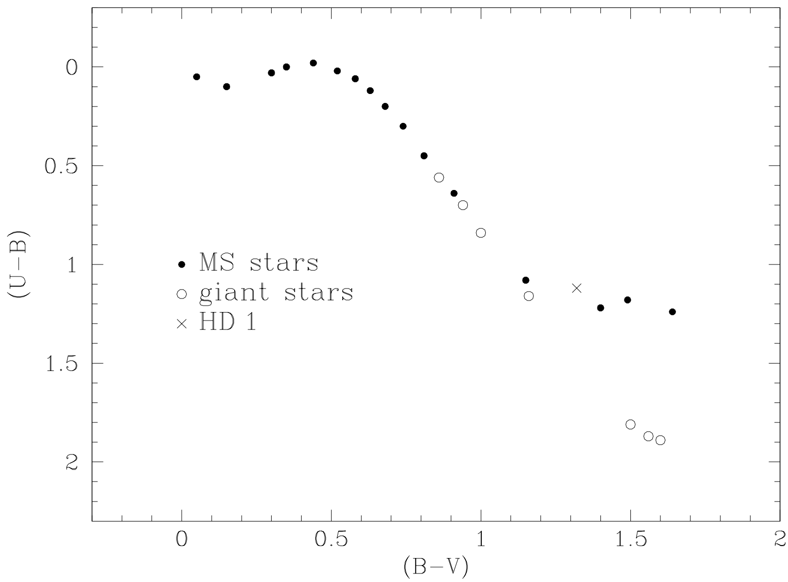

FIG. 1

Colour–colour plot showing the location of HD 1 relative to main-sequence and giant stars.

If one uses the relation $M = m + 5 + 5\log \pi - A_{E(B-V)}$, together with the observed $V = 7^{m}\cdot383$, and observed parallax $\pi = 0''\cdot00253$, and taking the colour excess as 0·836 from Schlegel, Finkbeiner & Davis[9], then one finds $M_V = -3^{m}\cdot2$. If one assumes that the colour excess is 0·0, then one finds $M_V = -0^{m}\cdot6$. If one makes use of the standard reddening line with a slope of 0·72, only marginally appropriate for red stars and giant stars, then one finds $(B-V)_0 = +1\cdot04$. Together with an observed $(B-V) = +1\cdot32$, the colour excess $E(B-V) = (B-V)_{obs} - (B-V)_0 = +0\cdot28$, which leads to $M_V = -1^{m}\cdot47$. None of these three derived absolute magnitudes closely corresponds to an early K giant. Zero colour excess provides the most reasonable absolute magnitude, but absorption is visible on the POSS prints. Since HD 1 has a small but measurable proper motion, its true distance is rather nearer than more distant.

Griffin & McClure[1] describe the spectrum of HD 1 as similar to that of a giant star, but with caveats. The position of HD 1 in Fig. 1, together with the discussion above, shows that a good classification spectrum and multi-colour photometry would be useful in any further discussion. There is work to be done.

Acknowledgements

It always is a pleasure to thank the staff of the Kitt Peak National Observatory for their hospitality and assistance in making observing runs over the years a success. (KPNO is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.) The author thanks J. L. Clem for formatting this note to conform to *The Observatory's* standards. The data acquisition in this note was supported in part by NSF grants GP-37837, MPS 75-01890 and by AFOSR grant no. 77-3218. Preparation of this manuscript for publication has been supported in part by NSF grant AST-0803158.

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NOTES FROM OBSERVATORIES

A Dedicated Public-Use 30-Inch Telescope

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On Friday 2009 September 18 in the presence of about 70 guests, Professor Alec Boksenberg cut the ribbon on the new 30-inch (0·76-m) public-use reflecting telescope at the Hanwell Community Observatory's main site in the grounds of Hanwell Castle, near Banbury (Plate 3). This event marks the completion, after a decade's work, of the main structural and optical elements of what we believe will be, when fully commissioned, the largest instrument in Britain custom-designed as a dedicated public-use telescope.

HCO (with apologies to Harvard!) is a Public Understanding of Science initiative for the promotion of astronomy and astrophysics, primarily by free public-stargazing evenings at the Observatory's permanent open-air site in North Oxfordshire. It is being set up and will be run entirely by volunteers, currently numbering about a dozen, but the project also has links with the Oxford University Department for Continuing Education (OUDCE) and the British Astronomical Association. From its inception with a Royal Society Millennium Award for this purpose in 1999, HCO's goal has been *public* outreach in astronomy in the widest sense, aiming to attract not only visitors with an established interest in the subject but also, and perhaps most of all, those who have never seen a celestial body through a good telescope. Although modern digital technology will, of course, be used to promote these ends to their greatest possible benefit, the project focusses emphatically on first-hand experience at the eyepiece — on getting visitors 'out under the stars' to confront astronomical reality face-to-face. With this end in view, the 30-inch reflector has, from the start, been designed and built with the lay public in mind as its principal users, not as a general-purpose instrument with the public as an afterthought. This has dictated many of the telescope's major design features and is what makes it distinctive.

The 30-inch is a permanently mounted altazimuth of 3 tons moving weight, turning on a base ring 10 feet (3 m) in diameter — the azimuth 'bearing' — itself bedded on a foundation of 7 tons of high-specification reinforced concrete. The optical configuration is an *f*/6·2 Newtonian with eyepiece mounted parallel to the altitude axis; these deliberate design choices of altazimuth mounting and Newtonian optical train thus configured already go a considerable way towards achieving the user-friendliness we considered essential in such a public-use telescope, in that the eyepiece then remains permanently horizontal. The inconveniences of the two remaining motions of the eyepiece as the 30-inch slews or tracks have also been eliminated in the design: an optional 3-mirror configuration incorporating an alternative secondary flat, two-thirds of the way up the tube, at 11° to the optical axis, and a smaller tertiary, bring the light out along the altitude axis to a Nasmyth focus, so fixing the eyepiece at a conveniently accessible height above the ground; and finally, a large access-platform integrated into the structure of the azimuth turntable itself enables the observer to ride the telescope as it revolves in the horizontal plane, thus bringing eyepiece and observer completely fixed relative to one another. This platform is comfortably large enough to accommodate several observers simultaneously, the requirement that this should be possible, along with that of the simplest possible fixed-eyepiece configuration, being the main factors dictating the choice of altazimuth mounting geometry in the first place.

The last refinement of the basic design of the 30-inch will be to mount a beam-splitter system at the Nasmyth public focus, sending about 10% of the transmitted light to a 'guide' eyepiece and dividing the remainder equally between two guest eyepieces, so that visitor queuing times are halved and the host conducting the session can respond more meaningfully to questions at the telescope; it is for this reason that the access-platform has been made as large as it has. Incidentally, for the main staple diet of the public-stargazing sessions — the Moon, bright planets, double stars — the reduction in illumination of the final images without impairment of resolution, produced by this division of amplitude, will actually be a positive advantage, and there is little indeed which finds a legitimate place in such public observing for which it will be a significant disadvantage. Even with the transmitted light divided in this way, each guest-eyepiece will deliver the light-grasp equivalent of an 18-inch (0·45-m) aperture. The result: a fixed eyepiece, multiple-user telescope optimized for public use.

When fully commissioned, the 30-inch will be the Observatory's main work-horse for a regular programme of free public-stargazing evenings throughout the eight or nine darker months of the year, using the telescope to present a varied menu including sessions devoted to special themes, as well, of course, as the more usual tourist sightseeing. Such themed sessions could, for instance, very well include some exposure to the real science of astronomy, such as the gentle introduction of some of the ideas and methods of astrophysics if appropriately handled, even for the most unscientific of visitors. An obvious example here, which seems to be surprisingly little exploited in current astronomical public outreach, is stellar spectroscopy: even in a telescope of one third or less of the aperture of the 30-inch, fitted with a small direct-vision spectroscope, the spectrum of Sirius, for sheer beauty and visual impact, is easily in the same league as one's first good telescopic view of the rings of Saturn or the Orion nebula, yet it is probably never seen by more than 1% of novice observers, who eagerly queue up for views of the latter. It is therefore one of the plans for the 30-inch, whose light grasp will suit it handsomely to such application, to equip the Nasmyth focus with a suitable visual spectroscope so that occasional public evenings ('Stars and Rainbows') can be devoted to star colours and stellar spectra, with the odd bright planetary nebula thrown in for good measure.

At the time of writing, the simple Newtonian optical train is installed on the 30-inch and we are in the process of making the remotely-operated collimation controls fully functional. Evaluation and testing of the optical performance at that focus should commence within a few days and will continue through the autumn and winter of 2009–10 while work on the 3-mirror Nasmyth train for the public focus, for which all optics are in hand, goes ahead simultaneously. Some work also remains to be done on the drive and slewing systems but we anticipate that the period of full commissioning of the telescope will be over in a few months, the 30-inch then being ready to commence its full programme of public open evenings. For those, a minimum of two 'sky-guides' is needed to host each session, so their frequency will depend heavily on how large a pool of 'sky-guides' is available. At present, HCO is understaffed in this respect and this is the Observatory's greatest outstanding need, so the writer would like to use these pages to make an appeal: if there is anyone reading this, amateur or professional, novice or 'old hand' in such matters, who lives anywhere in this region and is interested in becoming involved in the HCO public-outreach project, most of all as a 'sky guide', please contact us. We would also like to hear from anyone who has particular ideas on how the Hanwell initiative could interact most productively with school and university physics or astrophysics, and are keen to establish links with relevant academic departments in the region to further that end. Contact can be made either through the website www.hanwellobservatory.org.uk or *via* the Observatory telephone line 01295 730762. The next general public opening will be for the sixth annual 'Stars and Snowdrops' event over the second weekend in February, noon till 5 pm.

CORRESPONDENCE

To the Editors of 'The Observatory'

Wābkanawī's Annular Eclipse

The June issue of this *Magazine* carries an article[1] saying that Wābkanawī presented the first 'scientific' report of an annular solar eclipse, *i.e.*, one in which numerical details were given. It goes on to give such numerical details of the eclipse of 1283 January 30: the apparent angular diameters of the Sun and Moon, as calculated by Wābkanawī, were respectively 32′ 41″ and 32′ 51″. So it seems that the Moon appeared bigger than the Sun, which is at odds with what one would normally expect at an annular eclipse. Moreover the article continues by saying that the real ratio [computed from present-day data] of the Moon's apparent size to the Sun's was 0·952, and it seems to praise Wābkanawī for obtaining a ratio that is 'only' 4·62% more than the modern one. But that number appears to be a mistake. A ratio that was 4·62% more than 0·952 would be very nearly 0·996, leaving the eclipse still marginally annular; on the figures given, Wābkanawī's ratio was actually 1·0051, 5·58% greater than the true figure, and by being on the wrong side of unity it very clearly changes the fundamental nature expected for the eclipse from annular to total.

Yours faithfully
R. F. Griffin

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2009 June 7

Reference

(1) S. M. Mozaffari, *The Observatory*, **129**, 144, 2009.

Wābkanawī's Annular Eclipse

Let me declare my great thanks to Professor Griffin for his attention to my paper[1]. His objections grew out of an error in my paper in which the apparent angular diameters of the Sun and Moon were inadvertently transposed. The correct values are 0° 32′ 41″ for the Moon and 0° 32′ 51″ for the Sun. I am responsible for this mistake. [It should also, of course, have been spotted by the Editors, who apologize for this lapse! — Ed.]

Yours faithfully,
S. Mozaffari

Tehran

2009 July 2

Reference

(1) S. M. Mozaffari, *The Observatory*, **129**, 144, 2009.

Will the Proposed European Telescope be the Answer to the Ultimate Question of Life, the Universe, and Everything?

I have, perhaps, just discovered why 42 is the answer to the "Ultimate Question of Life, the Universe, and Everything" put to the computer *Deep Thought* in Douglas Adams' *A Hitchhiker's Guide to the Galaxy*. I was making a graph of $\log_{10}$ (telescope mirror area in square metres) as a function of time, for telescopes, from Galileo's to the proposed European 42-m, for a forthcoming lecture, when I noticed that the log of the area of the 42-m, in square metres, is equal to the value of π to an accuracy of 5 parts in 3 million.

Yours faithfully,
Robin Catchpole

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2009 September 11

REVIEWS

Le Verrier: Savant magnifique et détesté, by J. Lequeux (EDP, Paris), 2009. Pp. 401, 24 × 16 cm. Price €32 (about £28) (paperback; ISBN 978 2 901057 61 1).

Even if you never specialized in French at school, the title of James Lequeux' biography clearly crystallizes Leverrier as a man with an impressive intellect whose social skills needed some attention. This is, of course, an oversimplification, but accurate.

Lequeux is an astronomer at the Paris Observatory, well placed to write about its history, and this book follows on from the same author's work about Leverrier's immediate predecessor as Director, François Arago. This is a thorough and even-handed examination of a fascinating personality and his world. It is written for non-astronomers, with any astronomical principles being explained if necessary. It is well-illustrated, and dotted around the text are short biographies of some of the leading figures including Foucault, Janssen, Faye, Wolf, Rayet, Delaunay, and Arago, while other names not heard since school-physics days, such as Fizeau, Cornu, and Buys-Ballot, also appear. This gives some idea of the intellectual strength of the physical-sciences community in France in the middle of the 19th Century.

After the recent hubbub surrounding the 're-discovery' of the missing Neptune papers from the Royal Observatory, it is nice to hear the French side of the matter, especially since the fuss that accompanied the discovery of Neptune has long since dissipated and the events can be examined calmly. Marshal Vaillant, who became Minister for Public Instruction (Public Education) around the time that Leverrier took on the job at Paris Observatory, had a pithy remark, which apparently he never tired of repeating. "The Observatory is impossible without Leverrier and is still more impossible with him". Contemporary views of Leverrier's character largely tend to emphasize his autocratic personality when dealing with official matters and members of staff. Camille Flammarion called him haughty, disdainful, and inflexible and suggested that he treated the Observatory staff like slaves. Flammarion reports that in the years of Leverrier's first directorship (1854–1870) more than 100 members of the Observatory staff left. They were not just lowly-paid assistants but included a few significant names such as Puiseux and Chacornac. Lequeux occasionally compares the situations at Paris and Greenwich and one can't help noting the similarities between Leverrier and Airy — the same autocratic attitude to work and aloof intellectualism. This is not the whole picture, as with his intimate acquaintances he was said to be cheerful and full of spirit, and he enjoyed playing the violin. He suffered from continual trouble with indigestion and this, the author suggests, may have contributed to his antagonism. His later life was also plagued by ill health, which is put down to the strain of his work.

Whatever the effect of Leverrier's personality was on the staff, there is no denying his achievements whilst he was in charge in Paris. His successful prediction of the discovery of Neptune was just a part of his lifetime work on the Solar System as a whole, the tables of which he saw on his death-bed in a striking similarity with Copernicus. He found a discrepancy in the orbit of Mercury which was also attributed to another (hypothetical, as it turns out) perturbing body called Vulcan, although it was left to Einstein to explain this anomaly. He tightened up the processing of astronomical information and tackled the reduction of the data amassed under Arago. Although a theoretician, he saw the need for improved and modern instrumentation and ensured that the Observatory would be equipped with the latest technology — the first silvered-mirror reflecting telescope built by Foucault, for instance, was installed in his time, and later moved to Marseilles to take advantage of the better climate for astronomy. He modernized meteorology by incorporating telegraphy for the dissemination of forecasts.

Nevertheless, such was the strain generated amongst the staff in Paris during his term of office that in 1870 Leverrier was forced to resign after a 16-page list of complaints, ending with their resignations, was signed by 13 astronomers and department heads. This brought in Delaunay as the next Director, but he died in a boating accident in Cherbourg harbour in 1872 and in 1873 Leverrier was back in charge, having been appointed personally by the President of the Republic. Leverrier's second term was less turbulent than the first and he died in office in 1877, the same year in which this publication was founded. Indeed, in Volume 1 of *The Observatory* (page 199), Edwin Dunkin pens a lengthy, if uncontroversial, appreciation of Leverrier and his achievements. With the bicentenary of his birth some eighteen months away the time is ripe for this balanced assessment which gives the man his full due — warts and all. An English translation must surely be forthcoming. — ROBERT ARGYLE.

God's Philosophers: How the Medieval World Laid the Foundations of Modern Science, by J. Hannam (Icon Books, London), 2009. Pp. 435, 24 × 16 cm. Price £20 (hardbound; ISBN 978 1 84831 070 4).

In this impressive book written for the general reader, Hannam surveys the development of Natural Philosophy from the Fall of Rome to the death of Galileo, tracing its changing relation with philosophy, theology, magic, and mathematics. His theses are that the progress of scientific thought and discovery continued throughout the Middle Ages, laying the foundation for the so-called scientific revolution, and that the Church did not obstruct this. The account is in the framework of the history of the Church, including popes and the papal schism, heretics, inquisitions, the Dominicans, Fransciscans, and the Reformation.

We meet a sequence of scholars, some relatively familiar like Adelard of Bath, Thomas Aquinas, Roger Bacon, William of Ockham, Paracelsus, Copernicus, Kepler, and Galileo, and many more who deserve to be known better. One of the latter was Gerbert of Aurillac, who spent some time around 970 working in Barcelona, then on the boundary between Christian and Muslim Europe, where he picked up enough mathematics to introduce Arabic numerals to Christian Europe and, possibly, produce an instruction manual for the astrolabe. Another was Richard of Wallington, who built an astronomical instrument, the Albion (presumably based on the equatorium, another Arabic instrument), for calculating lunar, solar, and planetary positions and predicting eclipses. Perhaps the most significant was John Buridan, who worked in Paris in the 14th Century and who made great progress in the study of moving bodies; but the most fun is Jerome Cardan, mathematician, gambler, inventor, astrologer, and physician who owed his medical successes to minimal intervention. They and many others are brought to life in highly readable accounts, including the well-known calamities of Peter Abelard and the lesser known magical ritual using candles and torches in a sealed room by which Pope Urban VIII and the astrologer Tommaso Campanella aimed to protect the pope from the astrological predictions of his death.

The development of heliocentricism is well covered, bringing out Copernicus' debt to his predecessors, but the reception of the theory in England was wider than discussion in a few textbooks. In 1576, Thomas Digges revised his father Leonard's perpetual almanac (*A Prognostication Everlasting* ...), adding a translation of part of *De Revolutionibus* and a diagram of the heliocentric universe with the fixed stars extending to the edge of the page. This was a popular work, going through seven editions, which would have reached a wide readership. The career, achievements, and trials of Galileo are also covered well, but in the account of the probably apochryphal experiment from the Tower of Pisa, Galileo is said to have mounted the tower with balls of very different sizes, which should presumably read "weights" for consistency with the following sentence.

The author takes pains to counter reports of the persecutions of errant scientists by the Church authorities, but inquiry in the Middle Ages was not that free: there was a strong strand of hostility to curiosity running from Augustine ("Curiosity which is stimulated by the lust of the eyes") through Bernard of Clairvaux (*Vana curiositas*) and beyond. The source of the main image on the dust jacket of this book, the *Bible Moralisée*, also pictures the tower of Babel, with a commentary: "That the pagans began the tower of Babel against God's commandment signifies the astronomers and dialecticians who make false proofs against the will of Jesus Christ, and He turns their work to nothing, and blinds them, and strikes them". Where the line was drawn depended on the individuals in authority at the time and, as Galileo discovered with his sometime friend Urban VIII, they could behave inconsistently.

The author wears his learning lightly, giving us an absorbing story backed by a solid framework of reference notes. In addition to an extensive bibliography, he gives a well-selected reading list for the new reader, an Index, a Timeline, and List of Key Characters, all of which I found very useful. Perhaps Bernard of Chartres, who provided the metaphor of standing on the shoulders of giants, which is a theme of this book, deserves a place in the List — at least to distinguish him from his better-known contemporary Bernard of Clairvaux. This book is a fine achievement which should stimulate interest in the medieval natural philosophers, and is warmly recommended. — PEREDUR WILLIAMS.

Carl Sagan: A Biography, by R. Spangenburg & K. Moser (Prometheus, Amherst), 2009. Pp. 181, 22·5 × 15·5 cm. Price $16·98 (about £10) (paperback; ISBN 978 1 59102 658 7).

Carl Sagan was quite probably the best science communicator of his or our generation, with his *Cosmos* television series the most-watched PBS show up to its time and until a 1990 series on the (American) Civil War. His books made money, his public talks attracted crowds, and virtually everyone who met him, and some who did not, has a Carl Sagan story (mine comes at the end). There have been at least two previous (1999) biographies, both of which left me feeling that the subject was indeed the person I knew. This is not true of multiple biographies of another great science communicator, Richard Feynman, who also had three wives, and for both men the third time was clearly the charm. Sagan's third, Ann Druyan, says (on the back cover) that this biography comes closer to the Carl she knew than other previous attempts, and the authors thank her for extensive help. It would have been nice to have in the book photographs of all three, and also of the six Sagan children, the sixth younger than his oldest grandson. Instead we got the building where he met Lynn Alexander (No. 1, now Lynn Margulis, best known for an hypothesis on the origin of eukaryotic cells); the plaque Linda Salzman (No. 2) drew for *Pioneer 10*; and some radio telescopes like those in *Contact*, the film on which he and Druyan collaborated.

The book is Carl Sagan-light all around — light on number of pages, light on explanations of his scientific work, and light on fact checking. The authors are science journalists, described as having written an earlier book on "Niels Boher." They award George Gamow the Nobel Prize omitted by Stockholm, tell us about "respected British astronomer Arthur C. Clarke", and "scientists who also wrote science fiction ... Arthur Eddington, Sir James Jeans, …". Mars is said to be 48 million miles from Earth on average, and they think one applies for membership in the US National Academy of Sciences. Oh, and Caltech is the "California Technical Institute". This takes care of six of my 15 "No"s. A typical example of the larger number of 'oopses' has Einstein writing $e = mc^2$. Another is the authors' suggestion that Sagan's middle name, Edward, honoured "the former Edward VIII ... who gave up the throne out of love …". But it was 1936 that was the year of three kings, and Sagan was born in 1934.

What can one learn (I hope with confidence) from this 'volumette'? Sagan's mother, Rachel Gruber Sagan, kept a kosher kitchen, and he suffered from achalasia ("an obstruction to the passage of food that develops in the terminal esophagus just proximal to the cardioesophageal junction", says my *PDR Medical Dictionary*). Yes, I had to look it up, and it is left as an exercise for the reader to decide whether *post hoc ergo propter hoc*. On the science side, there is, I think, too much of other peoples'. Life in the Universe starts with Galvani and wanders through Aristotle, Woehler, Urey and Miller, but then suddenly jumps to Eddington and the source of stellar energy before returning to Watson and Crick. Correspondingly, there is too little of Sagan's presented. We are told he had predicted a very high Cytherean surface temperature and convinced the designers of *Mariner 2* to include an instrument that would settle the issue. *Mariner 2* passes Venus. We turn the page to find the answer and encounter Whipple, Drake, Donald Menzel, and others, but no Venusian temperature. There is a not-very-clear discussion of Sagan's hypothesis that the Martian wave of darkening was wind-blown sand of different compositions, but no mention of his early suggestions that PAHs and tholins would be significant constituents of the Jovian and Titanic atmospheres. He was largely right on all three points. Drake's equation is here, but with the "rate of star formation in the Galaxy" said to be 200 000 000 000. Whipple reappears to assure Sagan that he will receive tenure at Harvard (he didn't). And Menzel vanishes with no mention of his charming drawings of life forms appropriate for other planets.

And now two of my Sagan stories, both I think illustrating that, again like Feynman, he was sometimes more considerate of acquaintances than of nearest and dearest. He wrote an article for *Parade* on women astronomers, and, when he realized he had left me out, sent me a charmingly autographed copy of *Pale Blue Dot* for my birthday (a few days after his). This must have been 1995. Skip back to the late 1970s. Half-a-dozen people standing in the foyer of a conference room, chatting before the first session was to begin. Someone started to try to introduce me to the others and was interrupted by the most senior, who said "there is no need to introduce Virginia. She's notorious." "No, no," interjected Carl, "she used to be notorious. Now she is just famous." One could reasonably say something similar about Carl, who would have turned 75 this year. — VIRGINIA TRIMBLE.

The Greatest Comets in History: Broom Stars and Celestial Scimitars, by David Seargent (Springer, Heidelberg), 2009. Pp. 260, 23·5 × 15 cm. Price £19·99/$34·95/€24·95 (paperback; ISBN 978 0 387 09521 7).

After reading the author's wonderful descriptions of the spectacular comets that have been given the moniker of "Great", I wish that I could have personally witnessed all of them. The author, Australian astronomer and student of comets David Seargent, covers these comets from Aristotle's Comet, in *c.* 372 BC, to McNaught's Comet (Comet C/2006 P1). Seargent has so magnificently described those comets and what we have learned from them that you will wish that you could have observed them all as well.

One chapter is devoted to Halley's Comet. From its first recorded appearance in 240 BC, Seargent gives details about each apparition right up to 1986 and what the predictions are for its next return in 2061. Using modern techniques, astronomers have calculated that Halley's Comet may have made an appearance as early as 1404 BC!

As a solar-eclipse chaser, I was fascinated to learn that a comet (C/1948 V1) was first observed during the total solar eclipse of 1948 November 1. This comet is included in the chapter on those that were bright enough to be observed in daylight, which this comet became days after the eclipse. At the solar eclipse of 1882 May 17 another comet was discovered, but this small sungrazer was never seen again.

Another class of comets that is discussed are those known as "Kreutz Sungrazers". These kamikaze comets have a perihelion distance that for some of them indicates that the comet actually passes through the solar corona. The *SOHO* satellite has detected over a thousand sungrazers, but only eight other comets seen visually are included in this class.

I thoroughly enjoyed the author's writing style and the way he has presented this material. I highly recommend this book to anyone interested in observing comets or reading about this aspect of astronomical history. — ROBERT A. GARFINKLE.

Magnificent Desolation: The Long Journey Home from the Moon, by Buzz Aldrin with Ken Abraham (Bloomsbury, London), 2009. Pp. 326, 24 × 16 cm. Price £16·99 (hardbound; ISBN 978 1 4088 0402 5).

Where were you on Sunday and Monday 1969 July 20/21? Well, Edwin Eugene Aldrin, Jr. (who changed his forenames to Buzz in 1988 — his little sister mispronounced 'brother' as 'buzzer' and it stuck) was on the surface of our satellite Moon with his commander Neil Armstrong. Their *Eagle* lander was resting on the basaltic surface of the Sea of Tranquillity. Most human lives have peaks and troughs and being the second man to walk on the Moon was certainly a climactic peak for Buzz. But it was mainly down-hill ever after.

NASA, the American space agency, was very good at preparing astronauts for the 'next big thing', but it was little help afterwards. On returning to Earth Aldrin was pitch-forked into the media circus and left to "talk about the last big thing" until the media, or this specific astronaut, got tired. Unfortunately, most of the early astronauts were military guys, accustomed to keeping their feelings reined in, and media-land was strange and un-enticing. Buzz turned to drink, Alcoholics Anonymous, depression, running the USAF test-pilot school at Edwards Air Force Base, selling Cadillac cars, divorce, remarriage, writing science fiction, divorce again, scuba diving, and another marriage.

The Moon might have been magnificent and desolate but it was the second of these adjectives that mainly applied to Buzz's post-Apollo life. Yet it was not all gloom and doom. Buzz's indomitable spirit eventually shone through. His third wife Lois Driggs Cannon was a huge help.

At heart Buzz never gave up on space. Of all the astronauts, he is the only one to keep his mind firmly on the next step. To Buzz it is vitally important that NASA does its missions better. He is convinced that humans are important in space; sending them to Mars should be the next goal, and the profile of space travel should be raised by encouraging space tourism. Buzz bemoans the fact that, since the Space Shuttle was declared operational, 100 flight seats have gone unoccupied. These could have been sold off for about 2 billion dollars, and the publicity would have greatly encouraged the USA's attitude to space travel.

Magnificent Desolation is a gripping biography, being warm, insightful, encouraging, and moving. Buzz took the highs with the lows. No one said that it would all be easy. And he is a great champion of the pioneering adventurous spirit. How about the time when he was confronted by Bart Sibrel, the man who suggested that the whole Apollo programme was a conspiracy cooked up on some Hollywood back-lot? Buzz's reaction was instinctive but he knew he'd done exactly the right thing by smacking him squarely in the jaw. — CAROLE STOTT.

The New Moon Race, by M. Jones (Rosenberg, Kenthurst, NSW 2156), 2009. Pp. 184, 29 × 22 cm. Price £22·50 (hardbound; ISBN 978 1 87705 882 0).

During the early years of the Space Age, dozens of automated spacecraft and nine Apollo missions visited the Moon. For a while it seemed that permanent lunar bases would be established before the end of the 20th Century. However, with the Moon race won by the United States, political priorities changed. After the flurry of robotic and human missions culminated with the *Luna 24* sample-return of 1976, there was also a general consensus that there was little new to be learned. Governments, space agencies, and scientists largely lost interest in Earth's neighbour.

Now, decades later, the Moon has once again become a major focus for the world's space-faring nations, a place for space newcomers to demonstrate their budding technological prowess and a possible staging post on the long, hazardous road to the red planet. As a result, this would seem to be an excellent time to publish an overview of the past lunar endeavours and to review the present and future programmes.

This glossy, highly illustrated, volume provides an attractive appetizer for the general reader, with chapters on the latest lunar endeavours by the United States, Russia, Europe, Japan, India, China, South Korea, and private enterprise. The non-technical text concentrates mainly on the launch vehicles and spacecraft technology, necessarily sprinkled with a fair amount of speculation when it comes to the future programmes of China, Europe, and Russia. There is also some brief discussion of possible lunar science, living on the Moon, and the possibility of mining helium-3 to power future fusion reactors on Earth.

The New Moon Race is a useful introduction to lunar exploration for the younger reader or someone looking for an attractive, coffee-table book on lunar exploration. However, anyone seeking a detailed, in-depth account of the Moon race in the 1960s will have to look elsewhere.

Unfortunately, there are some minor quibbles. The book gets off to a bad start by confusing the captions for the front and rear cover images. Some of the images are unnecessary and uninformative, appearing to be little more than space fillers or speculative sketches, and one chapter ends in mid-sentence. — PETER BOND.

Space Tethers and Space Elevators, by M. van Pelt (Springer, Heidelberg), 2009. Pp. 240, 24 × 16 cm. Price £18·99/$29·95/€29·95 (hardbound; ISBN 978 0 387 76555 6).

If any book can be said to be ahead of its time, this is it. Although experimental space tethers have already been developed and tested during a number of orbital missions stretching back more than 40 years, we are unlikely to see their large-scale introduction and commercial utilization for many decades. In the case of the ultimate space-tether application, the space elevator, there is still the distinct possibility that it may remain merely a magnificent, imaginative monolith, forever consigned to the realm of science fiction.

For those not familiar with the potential of such thin, but incredibly strong cables, author Michel van Pelt, a space analyst at the European Space Agency, begins with a useful overview of tether science before describing the missions that have flown since their introduction during the final manned Gemini missions. Despite the developmental difficulties associated with space tethers, the possible applications of this technology are numerous and varied. Having set the scene, van Pelt goes on to describe various space-tether concepts, some feasible and some verging on the fanciful. These include schemes to remove dead satellites from low Earth orbit, raise or lower satellite orbits without the use of chemical propulsion, deploy tethered satellites into Earth's upper atmosphere, or generate artificial gravity with a rotating tether system. Even more exotic are proposals to deploy an electromagnetic tether in order to enter a circular orbit around Jupiter, and to clean up Earth's radiation belts.

For anyone interested in learning more about the fascinating possibilities offered by space tethers, this well-written, clearly illustrated book is the ideal introduction. However, toward the end of the book, the author injects a dose of down-to-earth realism when he admits that there is minimal interest among the world's space agencies in developing large-scale tether applications. It seems that we may have to wait a very long time before tethers become an integral part of space missions or space elevators take the place of expensive, inefficient, chemical rockets for carrying people and cargo into orbit. — PETER BOND.

Annual Review of Earth and Planetary Sciences, Vol. 37, 2009, edited by R. Jeanloz & K. H. Freeman (Annual Reviews, Palo Alto), 2009. Pp. 615, 24 × 19·5 cm. Price $234 (institutions, about £143), $89 (individual, about £54); (hardbound; ISBN 978 0 8243 2037 9).

As usual, there is a broad coverage of subjects of interest in this year's volume of *Annual Review of Earth and Planetary Sciences*, including global warming, Earth structure, tectonics, palaeontology, the atmosphere, climate, and planetary science. Also as usual, the book is beautifully presented, with many colour figures and high-quality paper and printing.

The gloomy news is well represented, but, hey, that's Earth science! The book kicks off with an unusual article on Africa and global warming, guaranteed to be thought-provoking. Other chapters related to this subject discuss the atmospheric lifetime of anthropogenic carbon dioxide (longer than is convenient), the response of ecosystems to climate change, palaeoclimates, and devastating megafloods. Forensic seismology tells us that there is no one magic bullet to discriminate between clandestine nuclear tests and small, natural earthquakes. Devastating large ones are not forgotten, but covered by a chapter that reviews the tectonics of the plate boundary that generated the lethal 2004 Boxing Day Sumatran earthquake. The good news there is that such earthquakes are infrequent, but the bad news is that we are nowhere close to being able to forecast accurately when they are likely to occur.

Readers may find comfort by burying their heads in the mantle with a useful review of 'stagnant slabs'. This subject has wider significance than might at first be thought. Magmas popularly attributed to mantle plumes from the core–mantle boundary are known to contain material from recycled subducted slabs. However, if these 'stagnate' in the transition zone and do not founder to the core–mantle boundary, then explaining the magmas as arising from the core–mantle boundary begins to look difficult. In contrast, a useful chapter on intraplate deformation underlines the fact that large datasets are now available for modelling the alternative cause of intraplate volcanism — lithospheric extension. A subject of related importance to this matter — melt concentration in the mantle by shearing and deformation — is also helpfully summarized.

A review of the evolution of *Homo* makes compelling reading — arguably by every human being on the planet. A huge diversity of early hominids once existed, and the evidence seems compelling that this diversity was wiped out at the time of *Homo sapiens'* expansion. The biological gap between modern humans and other animal species is, sadly, probably man-made.

Many other topics of current interest are covered, including the evolution of amphibian limbs and life-cycles, the nature of the Hadean crust, current knowledge of Saturn's largest moon, Titan, planetary migration, the evolution of asteroids, and the polar regions of Mars. All in all, a book with goodies for almost everyone, and a useful addition to every serious scientist's bookshelf. — GILLIAN FOULGER.

Cosmic Magnetic Fields: From Planets, to Stars and Galaxies (IAU Symposium No. 259), edited by K. G. Strassmeier, A. G. Kosovichev & J. E. Beckman (Cambridge University Press), 2009. Pp. 686, 25·5 × 18 cm. Price £68/$135 (hardbound; ISBN 978 0 521 88990 2).

The laudably ambitious, long-term goal of this symposium is stated in the opening words of the editorial preface: "Understanding of the Universe is impossible without understanding cosmic magnetic fields, which span the enormous range of 24 magnitudes in strength and play a key role in the formation, structure and evolution of planets, stars and galaxies, and possibly the entire Universe". The magnetic field thus establishes conceptual links between most of the traditional areas of astrophysics, as represented by the divisions within the IAU, so demanding interdisciplinary sessions. Topics covered by both oral and poster presentations include magnetic fields in star-forming regions, the multi-scale field of the Sun and its interior, heliospheric and interplanetary fields, the Earth's magnetic field, surface fields of cool and hot stars and of degenerate objects, planetary-nebula and supernova shaping by magnetic fields, jet and accretion-disc fields of very young stars, fields around black holes and magnetars, the magnetic field and dynamo of spiral galaxies, the primordial field of the early Universe, and finally, instrumentation and techniques for measuring magnetic fields across all wavelengths.

In a picturesque metaphor, the editors refer to the Sun as "our Rosetta stone" for the study of magnetic fields in the entire Universe, whence their pleasure at the recent escalation in solar studies, both theoretical — *via* helioseismology — and observational, by the new, large, solar telescopes, both ground-based and in orbit. They are likewise gratified that the symposium has led to a revival and strengthening of the connections between the solar-physics community and night-time astronomy, which they see as having been previously weakened for non-scientific reasons. As a specific spin-off from the symposium, they cite some thoughts on a possible feedback interaction onto a stellar atmosphere from a magnetized planet, yielding enhanced stellar activity. In a visionary aside, they say that this has the potential to impact on how we believe life has formed on Earth and other planets.

Time will show; but their final prediction — that the 21st Century will become the century of cosmic magnetic-field research — is more than plausible. — LEON MESTEL.

High-Redshift Galaxies: Light from the Early Universe, by I. Appenzeller (Springer, Heidelberg), 2009. Pp. 363, 24 × 16 cm. Price £64·99/$99/€69·95 (hardbound; ISBN 978 3 540 75823 5).

This ambitious book aims to summarize our view of high-redshift galaxies and their contents. Immo Appenzeller has taken on the task of guiding the reader through recent events while keeping to a modestly sized (although not modestly priced) book.

How the Universe came to appear the way it now does is one of the most important branches of modern-day astrophysics and will become more so as we try to understand the first light sources in the Universe. Indeed, the detection of high-redshift objects drives the design of many of the most challenging telescope projects now under way, including, for example, the *James Webb Space Telescope* (*JWST*) and the *European Extremely Large Telescope* (*E-ELT*). Appenzeller has been involved in this field for some time and his careful eye for detail comes across throughout the text. The book begins with a summary of what we find in the nearby Universe (stars, galaxies, *etc.*) and some basic cosmology before getting on to the main chapters. He describes how to find high-redshift objects, how to characterize them, how to deal with selection effects, and so on. The use of a variety of discovery methods is important to help determine selection effects. The most important chapters then follow on the observed properties of high-redshift galaxies and their implications.

Until quite recently, high-redshift-galaxy samples could be described using two words: small and biassed. The samples are still biassed by the detection methods but at least the number of objects is steadily growing. This has been largely achieved by the numerous deep surveys undertaken in the last decade or so combined most notably with the very different approach of the observation of gamma-ray bursts. The highest spectroscopic redshift known at the time of writing is of GRB090423 at $z = 8{\cdot}2$. Observatory directors and time-allocation committees have recognized that although such projects require substantial amounts of telescope time they pay off in knowledge. The deepest surveys are the Hubble Deep Fields, which must be complemented by shallower, wider surveys. I sometimes wonder if we have too many of those, each with a slightly different set of multi-wavelength data. However, the various datasets are now sufficient to begin to reveal the complex way in which galaxies and their central massive black holes evolve. The variation with redshift of galaxy sizes, masses, and morphology remains somewhat hazy but there is no doubt that the distant Universe contains quite a different set of galaxy specimens from those used in the famous Hubble classification scheme.

Appenzeller ends the book with a look to the future. The future looks bright for the faintest galaxies (no pun intended) given the extraordinary observational capability of forthcoming facilities, such as *JWST* and *E-ELT*, particularly in the infrared. It's an amazing thought that only some 100 years since it was proven there were such things as other galaxies, we are about to enter a decade in which the very first galaxies that formed in the Universe may be observed.

It is inevitable that in a fairly short book (363 pages) for such a large topic some of the sections are shorter than perhaps required. This is a minor quibble. Appenzeller has done a fine job in summarizing the study of high-redshift galaxies and this will act as an excellent introduction to the subject for students and researchers. — PAUL O'BRIEN.

The Primordial Density Perturbation: Cosmology, Inflation and the Origin of Structure, by D. H. Lyth & A. R. Liddle (Cambridge University Press), 2009. Pp. 497, 25·5 × 18 cm. Price £40/$75 (hardbound; ISBN 978 0 521 82849 9).

Not long ago, I had the opportunity to review Steven Weinberg's long-awaited update of his classic *Gravitation and Cosmology* (Wiley, 1972) for the journal *Science* (**321**, 1637, 2008). The new version, simply called *Cosmology*, turned out to be quite different from the old one as a consequence of the many advances, both in theory and in observation, that have taken place in the field since the original was published. The author decided that a revised version simply wasn't worth doing so he wrote a fundamentally new book, focussing on the generation and evolution of cosmological perturbations and their relationship to observed phenomena such as the cosmic microwave background and spatial distribution of galaxies. And a very good piece of work it turned out to be too.

This book, *The Primordial Density Perturbation*, by David Lyth and Andrew Liddle, has a vaguely similar provenance in the sense that it started out with the intention of being an update of their earlier book *Cosmological Inflation and Large-Scale Structure* (CUP, 2000). It's an even deeper testament to the rapid evolution of the field that, even after a much shorter interval, these authors also decided to write a fundamentally different kind of book from their original.

As its title suggests, the new volume focusses, like Weinberg's, on the issue of cosmological density perturbations. Its narrower scope allows it go into greater depth on specific issues to do with inflationary cosmology and quantum field theory as well as including recent advances in the subject. Zooming in this way within a book of manageable size is only made possible by taking the standard cosmological framework largely for granted, but with a plethora of observations supporting the so-called "concordance" cosmology it is justifiable for an advanced text, aimed at graduate students, to make such an assumption.

I like this book a lot. It is written very clearly and organized so well that it is easy to navigate. Both authors are undoubted experts and they handle the material with confidence as well as displaying deep insights and physical understanding. There is sufficient background material to make it accessible and self-contained for those without an extensive training in cosmology, but it is quite easy to skip such sections without becoming lost. Given the different backgrounds of people coming into graduate programmes in cosmology, this is a great advantage for a book at this level. I've seen a number of books about similar topics and at a similar level over the past year or so, and this is definitely one of the better ones. Setting it directly against Weinberg's book is putting the bar very high, but it does not suffer at all in such a comparison. — PETER COLES.

A First Course in General Relativity, 2nd Edn., by B. Schutz (Cambridge University Press), 2009. Pp. 393, 25·5 × 18 cm. Price £35/$70 (hardbound; ISBN 978 0 521 88705 2).

This marvellous book is a very clear, self-contained introduction to General Relativity. The only pre-requisite is a knowledge of physics and mathematics-for-physics at undergraduate level. All necessary additional mathematics is developed in the text and anyone using this book for serious self-study will gain much from it.

In common with other authors, Schutz begins by developing Special Relativity on Minkowski spacetime before moving on to curved manifolds. However, unlike many older introductory texts, Schutz adopts a modern geometrical approach from the outset, defining tensors as linear maps on vector spaces rather than objects that transform in a particular way. A grasp of modern differential geometry is extremely useful for understanding General Relativity, and Schutz provides a lucid exposition for the uninitiated reader; for example, pictorial representations of vectors and 1-forms are used to help the readers develop their geometrical intuition. Furthermore, the blend of mathematical and physical reasoning used throughout the text is commendable. Schutz doesn't hesitate to provide worked examples to illustrate new concepts and the book includes over 300 exercises in total (password-protected solutions are available on-line). Numerous suggestions for further reading are also given throughout.

After developing the necessary mathematical skills and geometric intuition, and given an introduction to relativistic fluids on Minkowski spacetime, the reader is provided with a solid introduction to General Relativity and a survey of its modern applications. It is here that the second edition deviates most from its predecessor; the new book includes an up-to-date discussion of gravitational-wave sources and detectors, and an updated chapter on cosmology. Of particular note is the discussion of gravitational-wave emission; no assumptions are made about the reader's prior experience of solving the inhomogeneous wave equation in three spatial dimensions, and the discussion of gravitational-radiation reaction is very accessible.

There is little I can say that is negative about this book. A thorough discussion of gravitomagnetism in linearized gravity is missing (the sections employing linearized gravity focus almost entirely on gravitational waves). There are a couple of glitches in the mathematics (incorrect symbols due to printing errors), but any confusion can be easily remedied by consulting the first edition. In short, I cannot recommend this book highly enough to any physicist who wants a good introduction to General Relativity. — David Burton.

Other Books Received

Solar Polarization 5: In Honor of Jan Olof Stenflo (ASP Conference Series, Vol. 405), edited by S. V. Berdyugina, K. N. Nagendra & R. Ramelli (Astronomical Society of the Pacific, San Francisco), 2009. Pp. 553, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 690 5).

This volume carries the proceedings of a workshop held in Switzerland in 2007 September. It reports the progress in the two years since SP4, mainly with the same teams involved. The main difference is that this conference was convened in honour of Jan Stenflo, who was the initiator and has been the chief driving force of the subject since about 1985.

NOTES

Young Astrophysicists' Prizes

Commission 19 (Astrophysics) of the International Union of Pure and Applied Physics plans to present two young scientists' prizes in astrophysics for 2009 and 2010 at the 25th Texas Symposium on Relativistic Astrophysics in Heidelberg in 2010 December. Each prize will consist of €1000, a medal, and probably an invitation to speak at the conference.

Criteria are: (*a*) Outstanding contributions by the individual. (*b*) Fewer than 8 years of post-PhD research by 2009 December (for the 2009 prize) or by 2010 December (for the 2010 prize). Interruptions for military service, family emergencies, *etc*. (but not teaching), are allowed.

A nomination package consists of: (*i*) A letter from the nominator outlining the reasons for the nomination. (*ii*) A complete CV and list of publications. (*iii*) Two supporting letters, at least one of which must come from someone not at the nominee's institution and not a mentor or significant collaborator. Self-nominations are not permitted, but a candidate could ask a mentor or colleague to provide a nomination.

Nomination packages should be sent either electronically to the C19 chair, Victoria Fonseca (fonseca@gae.ucm.edu) or as paper to the selection-committee chair Virginia Trimble (Physics Dept, Univ. of California, Irvine CA 92697 USA) so as to arrive by 2010 June 1. The winners will be selected and notified over the few weeks following that date.

Here and There

HARDLY A HURTLE

For astronauts hurtling round the Moon at 20 feet per second — *The Telegraph*, 2009 July 20, p. 19.

O NO IT ISN'T!

All right, CH_4 is methanol. — *The Observatory*, **129**, 231, 2009.

NOT VERY FRIENDLY

… telescope time at Cerro Tololo Anti-American Observatory — *AJ*, **136**, 1310, 2008.

NOT BY US

The astronomical name for our Sun is Sol … Sol is an average to small star, known as a white dwarf. — *Telegraph Weekend*, 2009 August 1.

FROM OUR ANDROMEDA CORRESPONDENT

Look at an image of the Milky Way galaxy, and you can't help but notice its exquisite spiral arms. — *Science*, 2009 August 28, p. 1059.

BUT NOT JUST YET

Many leading scientists agree that carbon emissions must be cut to keep a global rise in temperature to below 35·6F — *The Telegraph* (overseas *Daily Telegraph*), 2009 September 9–15, p. 11.

VIA GRAVITATIONAL LENSING PERHAPS?

Through the naked eye, the galaxy NGC 1313 can be seen only as a faint smudge beyond our southern horizon. — *Daily Telegraph*, September Night Sky.

STAR OVER GASCONY

Zera Aurignac, a double star system ... — *Dollheimers Grosses Buch des Wissens in zwei Bänden* (G. Dollheimer, Leipzig), 1938, vol. 2, p. 1633.

PEARLS BEFORE SWINE

The Local Volume is a treasure trough. — Preface to *Galaxies in the Local Volume* (Springer), 2008.

LONG AGO AND NOT SO FAR AWAY

The most distant water found in the universe has been detected in a galaxy more than 11 light-years away — *A&G*, **50**, 1·6, 2009.

TOO CLOSE FOR COMFORT

NASA saw Kepler safely into its solar orbit, trailing 950 km behind Earth. — *A&G*, **50**, 2.7, 2009.